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ABSTRACT

The importance of amaranth in the fight for nutrition security, especially in developing countries, is increasing because of its high nutritional quality and dual-purpose nature. Interest for amaranth leaves as a vegetable and seeds as grain is increasing in rural, per-urban and urban areas in many countries in Africa. However, the number of improved varieties grown by farmers is limited on the continent. Enhancing the access of improved varieties to farmers will increase productivity and production, and availability to consumers. The objectives of this study were to evaluate vegetable amaranth entries for yield, horticultural and agronomic traits, and leaf nutrient contents, and identify promising lines for release as commercial varieties. The materials were evaluated in Tanzania and Kenya in replicated trials in 2016 and 2017. Differences among the entries were significant or highly significant for yield and various agronomic traits in most of the trials conducted in both countries. Two amaranth lines, Ex-Zim-Sel and AM 38-Sel, previously released in Tanzania, were identified as promising in Kenya based on yield performance and preferences of farmers, and were registered as improved varieties in the country in 2017/18. Differences among the evaluated entries in Zn, K and Na contents analyzed in leaf samples collected from trials conducted in Tanzania were significant or highly significant in both years. Four *Amaranthus dubius* entries were recognized for their consistent high Zn and Na contents in 2016 and 2017. The high nutrient content entries are useful for further evaluation and use in breeding programs. Currently, nutrient contents are not considered in variety release procedures and should be something breeders push for in future variety release procedures.

INTRODUCTION

Amaranth belongs to the family Amaranthaceae and the genus *Amaranthus*. It is believed to have been introduced into sub-Saharan Africa from its origins in South America and Central America (Sauer, 1950, 1967). The popularity of amaranth comes from its high nutritional quality and dual-purpose characteristic as a leafy vegetable and cereal like grain, and its ability to grow in adverse environmental conditions (Das, 2016). The crop grows from sea level to as high as 3,200 m elevation although only few strive above 2,500 m elevation (National Research Council, 1984). The crop has become an important African leafy vegetable that is popular across the continent. Demand for amaranth and other African traditional vegetables by city populations is increasing (Chelang'a et al., 2013). Amaranth germplasm improvement, however, is in the early stages with a need to develop improved varieties that suit the various consumer demands. For centuries, farmers have grown their own local varieties mainly for home consumption or for sale in local markets. Only about 50% of the amaranth production area in Kenya and 70% in Tanzania is grown from improved varieties (Ochieng et al., 2019). Recently, the World Vegetable Center (WorldVeg) and private and public sector organizations have initiated amaranth improvement programs on the continent. To date, only a few improved varieties have been released, mainly from WorldVeg developed lines, for commercial use (Dinssa et al., 2016). Organizations such as Kenya Agriculture and Livestock Research Organization (KALRO), Jomo Kenyatta University of Agriculture and Technology (JKUAT), Tanzanian Agricultural Research Institute-Tengeru (TARI-Tengeru), Ethiopian Institute of Agricultural Research (EIAR), and other countries on the continent are involved in germplasm evaluation and variety release mostly based on initial lines obtained from WorldVeg. Local, regional, and multinational seed or breeding companies have started amaranth seed marketing and some have initiated breeding programs.

Breeding research is one of the activities conducted in amaranth improvement at the WorldVeg. Dinssa et al. (2019) described amaranth selection environments in Tanzania and identified at least two selection sites each for different target growing environmental conditions. They, moreover, reported that a genotype found best in one location or season may not necessarily be the best in another location or season, and therefore, the need for selection in a target environment. At the same time, their study also identified some genotypes adapted across environments, i.e., widely adapted genotypes.

Under the framework of the Feed the Future Innovation Lab for Horticulture Project *Improving nutrition with African indigenous vegetables in Kenya and Zambia*, amaranth variety evaluation activity was conducted in Tanzania, Kenya, and Zambia with project partners including WorldVeg (Tanzania), KALRO, Moi University/Academic Model Providing Access to Healthcare (AMPATH) Family Preservation Initiative (Kenya), Hantambo women group (Zambia), and Purdue University and Rutgers University (USA). Although the project, at large, focused on a suite of African traditional vegetables, a major focus of the project was the selection and improvement of amaranth. The study objectives were to evaluate amaranth entries for horticultural and agronomic traits, leaf nutrient contents, and identify promising lines for release as commercial varieties. This paper reports the results of field performance and the nutrient contents of entries included in the study, and varieties registered as the outcome of the study.

MATERIALS AND METHODS

Study location. The study was conducted in northern Tanzania at the World Vegetable Center Eastern and Southern Africa, Arusha, Tanzania (hereafter referred as WorldVeg) with one trial carried out from January to March 2016 (hot-dry season) and another trial conducted from May to September 2017 (cool season), and in Western Kenya at Turbo in Eldoret region (hereafter referred as Turbo). Three trials were carried out at Turbo in Kenya: (1) Trial-1 conducted during hot-dry season (November 2016 – March 2017), (2) Trial-2 during wet-cool season (April – August 2017) and (3) Trial-3 conducted during short rainy season with warm to hot temperature (September – December 2017). Differences in moisture and temperatures among seasons, and between locations were considered as environmental differences. The

WorldVeg station is characterized by a well-drained clay loam soil with pH 6.5, CEC 34.7 meq/100g, 1.4% organic matter content, and is located at lat. 3.4°S, long. 36.8°E, and elevation 1235 m. The Turbo location in Kenya is characterized by red soil with pH 5.7, CEC 14.2 meq/100g and 4.3% soil organic matter, and is located at lat. 0.37°N, long. 35.10°E and elevation 1789 m.

