International Journal of Plant Breeding ©2013 Global Science Books

Selection, Evaluation and Release of Varieties from Genetically Diverse African Nightshade Germplasm

Chris O. Ojiewo[1,5*] • Omary Mbwambo[2] • Ignas Swai[1,2] • Silvesta Samali[2] • Mansuet S. Tilya[2] • Ruth N. Mnzava[2] • Leon Mrosso[3] • Ruth Minja[4] • Mel Oluoch[1,6]

[1] AVRDC – The World Vegetable Center, Regional Center for Africa, P.O. Box 10, Duluti, Arusha, Tanzania
[2] Horticultural Research and Training Institute -Tengeru, P. O. Box 1253, Arusha, Tanzania
[3] Makutopora Viticulture Research Institute, P.O. Box 1676, Dodoma, Tanzania
[4] Agricultural Research Institute, Mikocheni. P.O. Box 6226, Dar es Salaam, Tanzania
[5] Current address: International Crops Research Institute for the Semi Arid Tropics (ICRISAT), c/o ILRI-Ethiopia, P. O. Box 5689, Addis Ababa, Ethiopia
[6] Current address: International Institute for Tropical Agriculture (IITA), PMB 3112, Kano, Nigeria

***Corresponding author*: * c.ojiewo@cgiar.org** or **cojiewo@yahoo.com**

ABSTRACT

Leaf yields of African nightshades are lower than their optimal potential, partly due to lack of improved varieties. Field evaluation of selected African nightshade lines was conducted in Arusha, Tanzania to identify superior lines for variety release, registration and promotion. Three field trials were carried out from August 2007 to January 2008, April to October 2008, and August 2008 to January 2009. Lines SS52 and BG16 had significantly higher leaf yields in trial 1 with 33 and 30 t/ha and in trial 2 with 14 and 17 t/ha, respectively; while in trial 3, lines BG 16 and BG 21 had the highest leaf yields of 24 and 15 t/ha, respectively. These results were confirmed with earlier studies and nine promising lines were selected and subjected to multilocational trials across four Agroecological zones in Tanzania between 2008 and 2010. In year 2011, lines BG 16 and SS 49 were officially released and registered as "Nduruma" and "Olevolosi", respectively based on their superior yield and acceptability. "Nduruma" is late flowering and produce large succulent leaves, which accumulate photoassimilates leading to high leaf yields during the vegetative phase and high seed yields during the reproductive phase. It is also sweet tasting. "Olevolosi", on the other hand, is mildly bitter and is most preferred by communities in Tanzania which associate bitterness with medicinal value.

Keywords: African nightshade, leaf yields, seed yields, reproductive growth, vegetative growth

INTRODUCTION

African nightshade are a group of *Solanum* section *Solanum*, with several distinct taxa (Ojiewo *et al*. 2013) occurring in greatest concentrations in tropical and warm temperate regions with centres of diversity in South America, Australia, and Africa, with relatively few and less diverse species in Europe and Asia (D'Arcy 1991; Mwai 2007; Mwai *et al*. 2007; Manoko 2007; Manoko *et al*. 2007, 2008, 2012). Although nightshades are historically considered inedible poisonous plants or troublesome agronomic weeds in Europe and the Americas, most members of the section *Solanum* have long been used as leafy herbs and vegetables, as a source of fruits and dye, and for various medicinal purposes in Western, Eastern, and Southern Africa as well as in India, Indonesia, and China (Edmonds and Chweya 1997). Some species such as deadly nightshade (*Atropa belladonna*) are indeed poisonous. Increased use of indigenous vegetables including African nightshade and decreased use of globally important vegetables (cabbage, kale, spinach) has been reported in Eastern Africa, mainly because the indigenous vegetables require less inputs to produce and consequently are more affordable for rural households in the low-income bracket (Weinberger and Msuya 2004). About a decade ago, the potential for African nightshade to become a commercially important crop in urban and peri-urban areas could only be a prediction based on the high market prices they were fetching in these under-supplied markets (Schippers 2000). Today these vegetables are on high demand in municipal, urban, super markets and hotel chains (Weinberger *et al.* 2011). The farm gate prices are as variable as the location of the various farms; the local open air market prices attract similar trends. The super markets' prices are similarly variable. The prices are mostly driven by the informal sector on the basis of the supply-demand forces.