Plant materials. Seven amaranth entries – four *Amaranthus cruentus* (UG-AM-40-Sel, AM 38-Sel, AC-NL-Sel and Ex-Zim-Sel), two *A. dubius* (AM-45-Sel and Ex-Zan-Sel) and one *A. hypochondriacus* (AH-TL-Sel) – were evaluated for vegetable yield and horticultural traits at WorldVeg in Tanzania in 2016. The same seven entries plus one *A. dubius* advanced line (UG-AM-9-ES13-2) from WorldVeg, and another *A. dubius* entry (Kikavu chini) a local cultivar from northern Tanzania were evaluated in 2017. The characteristics and importance of each species in Africa have been compiled from different sources and summarized by Dinssa et al. (2019). The lines from WorldVeg were developed by mass or single plant selection at the WorldVeg from germplasm collections and underwent at least four cycles of selfing and selection. Seven of the nine entries evaluated at the WorldVeg were also evaluated at Turbo in three seasons from November 2016 to December 2017. A total of 10 entries, seven from WorldVeg, and one entry from each of the USA, Kenyan farmers and the Similaw Seeds Company, Kenya, were evaluated in each of the three trials conducted at Turbo. At WorldVeg, the entries were sown on 29 December 2015 and transplanted on 20 January 2016 in the 2016 trial, and sown on 30 May and transplanted on 22 June 2017 in the 2017 trial. At Turbo, Trial-1, Trial-2 and Trial-3 was sown on 17 November 2016, 20 April 2017 and 9 September 2017, respectively. Transplanting of Trial-1, Trial-2 and Trial-3 was conducted on 12 December 2016, 19 May 2017 and 10 October 2017, respectively.

Experimental design and plot size. Each trial was laid out in a randomized complete block design with four replications at the WorldVeg and three replications at Turbo. In all locations and trials, each plot had two rows at 60 cm spacing between rows, and 30 cm spacing between plants within row. Ten plants were grown per row, and the central eight plants per row were repeatedly harvested, starting at 50 days after sowing, in all trials for marketable fresh vegetable yield (marketable yield hereafter) determination.

Field management. Farrow, drip, or handheld hose irrigation was used as required. At WorldVeg, fertilizer 20N–10P–10K at 200 kg.ha^{-1} rate was manually applied as a basal application one week after transplanting, and urea (46N-0P-0K) at the rate of 120 kg.ha^{-1} was applied as side-dressing three weeks after transplanting. At Turbo, 17N–17P–17K was applied at the rate of 270 kg.ha^{-1}, and urea (46N-0P-0K) at the rate of 270 kg.ha^{-1}. Weeding was conducted manually using a handheld hoe.

Yield and agronomic data collection. Data collected per plot at both WorldVeg and Turbo included marketable yield, plant height and number of branches per plant; the number of branches per plant was not measured at WorldVeg in 2017. Leaf length and width were measured in the WorldVeg trials. The marketable yield was harvested following the method used by Dinssa et al. (2019), i.e., topping approximately one-third of the plant height measured from the apex to the bottom of the plant on the main stem during the first harvest, and to the stem node on which the tallest branch appeared in the subsequent harvests. Three rounds of harvests per plot were conducted in all trials except at WorldVeg in 2017, in which five harvests were carried out. The first harvest was started when the plants were about 50 days old, which is the practice of farmers exercising transplanting and repeat harvest from the same planting material. There was about a 14 days interval between two consecutive harvest dates in all trials. The total marketable yield for statistical analysis was obtained by adding all harvests per plot.

Plant height and number of branches per plant were measured on four random sample plants per plot. Leaf sizes were measured on four plants per plot and three leaves per plant. Analysis of variance in each trial on each of plant height, number of branches per plant, leaf length and leaf width was carried out after obtaining the average of all harvests per plot. The aim of measuring plant height, number of branches and leaf sizes was to have a feeling of the recovery potential of the entries after every repeat harvest. Comparisons of plant height measured at first harvest and last (fifth) harvest, and similarly, leaf sizes measured at the first harvest and last (fifth) harvest are depicted in graphs for the 2017 WorldVeg trial. Number of days to flowering from sowing was recorded on the entries grown for seed in increase plots at the WorldVeg in 2017.

Farmers' participatory variety selection was conducted using a 0 – 4 scale with 0 = very poor, 1 = poor, 2 = good, 3 = very good and 4 = excellent to identify their preferred entries. A total of 12 and 20 farmers were involved in the 2016 and 2017 selection at WorldVeg, respectively. Before entering field plots for visual selection, farmers discussed the selection scale with researchers and among themselves, and they agreed to rate each plot based on its performance in yield and various horticultural traits, and resistance/tolerance to biotic and abiotic stresses. Each plot selection scores were averaged across all farmers for statistical analysis.

Leaf nutrient content assessment. A total of 150 g marketable type fresh leaf samples was collected per plot from about 50 days old plants from each of the first three replications in the WorldVeg field trials. The samples were freeze-dried for nutrient content analysis. About 12 g dried samples were shipped to Rutgers University, USA for the analysis. Aluminum foil was used for storing and transporting the dried samples. An elemental micronutrient analysis was conducted on the dried leaf samples from each plot by inductively coupled plasma (ICP) mass spectrophotometry at Penn State Agricultural Analytical Services Lab, University Park, PA. Nutrients analyzed included Ca, Mg, S, P, K, Zn, Mn, B, Cu, Na and Fe. The Fe data of 2016 trial was excluded from this report as its content across plots was inflated, perhaps because of contamination in a deep freezer used to preserve the samples where the inside lining or coating material showed some cracking.

Analyses of variance. Individual trial analysis of variance was conducted on marketable yield, plant height, number of branches per plant, leaf length, leaf width, and the different nutrient contents using GenStat (release 19.1; VSN International, Hemel Hempstead, UK).

RESULTS

Marketable yield and other horticultural traits measured on the amaranth entries evaluated at the WorldVeg in 2016 and 2017 are presented in Table 1. The same horticultural traits for the entries evaluated at Turbo in Kenya in three seasons in 2017 are shown in Table 2.

WorldVeg-Tanzania. In both 2016 and 2017, differences among the entries were highly significant ($P \leq 0.01$) for marketable yield, plant height, leaf length, leaf width and farmers' selection score (Table 1). In 2016, AM-45-Sel gave the highest marketable yield (23.6 t/ha). Ex-Zan-Sel, Ex-Zim-Sel and AM-45-Sel ranked high in the farmers' selection score, although they differed significantly in their marketable yield. In 2017, UG-AM-9-ES13-2 gave the highest yield (27.4 t/ha) followed by AM-45-Sel and Kikavu chini (Table 1). UG-AM-9-ES13-2, Ex-Zim-Sel and Ex-Zan-Sel were the three most preferred entries by farmers in farmers' participatory selection this year too. Traits such as deep green leaf color, soft leaf texture, and stay-green ability were primary selection criteria of farmers. Ex-Zim-Sel, UG-AM-9-ES13-2, AM 38-Sel and Ex-Zan-Sel flowered late while AH-TL-Sel and UG-AM-40-Sel flowered early. Plant height measured across all harvests ranged from 21.4 cm (AM 38-Sel) to 56.1 cm (AM-45-Sel) in 2016 and from 30.5 cm (Ex-Zan-Sel) to 62.4 cm (UG-AM-40-Sel) in 2017. Plant height measured on the main stems at the first harvest, and on the tallest branches in subsequent harvests is a useful parameter to assess the recovery potential of a genotype from periodical cuttings. Regardless of five rounds of harvests, the height measured at the last (fifth) harvest was taller than the height measured at the first harvest in all entries (Fig. 1). On the average of all entries, the height progressively increased from the first harvest until the fourth harvest and tended to decline thereafter (Data not shown). Both leaf length and leaf width measured at the first harvest were greater than the sizes measured at the last harvest compared to the case in plant height (Figs. 2 and 3). Both traits progressively increased in size until the third harvest and then dropped below their respective values measured at the first harvest (Data not shown).

AM-45-Sel and Kikavu chini in that order had the shortest leaf lengths while Ex-Zim-Sel had the longest leaf length (Table 1). Ex-Zim-Sel had the narrowest leaf width while Ex-Zan-Sel followed by UG-AM-9-ES13-2 had the broadest width (Table 1). The line UG-AM-9-ES13-2 was a candidate variety under distinctiveness, uniformity and stability (DUS) test for release in Tanzania by the time it was included for comparison purposes in the trial conducted at the WorldVeg in 2017, and consequently was released in 2018/19.

Turbo-Kenya. Differences among the entries were highly significant for marketable yield in all the trials conducted at Turbo (Table 2). Ex-Zim-Sel gave the highest marketable yield in Trial-1 (32.7 t/ha), AM 38-Sel in Trial-2 (31.4 t/ha) and Trial-3 (50.1 t/ha). The entries significantly differed in plant height in Trial-1 and Trial-3. Ex-Zim-Sel was the tallest (44.2 cm) in Trial-1, AM 38-Sel (38.8 cm) in Trial-2, and AC-NL-Sel (46.3 cm) in Trial-3. The number of branches per plant differed significantly among the entries only in Trial-1 in which Ex-Zim-Sel produced the highest number of branches per plant (15.2 branches), and AM-45-Sel produced the lowest number of branches per plant (10.8 branches) (Table 2).

The nutrient contents of the leaves from each amaranth entry were also collected from field trials conducted at WorldVeg in 2016 and 2017, and the tissue analyzed for elemental composition (Table 3). In 2016, differences among the entries were highly significant ($P \leq 0.003$) for K, Zn, and Na contents while non-significant for the other seven nutrient elements analyzed (Table 3). Zinc content ranged from 4.8 mg/100 g in Ex-Zim-Sel to 7.5 mg/100 g in Ex-Zan-Sel on dry weight basis. Na ranged from 22.5 mg/100 g in AM 38-Sel to 46.5 mg/100 g in Ex-Zan-Sel, while K ranged from 4.6% in AM-45-Sel to 6.7% in AH-TL-Sel. The two *A. dubius* entries – Ex-Zan-Sel and AM-45-Sel – ranked high in their Zn and Na contents in 2016. From among *A. cruentus* and *A. hypochondriacus* entries tested in both 2016 and 2017, line UG-AM-40-Sel (*A. cruentus*) was exceptional for its high Zn content (Table 3). AH-TL-Sel followed by AM 38-Sel and Ex-Zan-Sel had the highest K while AM-45-Sel followed by AC-NL-Sel gave the lowest K content.