The traditional system of production in the rural and marketing in the urban markets does not work for these leafy vegetables because of high perishability that makes them very difficult to transport over long distances and store for several days before selling. As such the supply of these vegetables in the urban areas has struggled to respond to this steadily increasing demand through contractual farming in urban and peri-urban areas, although with challenges including lack of improved high yielding varieties, poor and underdeveloped indigenous vegetable seed systems, and high costs of planting material among others (Afari-Sefa *et al*. 2011; Ojiewo *et al.* 2013). In Tanzania for example, the share of indigenous vegetable seeds sold in the formal market was reported to be only 10% (Weinberger and Msuya 2004). It is a regulatory requirement that only seed of varieties registered in the national variety catalogue can be commercialized. Therefore, a step towards variety development, release and registration is significant towards bridging the gap between supply and demand of African nightshade in the cities through provision of superior planting material of elite varieties.

African nightshade is among indigenous vegetables which have been identified in the Southern African Development Community (SADC region) for promotion due to its nutritional and market potential (SADC-ICART Project – 2009). Besides being an important crop in the rural agricultural, economic and nutritional systems, it supports a large number of small businesses along the supply chain in

Received: 13 December, 2012. Accepted: 5 February, 2013.

Original Research Paper

urban and peri-urban areas in Kenya and Uganda (Weinberger 2011). In Tanzania, African nightshades have become a common part of household menu in many regions where they are known by vernacular names such as *Mwhaka* (Hehe), *Mnavu* (Swahili, Pogolo, Bondei and Sambaa), *Mhaki* (Bena), *Kisuhume nsoka* (Sukuma), *Mnafu* (Chagga) (Manoko 2007). Besides, it has found its way into common eateries in Eastern Africa.

The leaf yields of commonly grown African nightshade species (*S. villosum*, *S. scabrum*, *S. americanum* and *S. sarrachoides*) are low. In Kenya, growers of African nightshade have been reported to obtain yields of 1.5-3.0 tonnes ha^{-1} which are relatively lower than their potential yields of 30-50 tonnes ha^{-1} (Chweya and Eyzaguirre 1999). Early flowering and excessive fruiting are major limitations to leaf expansion and higher yields in this species. Dry matter partitioning at reproductive stage is directed mainly towards fruit and seed development (Ojiewo *et al*. 2009). The respiratory costs of reproductive functions and the concomitant source-sink skew after anthesis slows down leaf formation and expansion. More evidence of this is clear from leaf-yield increase by 40% through manual deflowering (Mwafusi 1992). However, deflowering is cumbersome, costly, and labour-intensive.

Lines of *S. scabrum* have been shown to respond significantly better than other nightshade species to spacing and fertilizer application in leaf, fruit, and seed yields (Mwai *et al*. 2009a, 2009b). Characterization results also have shown good diversity between species and among the lines of nightshade, especially of *S. scabrum*, for morphological characteristics (Muenyi *et al*. 2006; Manoko 2007; Manoko *et al*. 2007; Mwai 2007; Mwai *et al*. 2007; Manoko *et al*. 2008; Volis *et al*. 2009; Manoko *et al*. 2012). There is potential to evaluate and select more leafy African nightshade lines with higher leaf yields, as well as lines with late flowering characteristics, especially among the *S. scabrum* group. Although farmers seek high leaf yields, seed companies and dealers would be interested in a largely vegetative plant with high seed yields. Therefore, the objective of this study was to identify superior lines with both high leaf and seed yields for release, registration and commercialization.