In 2017, differences among the entries were highly significant ($P \leq 0.012$) in Ca, Zn, B and Na contents, significant ($P \leq 0.034$) in Mg, K and Fe contents, and non-significant in S, P, Mn and Cu contents (Table 3). Fe content ranged from 19 mg/100g (AC-NL-Sel) to 26 mg/100g (AM-45-Sel) on dry weight basis. Zn content ranged from 3.2 mg (AC-NL-Sel) to 7.7 mg/100g (UG-AM-9-ES13-2). UG-AM-9-ES13-2 that was not included in the 2016 trial gave the highest Zn, K and Na contents in 2017. The four *A. dubius* entries – UG-AM-9-ES13-2, AM-45-Sel, Ex-Zan-Sel, and Kikavu chini (Local variety) – had high concentrations of Zn and Na, which agrees with the 2016 result where the two *A. dubius* entries ranked high in these nutrient elements (Table 3). UG-AM-9-ES13-2, Ex-Zan-Sel and AH-TL-Sel had high K content in 2017.

Lines Ex-Zim-Sel and AM 38-Sel were registered in Kenya for commercial production. The lines were selected mainly based on yield, and farmers' preference scores that are based on desirable traits such as green leaf color and cooking quality. The descriptions of these lines are given in Table 4. Ex-Zim-Sel has a lanceolate (long and narrow) leaf shape, green stem, leaf, leaf petiole and panicle color, and black seed coat color. Ex-Zim-Sel is late in flowering and tall in plant height when it is allowed to grain production without cutback. AM 38-Sel is categorized among broadleaf type entries. AM 38-Sel has an elliptical-ovatainate leaf shape, green stem, leaf, leaf petiole and panicle color, and black seed color, and is late in flowering and tall in plant height (Table 4).

DISCUSSION

In the present study, some lines that performed very well in one season did not achieve the same in another season within the same country or different country. Ex-Zim-Sel and AM 38-Sel gave low yield in Tanzania, especially in the 2016 trial, but showed high performance in all seasons in Kenya. Dinssa et al. (2019) reported that not all amaranth genotypes that perform well in one season or location may perform the same in another season or location, and they reiterated the importance of selection in target environments whenever resource is available. They reported that Ex-Zim-Sel, registered under the commercial variety name 'Madiira 1' in Tanzania in 2011, has been out yielded by many breeding lines across seasons and locations in Tanzania. The variety, however, stayed under production because of farmers' and consumers' preferences, mainly due to its deep green leaf color, and good cooking quality; it does not get too soft in cooking (Dinssa, WorldVeg, personal experience). Ex-Zim-Sel was among the top three entries based on farmers' selection score in farmers' participatory selection conducted in both 2016 and 2017 at the WorldVeg in Tanzania. Both Ex-Zim-Sel and AM 38-Sel are highly preferred by farmers in farmers' participatory selection in western Kenya for their yields, and desirable horticultural traits such as deep green leaf color and cooking quality (Ndinya, KALRO, personal communication). The selection criteria for improved amaranth varieties largely depend on farmers' preference scores. Fufa et al. (2010) described that farmers' preferences rely not only on yield but also on various agronomic and quality traits. Farmers selection criteria in amaranth in Tanzania include (1) deep green leaf color and stay green, (2) broadleaf if it possesses deep green color, (3) early seedling vigor or biomass accumulation for early uprooting in uproot harvesting system and for early first harvest in continuous harvesting system, (4) fast recovery growth from scheduled repeat cuttings, (5) high nutrient content although our understanding is limited how farmers identify entries with high nutrient content in their visual selection, (6) cooking quality, (7) high yield, (8) high number of repeat harvests per season, and (9) tolerance to low moisture stress conditions to reduce the number of irrigation frequencies required. There are two types of harvesting systems in amaranth – uproot harvesting and continuous (periodical repeat) harvesting systems. Uproot harvesting, also called clear harvesting, is a one-go-harvesting system where producers uproot their plot in one go (Dinssa et al., 2016). In contrast, continuous harvesting is the harvesting of the same planting material over an extended period with the harvesting done at about 10-15 days interval between two consecutive harvesting dates.

An increase in plant height and leaf sizes in the continuous harvesting system of amaranth indicates the recovery potential of a genotype from periodical cuttings. The progressive growth of leaf sizes and plant height from the first harvest until the third or fourth harvest is in agreement with Shukla et al. (2006), who reported an increase in individual cuttings for both leaf size and plant height till the third cutting and a decline thereafter.

Breeding for high nutrient content is a timely approach for nutrition security. The significant differences among the amaranth entries in Ca, Mg, K, Zn, Na and Fe observed in the current study agree with the findings of Mnkeni et al. (2007). The minimum critical breeding value set by the Feed the Future program of the USA is 4.2 mg/100g for Fe and 4.5 mg/100g for Zn (Feed the Future, 2014). The Zn contents of the seven entries evaluated in 2016, and five of the nine entries evaluated in 2017 were higher than the critical breeding value of 4.5 mg/100g on dry weight basis. Byrnes et al. (2017) reported lower Zn value in samples collected from trials conducted in Tanzania, and New Jersey in USA; many of the current entries were among entries evaluated in their study. Plant nutrient contents may vary with growing environments such as soil type and fertility levels, and agronomic practices in addition to genotype (Riedell, et al., 2009). Zn content may also vary with harvest time. Makobo et al. (2010) reported that Zn content in amaranth leaves harvested at 3-weeks after emergence is 85% higher than the content in leaves harvested 8-weeks after emergence in the same genotype. The nutrient analysis in the present study was conducted on leaf samples collected from about 50 days old plants counted from the sowing date.

Fe content in the current study was to the highest side. Reports on the Fe concentration found in leaves varied in different studies. For instance, Byrnes et al. (2017) reported less than 10 mg/100g Fe in a study conducted in Tanzania and New Jersey, Kachiguma et al. (2015) reported 14.2-31.2 mg/100g in 19 amaranth accession analyzed in Malawi, and Mnkeni et al. (2007) reported 14.6 mg/100g in South Africa. The World Health Organization (WHO, 2012) recommends 30 mg to 60 mg elemental iron per day as a supplement for pregnant women.

Zn contents of the four *A. dubius* entries – UG-AM-9-ES13-2, AM-45-Sel, Ex-Zan-Sel, and Kikavu chini – were high in both 2016 and 2017 trials, and these entries could be considered as a promising high source of Zinc for future studies. A previous study by Byrnes et al. (2017) too indicated that *A*. *dubius* and *A*. *tricolor* entries tended to have higher Zn contents. In the present study, Fe content also tended to be higher in the *A*. *dubius* entries than in the other species with the exception of one *A*. *cruentus* entry that was as good as at least one of the *A*. *dubius* entries. Entries high in Zn contents were also found high in their Na content. Ca content results varied in different studies. Kachiguma et al. (2015) reported a Ca content range of 1512 – 2381 mg/100g and Byrnes et al. (2017) reported a much lower range of 366 mg – 552 mg/100g. The WHO (2013) suggested that pregnant women should receive Ca supplements in the range of 1500 mg to 2000 mg per day. The content we observed ranged from 2.1 to 3.1% (about 2100 mg to 3100 mg/100g) in 2016, and 2.6 to 3.6% (2600 mg to 3600 mg/100g) in 2017, way above the daily requirement threshold set by the WHO for expectant women.

An outcome of the current study was the registration of two amaranth entries, Ex-Zim-Sel and AM 38-Sel, as commercial varieties in Kenya. The entries performed well in vegetable yield in all trials conducted in Kenya and were also highly preferred by farmers. Both Ex-Zim-Sel and AM 38-Sel were released in Tanzania in 2011 under the commercial variety names of 'Madiira 1' (Ex-Zim-Sel) and 'Madiira 2' (AM 38-Sel) (Dinssa et al., 2016). 'Madiira 1' is highly liked by farmers in Tanzania, although it is not exceptionally high yielding in the country, indicating that farmers selection criteria are more than vegetable yield alone. Ex-Zim-Sel and AM 38-Sel, developed by mass selection with repeated selfings and evaluation for a continuous harvest production system, have slow early seedling establishment but high rejuvenation capacity after every cut as long as moisture and fertilizers are available.

In conclusion, our study and previous studies suggest that vegetable amaranth contributes to nutrition security, especially for resource-poor populations in developing countries. Although a large number of entries from each species of amaranth required to statistically compare for their nutrient contents, the consistent high Zn content, above the breeding value threshold set by Feed the Future (2014), observed across years in the *A. dubius* entries indicates that this species warrants additional focus and attention as one of high source species for this mineral element. The *A. dubius* entries were also the farmers' best-preferred selections in the current study and from our previous experiences working with farmers in Tanzania. Upscaling the released varieties could improve the productivity, production, and availability of the vegetable to consumers to enhance nutrition security. The high nutrient content source lines will serve as essential breeding materials for amaranth breeders. Nutrient content data is not mandatory in the current variety release regulations of many countries in Africa, and it is vital future release procedures will consider nutrient contents.

Table 1. Marketable vegetative yield, horticultural traits and farmers' selection scores in amaranth entries evaluated at WorldVeg research station in Tanzania in 2016 and 2017[1].

Entry	Species	2016 NBR	2016 PH	2016 LL	2016 LW	2016 FS	2016 FMYD	2017 PH	2017 LL	2017 LW	2017 TF at WVE	2017 FS	2017 FMYD
UG-AM-40-Sel	*Amaranthus cruentus*	6.5	47.1	14.3	7.1	1.8	14.5	62.4	9.9	5.5	38.0	1.7	19.0
AM-45-Sel	*A. dubius*	8.8	56.1	9.2	6.3	3.1	23.6	47.4	9.1	6.5	46.5	2.4	26.9
AM 38-Sel	*A. cruentus*	6.7	21.4	11.8	5.9	1.6	7.6	44.7	12.3	6.6	76.0	2.4	22.5
AC-NL-Sel	*A. cruentus*	6.4	38.8	12.6	6.1	2.0	14.2	45.5	10.8	5.9	49.5	2.2	22.0
AH-TL-Sel	*A. hypochondriacus*	6.6	47.8	11.6	6.3	1.9	15.2	49.2	11.5	7.0	37.7	2.1	19.6
Ex-Zim-Sel	*A. cruentus*	6.8	33.4	14.6	3.6	3.1	10.9	42.0	14.2	3.4	82.2	3.4	17.7
Ex-Zan-Sel	*A. dubius*	6.4	26.6	13.5	8.9	3.2	15.1	30.5	12.9	8.4	56.7	3.3	18.4
UG-AM-9-ES13-2	*A. dubius*	-	-	-	-	-	-	35.9	12.6	8.2	81.2	3.6	27.4
Kikavu chini (Local)	*A. dubius*	-	-	-	-	-	-	45.5	9.7	6.6	47.0	2.8	26.9
Mean		6.9	38.8	12.5	6.3	2.4	14.4	44.8	11.4	6.4	57.2	2.7	22.3
Prob.		0.104	<0.001	0.001	0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.012
LSD (5%)		NS	11.5	1.4	0.7	0.4	4.4	6.9	1.1	0.7	2.2	0.3	6.3