MATERIALS AND METHODS

Trial establishment and management

Three trials were carried out at the experimental farm of AVRDC – The World Vegetable Center in Arusha, Tanzania. The area is located at 48° S 37° E with an altitude of 1290 meters above sea level (masl). The soil type is clay loam. The first trial was conducted from August 2007 to January 2008, the second from April 2008 to October 2008 and the third from August 2008 to January 2009. A total of 25 lines mainly of *S. scabrum* group and including other species from *S. villosum*, *S. americanum* and *S. sarrachoides* collected from Tanzania, Kenya, and Cameroon were evaluated in trials 1 and 2. Results of morphological characterization in the two seasons were used to develop a core collection and eliminate or replace some lines. In trial 3, 20 lines were evaluated. The lines were selected from a gene pool of about 150 accessions earlier characterized and evaluated (ProNIVA Report 2006; Mwai 2007; ProNIVA Report 2010). Some phenotypic characteristics of the lines are shown in **Table 1**. All experiments were laid out in a randomized complete block design (RCBD) with three replications. The treatments were laid out in two rows per line per replication in plot sizes measuring 6 m long with spacing of 40 cm within and 60 cm between rows. Furrow irrigation was carried out once or twice a week and manual weeding done as per need. NPK (20-10-10) fertilizer was applied two weeks after transplanting at the rate of 250 kg/ha while 120 kg/ha urea (46% N) was applied in two splits, with the first application (60 kg N/ha) applied together with NPK and the second application applied three weeks thereafter. To control fungal diseases, insects, and red spider mites, Ridomil (60 g/15 L; Syngenta Crop Protection Inc., Ontario, Canada), Confidor (10 ml/15 L; Bayer Crop Science Inc, Alberta, USA) and Dynamec (10 ml/15 L; Fargo Ltd. West Sussex, UK) were applied, respectively.

Evaluation of genotypic differences in yield and yield components

Harvesting of fresh leaves commenced 4 weeks after transplanting and continued at bi-weekly intervals; a total of 4 harvests were done. Fresh leaf weight was measured immediately using a balance (model Globe Brand; Dayton, Ohio, USA). Harvesting was done by pinching off tender and new shoots and leaves, and carried out early in the morning to get fresh weight and to avoid weight loss during the day. Half of the rows in each treatment were not harvested and were used to generate data for fruit and seed yields. Data was collected on quantitative traits associated with yield, including leaf and fruit length and width (cm), days to 50% flowering and fruiting after transplanting (DAT) and finally seed and leaf yields. Leaf and fruit length and width were measured during vegetative growth and at fruit maturity respectively. "50% flowering and fruiting" was computed as flowering or fruiting in half the number of plants in each plot or treatment. Berries were harvested as they ripened in *S. villosum* and *S. scabrum* lines. In *S. americanum* and *S. sarrachoides* where berries drop off at ripening, berries were harvested just before ripening. Seed was extracted by crushing berries in a plastic container, squeezing out the seeds and fruit pulp and fermenting for 24hrs before washing with clean water and decanting. Seed was shade-dried during the hot season and sun-dried during the cool season for 7-10 days to a moisture content of 10-12%. Dry seed was weighed with an electronic balance (Mettler Toledo, Bradford, MA, USA). Leaf and seed yield data were subjected to analysis of variance (ANOVA) using CoStat (CoHort Software, MN, USA).

Multilocational testing and participatory evaluation of African nightshade lines

The researcher-managed on-station multilocational trials were conducted for two seasons in four Agro-ecological Zones (AEZs): cool wet, medium altitude (Arusha: 1260 masl; 3° 22′ S, 36° 41′ E); cool dry, medium altitude (Dodoma: 1290 masl; 6° 11′ S, 35° 45′ E), cold wet, highland tropics; (Iringa: 1630 masl; 7° 46′ S, 35° 42′ E) and hot humid, low altitude (Bagamoyo: 0 masl; 06° 28′ S; 38° 55′ E). Besides, three farmer-managed on-farm trials were conducted concurrently with the on-station trials at each location and participatory variety selection (PVS) conducted at the on-farm sites to determine acceptability. The average max/min temperatures in Arusha vary with season between 13 and 34°C, with June and July being the coldest months. The rainfall is bimodal with a mean annual rainfall of 800 mm. The main rainy period is from March to May. Dodoma is characterized by a long dry season lasting from late April to early December and a short single wet season occurring from January to March. The rainfall is unimodal and the average rainfall per year is 570 mm·yr^{-1}. Temperature in the region varies according to season, with an average minimum of 14°C and average maximum of 32°C. Temperatures in Iringa range from 12°C in the highlands to 30°C in the lowlands. The weather from June until November is dry and cold, whereas it is relatively wet and warm from December to April. The rainfall is unimodal and the rainfall averages about 1100 mm p.a.; the rainy season is from December to April. Bagamoyo is a hot, low-altitude area. Annual rainfall is approximately 900 mm with a bimodal pattern: the "long rains" fall between March and May, and the "short rains" fall during October and November.