[1]NBR = number of branches per plant, PH = plant height (cm), LL = Leaf length (cm), Leaf width (cm), FS = Farmers selection score (0-4 scale, mean of 12 farmers in 2016 and mean of 20 farmers in 2017), where 0 is very poor and 4 is excellent, FMYD = Fresh marketable vegetative yield (t/ha), TF = Time to flowering from sowing (days), WVE = World Vegetable Center Eastern and Southern Africa.

Table 2. Marketable vegetative yield and horticultural traits in amaranth entries evaluated at Turbo in Kenya in three seasons from 2016 to 2017[1].

		2016/17 (hot-dry season)			2017 (wet-cool season)			2017 (short rainy season warm to hot temperature)		
Entry		NBR	PH	FMYD	NBR	PH	FMYD	NBR	PH	FMYD
UG-AM-40-Sel	*Amaranthus cruentus*	12.1	33.7	16.5	6.3	28.4	9.3	6.9	42.6	35.7
AM-45-Sel	*A. dubius*	10.7	33.4	22.3	7.2	36.3	14.9	7.9	34.1	37.3
AM 38-Sel	*A. cruentus*	12.5	30.4	27.8	7.2	38.8	31.4	8.7	37.4	50.1
AC-NL-Sel	*A. cruentus*	13.7	33.0	16.9	5.7	29.8	9.9	7.0	46.3	45.1
AH-TL-Sel	*A. hypochondriacus*	14.1	39.4	27.1	3.9	29.1	9.5	8.5	36.7	36.0
Ex-Zim-Sel	*A. cruentus*	15.2	44.2	32.7	5.9	36.5	21.9	7.4	40.3	29.1
Ex-Zan-Sel	*A. dubius*	12.4	33.0	22.9	6.9	27.8	14.8	6.2	27.1	24.8
RUAM24	*Amaranthus* sp.	10.9	22.9	6.1	4.8	27.3	1.1	7.3	16.4	10.3
Kenya Seeds variety	*Amaranthus* sp.	14.6	40.9	30.1	4.7	24.3	1.7	5.5	24.8	21.1
Local variety	*Amaranthus* sp.	15.1	41.1	29.2	5.7	30.1	13.5	6.7	34.8	33.0
Mean		13.1	35.2	23.2	5.8	30.8	12.8	7.2	34	32.2
Prob.		0.003	<0.001	<0.001	0.795	0.873	<0.001	0.171	0.002	<0.001
LSD (5%)		2.3	7.3	9.2	NS	NS	10.5	NS	11.78	14.3

[1]NBR = number of branches per plant, PH = plant height (cm), FMYD = Fresh marketable vegetative yield (t/ha).

Table 3. Nutrient contents analyzed on dry weight basis on amaranth entries grown at WorldVeg in Tanzania in 2016 and 2017.

		Nutrient content (%)					Nutrient content (mg/100g)					
Entry	Species	Ca	Mg	S	P	K	Zn	Mn	B	Cu	Na	Fe
Year 2016												
UG-AM-40-Sel	*Amaranthus cruentus*	2.4	0.9	0.3	0.5	5.3	6.4	20.1	3.6	1.6	22.8	-
AM-45-Sel	*A. dubius*	3.1	1.1	0.4	0.6	4.6	7.3	18.1	3.4	1.1	38.3	-
AM 38-Sel	*A. cruentus*	2.1	0.9	0.3	0.5	5.8	5.5	21.0	3.8	1.1	22.5	-
AC-NL-Sel	*A. cruentus*	2.6	1.1	0.3	0.5	4.8	5.3	19.6	3.5	1.3	25.9	-
AH-TL-Sel	*A. hypochondriacus*	2.5	0.9	0.4	0.6	6.7	5.3	19.5	3.4	1.3	31.2	-
Ex-Zim-Sel	*A. cruentus*	2.4	1.1	0.3	0.6	5.1	4.8	17.9	3.9	1.3	22.8	-
Ex-Zan-Sel	*A. dubius*	2.5	0.9	0.4	0.6	5.5	7.5	21.0	3.4	1.3	46.5	-
	Mean	2.5	1.0	0.3	0.6	5.4	6.0	19.6	3.6	1.3	30.0	-
	Prob.	0.20	0.19	0.41	0.16	<0.001	0.003	0.83	0.28	0.53	<0.001	-
	LSD (5%)	NS	NS	NS	NS	0.7	1.2	NS	NS	NS	8.2	-
Year 2017												
UG-AM-40-Sel	*Amaranthus cruentus*	3.4	1.1	0.4	0.7	4.6	5.3	10.7	4.2	9.4	15.7	24.6
AM-45-Sel	*A. dubius*	3.6	1.2	0.4	0.8	4.4	7.1	10.7	3.7	10.8	46.5	26.0
AM 38-Sel	*A. cruentus*	2.8	1.0	0.4	0.7	4.9	3.7	11.3	3.8	9.2	15.0	20.4
AC-NL-Sel	*A. cruentus*	3.1	1.0	0.4	0.7	4.3	3.2	15.3	4.8	8.8	14.5	19.0
AH-TL-Sel	*A. hypochondriacus*	3.5	1.1	0.5	0.6	5.0	4.3	16.6	3.2	9.4	19.7	21.5
Ex-Zim-Sel	*A. cruentus*	3.2	1.2	0.4	0.7	4.8	3.8	11.2	4.1	8.2	18.0	21.0
Ex-Zan-Sel	*A. dubius*	2.6	0.9	0.4	0.9	5.1	6.8	16.6	3.6	10.3	40.9	24.6
UG-AM-9-ES13-2	*A. dubius*	2.9	1.0	0.4	0.8	5.2	7.7	12.8	3.4	9.7	65.4	22.4
Kikavu chini (Local)	*A. dubius*	3.5	1.1	0.4	0.7	4.4	6.3	17.3	3.8	10.0	35.6	23.8
	Mean	3.2	1.1	0.4	0.7	4.7	5.4	13.6	3.8	9.5	30.2	22.6
	Prob.	<0.001	0.034	0.163	0.230	0.025	<0.001	0.937	0.012	0.405	<0.001	0.026
	LSD (5%)	0.453	0.2	NS	NS	0.6	0.7	NS	0.8	NS	14.1	4.1

Table 4. Descriptors of two amaranth lines registered in Kenya for commercial production in 2018/19.

	Characteristic score	
Characteristic	Ex-Zim-Sel	AM 38-Sel
Growth habit	Erect	Erect
Branching index	Many branches	Many branches
Stem pubescence	Low	Low
Stem pigmentation	Green	Green
Spines in leaf axils	Absent	Absent
Leaf pubescence	None	None
Leaf pigmentation pattern	Normal green	Normal green
Leaf shape	Lanceolate (long and narrow)	Elliptical (big leaves)
Leaf margin	Entire	Entire
Leaf vein prominence	Rugose	Rugose
Petiole pigmentation	Green	Green
Number of days to flowering from sowing	Very late flowering (82 days)	Late flowering (76 days)
Terminal inflorescence shape	Panicles with short branches	Panicles with short branches
Presence of auxiliary inflorescence	Present	Present
Sex type	Dioecious	Dioecious
Inflorescence density	Intermediate	Dense (heavily branched)
Inflorescence color	Light green	Light green
Seed shattering	Low	Low
Seed color	Black	Black
Seed coat type	Translucent	Translucent
Seed shape	Ellipsoid	Ellipsoid
Terminal inflorescence attitude	Drooping	Drooping

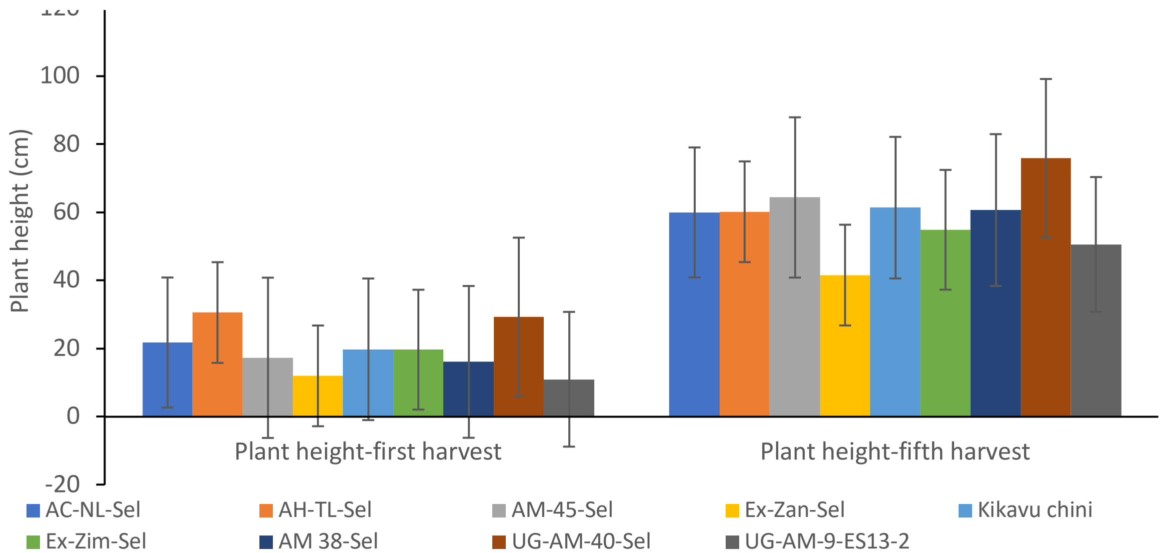

Figure 1. Plant height (cm) measured at first and last (fifth) harvests on nine amaranth entries grown at WorldVeg in 2017. AC-NL-Sel, Ex-Zim-Sel, AM 38-Sel and UG-AM-40-Sel (*Amaranthus cruentus*), AH-TL-Sel (*A. hypochondriacus*), and AM-45-Sel, Ex-Zan-Sel, Kikavu chini and UG-AM-9-ES13-2 (*A. dubius*). Bars indicate standard errors.