Trials were conducted for two seasons, with 9 elite lines from October 2008 to April 2009 and repeated from October 2009 to April 2010. The weather conditions during these trials are summarized in **Table 7**. The lines evaluated belonged to the species *S. scabrum* and which were pre-selected and evaluated on-station on the basis of yield and yield components, stakeholder acceptability and other positive horticultural traits. Trials were arranged in RCBD with three replications. Plot size at all locations, in both years, was 6 m long and 1 m wide consisting of two rows. For each plot, rows were 40 cm apart and seedlings were established with an in-row spacing of 30 cm between plants. Seedlings were transplanted 2-3 weeks after sowing. For each region, cultural

Table 1 Description of phenotypic features (based on AVRDC Descriptor list; Chadha *et al*. 2001) of the African nightshade lines evaluated in Arusha, Tanzania for three seasons.

Line	AVRDC distribution code	Collected from	Location of 1st inflorescence	Inflorescence type	Peduncle (at fruiting stage)
S. scabrum **(Hexaploid; 2n = 6x =72)**					
BG 4	RVI00510	Tanzania	On primary branch	Forked cyme	Facing upwards
BG 7	RVI00495	Tanzania	Along main stem	Simple umbellate cyme	Horizontal
BG 8	RVI00496	Tanzania	On primary branch	Simple umbellate cyme	Horizontal
BG 9	RVI00515	Tanzania	Along main stem	Simple umbellate cyme	Horizontal
BG 11	RVI00498	Tanzania	On primary branch	Simple umbellate cyme	Horizontal
BG 13	RVI00500	Tanzania	Along main stem	Simple umbellate cyme	Horizontal
BG 14	RVI00501	Tanzania	On primary branch	Forked cyme	Horizontal
BG 16	RVI00502	Cameroon	Along main stem	Forked cyme	Facing upwards
BG 17	RVI00517	Tanzania	On primary branch	Forked cyme	Horizontal
BG 21	RVI00505	Tanzania	On primary branch	Simple umbellate cyme	Horizontal
BG 22	RVI00506	Tanzania	On primary branch	Simple umbellate cyme	Facing upwards
BG 24	RVI00522	Tanzania	Along main stem	Simple umbellate cyme	Horizontal
BG 26	RVI00520	Tanzania	Along main stem	Forked cyme	Facing upwards
BG 29	RVI00504	Tanzania	Along main stem	Simple umbellate cyme	Horizontal
SS 04.2	RVI00575	Cameroon	On primary branch	Simple umbellate cyme	Horizontal
SS 40	RVI00585	Cameroon	On primary branch	Simple umbellate cyme	Facing upwards
SS 49	RVI00587	Cameroon	On primary branch	Simple umbellate cyme	Horizontal
SS 52	RVI00588	Cameroon	Along main stem	Simple umbellate cyme	Facing upwards
TZSMN 11-5	RVI00525	Tanzania	On primary branch	Simple umbellate cyme	Horizontal
TZSMN 55-2	-	Tanzania	Along main stem	Simple umbellate cyme	Horizontal
TZSMN 55-3	RVI00614	Tanzania	Along main stem	Simple umbellate cyme	Horizontal
UG-NS3	-	Uganda	On primary branch	Forked cyme	Horizontal
MW 25	RVI00545	Kenya	On primary branch	Simple umbellate cyme	Facing upwards
S. sarrachoides **(Diploid; 2n = 2x =24)**					
NS3CR2	-	Kenya	On primary branch	Simple umbellate cyme	Facing upwards
NSR23B	-	Kenya	On primary branch	Simple umbellate cyme	Facing upwards
S. villosum **(Tetraploid; 2n = 4x = 48)**					
RC 18	RVI00521	Tanzania	On primary branch	Simple umbellate cyme	Facing upwards
BG 27	RVI00571	Kenya	Along main stem	Simple umbellate cyme	Facing upwards
S. americanum **(Diploid; 2n = 2x =24)**					
BG 1	RVI00615	Tanzania	Along main stem	Simple umbellate cyme	Facing upwards
RC 1	RVI00493	Tanzania	On primary branch	Simple umbellate cyme	Horizontal

Line	Colour of mature berry	Fruit attachment	Colour of fruit flesh	Color of stem and branches
S. scabrum **(Hexaploid; 2n = 6x =72)**				
BG 4	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 7	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 8	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 9	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 11	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 13	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 14	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Light purple
BG 16	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 17	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 21	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 22	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 24	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
BG 26	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Light purple
BG 29	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
SS 04.2	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
SS 40	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Light purple
SS 49	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Light purple
SS 52	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Light purple
TZSMN 11-5	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
TZSMN 55-2	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
TZSMN 55-3	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Green
UG-NS3	Dark purplish black	Falling from calyxes when ripe	Purple	Green
MW 25	Dark purplish black	Fruits remain on plant when fully ripe	Purple	Dark purple
S. sarrachoides **(Diploid; 2n = 2x =24)**				
NS3CR2	Light green	Falling with pedicels still attached	Green	Green
NSR23B	Light green	Falling with pedicels still attached	Green	Green
S. villosum **(Tetraploid; 2n = 4x = 48)**				
RC 18	Orange	Falling from calyxes when ripe	Orange	Green
BG 27	Orange	Falling from calyxes when ripe	Orange	Green
S. americanum **(Diploid; 2n = 2x =24)**				
BG 1	Purple	Falling from calyxes when ripe	Purple	Green
RC 1	Purple	Falling from calyxes when ripe	Purple	Green

Table 1 (Cont.)

Line	Leaf shape	Leaf edge	Leaf apex	Leaf colour
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	Oval	Smooth	Round to flattened	Dark green
BG 7	Oval	Smooth	Acute (approx 30 or less)	Light green
BG 8	Oval	Smooth	Acute (approx 30 or less)	Light green
BG 9	Oval	Smooth	Acute (approx 30 or less)	Green
BG 11	Oval	Smooth	Acute (approx 30 or less)	Light green
BG 13	Round	Smooth	Obtuse (about 110)	Green
BG 14	Oval	Smooth	Round to flattened	Dark green
BG 16	Lanceolate	Undulate	Acute (approx 30 or less)	Green
BG 17	Oval	Smooth	Round to flattened	Dark green
BG 21	Round	Smooth	Obtuse (about 110)	Dark green
BG 22	Oval	Smooth	Obtuse (about 110)	Light green
BG 24	Round	Smooth	Obtuse (about 110)	Green
BG 26	Oval	Smooth	Acute (approx 30 or less)	Dark green
BG 29	Round	Smooth	Obtuse (about 110)	Dark green
SS 04.2	Oval	Smooth	Round to flattened	Dark green
SS 40	Oval	Smooth	Acute (approx 30 or less)	Dark green
SS 49	Oval	Smooth	Acute (approx 30 or less)	Dark green
SS 52	Oval	Undulate	Intermediate (about 60-75)	Dark green
TZSMN 11-5	Round	Smooth	Acute (approx 30 or less)	Dark green
TZSMN 55-2	Round	Smooth	Obtuse (about 110)	Dark green
TZSMN 55-3	Round	Smooth	Acute (approx 30 or less)	Green
UG-NS3	Lanceolate	Smooth	Round to flattened	Green
MW 25	Oval	Smooth	Acute (approx 30 or less)	Dark green
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NS3CR2	Lanceolate	Dentate	Round to flattened	Light green
NSR23B	Lanceolate	Dentate	Acute (approx 30 or less)	Light green
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
RC 18	Lanceolate	Smooth	Round to flattened	Dark green
BG 27	Lanceolate	Smooth	Round to flattened	Light green
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	Lanceolate	Crenate	Round to flattened	Light green
RC 1	Lanceolate	Crenate	Acute (approx 30 or less)	Light green