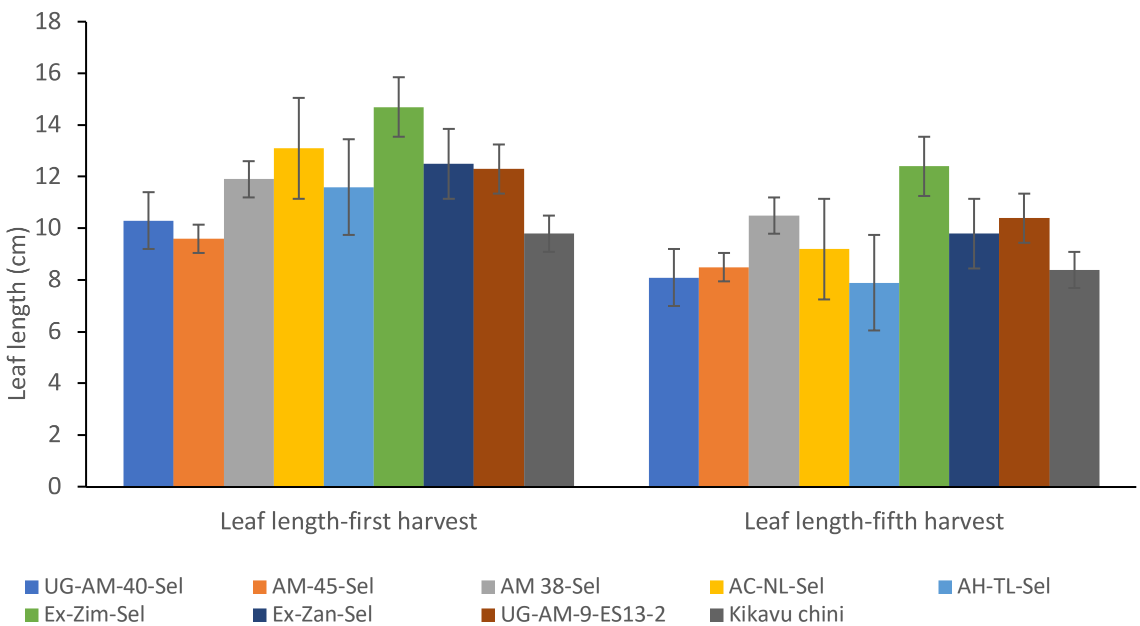

Figure 2. Leaf length (cm) measured at first and last (fifth) harvests on nine amaranth entries grown at WorldVeg in 2017. UG-AM-40-Sel, AM 38-Sel, AC-NL-Sel and Ex-Zim-Sel (*Amaranthus cruentus*), AH-TL-Sel (*A. hypochondriacus*), and AM-45-Sel, Ex-Zan-Sel, UG-AM-9-ES13-2 and Kikavu chini (*A. dubius*). Bars indicate standard errors.

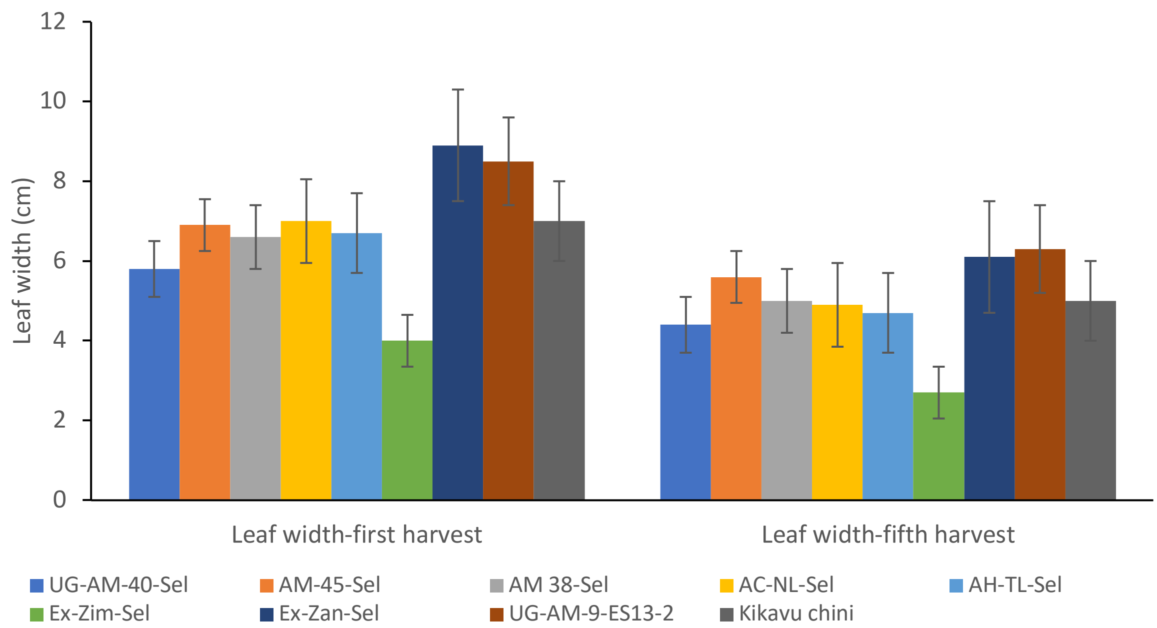

Figure 3. Leaf width (cm) measured at first and last (fifth) harvests on nine amaranth entries grown at WorldVeg in 2017. UG-AM-40-Sel, AM 38-Sel, AC-NL-Sel and Ex-Zim-Sel (*Amaranthus cruentus*), AH-TL-Sel (*A. hypochondriacus*), and AM-45-Sel, Ex-Zan-Sel, UG-AM-9-ES13-2 and Kikavu chini (*A. dubius*). Bars indicate standard errors.

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