Line	Hairiness of leaves	Branching	Hairiness of stems
***S. scabrum* (Hexaploid; 2n = 6x =72)**			
BG 4	Few hairs or very short hairs	primary and secondary branches only	Glabrous or appearing hairless
BG 7	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
BG 8	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
BG 9	Few hairs or very short hairs	primary and secondary branches only	few hairs or very short hair
BG 11	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
BG 13	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
BG 14	Few hairs or very short hairs	primary and secondary branches only	Glabrous or appearing hairless
BG 16	Few hairs or very short hairs	primary and secondary branches only	Glabrous or appearing hairless
BG 17	Glabrous or appearing hairless	primary and secondary branches only	Glabrous or appearing hairless
BG 21	Glabrous or appearing hairless	primary and secondary branches only	Glabrous or appearing hairless
BG 22	Glabrous or appearing hairless	primary and secondary branches only	Glabrous or appearing hairless
BG 24	Few hairs or very short hairs	primary and secondary branches only	Glabrous or appearing hairless
BG 26	Glabrous or appearing hairless	primary and secondary branches only	Glabrous or appearing hairless
BG 29	Few hairs or very short hairs	primary and secondary branches only	Glabrous or appearing hairless
SS 04.2	Few hairs or very short hairs	primary and secondary branches only	Glabrous or appearing hairless
SS 40	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
SS 49	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
SS 52	Glabrous or appearing hairless	primary and secondary branches only	Glabrous or appearing hairless
TZSMN 11-5	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
TZSMN 55-2	Few hairs or very short hairs	primary and secondary branches only	Glabrous or appearing hairless
TZSMN 55-3	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
UG-NS3	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
MW 25	Few hairs or very short hairs	primary and secondary branches only	Few hairs or very short hair
***S. sarrachoides* (Diploid; 2n = 2x =24)**			
NS3CR2	Pubescent	Bushy (with well-developed secondary and other divided braches)	Few hairs or very short hair
NSR23B	Pubescent	Bushy (with well-developed secondary and other divided braches)	Hairs clearly present, short or long
***S. villosum* (Tetraploid; 2n = 4x = 48)**			
RC 18	Glabrous or appearing hairless	primary and secondary branches only	Glabrous or appearing hairless
BG 27	Glabrous or appearing hairless	primary and secondary branches only	Glabrous or appearing hairless
***S. americanum* (Diploid; 2n = 2x =24)**			
BG 1	Glabrous or appearing hairless	Bushy (with well-developed secondary and other divided braches	Few hairs or very short hair
RC 1	glabrous or appearing hairless	Bushy (with well-developed secondary and other divided braches	Glabrous or appearing hairless

Table 2 Mean days to 50% flowering, 50% fruit set and plant height of genetically diverse African nightshade lines evaluated in Arusha, Tanzania for three seasons.

Line	Days to 50% flowering			
	Season 1	Season 2	Season 3	Mean
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	29 gh	51 fg	73 fg	51
BG 7	31 fg	53 ef	84 c	56
BG 8	34 de	56 de	87 b	59
BG 9	33 def	65 bc	84 c	61
BG 11	32 ef	53 ef	-	43
BG 13	32 def	54 ef	-	43
BG 14	29 gh	59 d	83 c	57
BG 16	45 a	89 a	95 a	76
BG 17	-	-	72 g	72
BG 21	27 h	53 ef	74 efg	52
BG 22	34 de	54 ef	72 g	53
BG 24	32 ef	55 e	83 c	57
BG 26	28 gh	62 c	85 c	59
BG 29	33 def	55 e	81 d	56
SS 04.2	32 ef	51 fg	-	42
SS 40	31 efg	54 ef	-	43
SS 49	43 a	59 d	-	51
SS 52	37 c	67 b	-	52
TZSMN 11-5	40 b	53 ef	84 c	59
TZSMN 52-3	-	-	84 c	84
TZSMN 55-3	35 cd	48 gh	84 c	56
UGNS 3	-	-	75 ef	75
MW 25	40 b	55 e	-	48
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	23 i	54 ef	84 c	53
NS3CR2	23 i	55 e	-	39
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	21 i	59 d	72 g	51
RC 18	21 i	46 h	-	33
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	21 i	48 gh	73 fg	47
RC 1	-	-	76 e	76
F-test	***	***	***	-
CV (%)	4.7	3.2	1.5	-

Line	Days to 50% fruit set			
	Season 1	Season 2	Season 3	Mean
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	41 e-h	89 c-f	80 i	65
BG 7	40 fgh	83 fgh	86 def	66
BG 8	41 e-h	83 fgh	90 b	68
BG 9	40 fgh	83 fgh	88 bcd	68
BG 11	41 e-h	83 fgh	-	56
BG 13	42 d-g	84 efg	-	57
BG 14	42 d-h	89 c-f	86 def	69
BG 16	56 a	103 a	98 a	83
BG 17	-	-	79 ij	76
BG 21	39 fgh	82 fgh	84 fg	64
BG 22	45 cde	76 h	79 ij	63
BG 24	39 fgh	83 fgh	85 efg	66
BG 26	42 d-g	101 ab	89 bc	73
BG 29	41 e-h	81 gh	85 e-g	66
SS 04.2	50 b	92 cd	-	61
SS 40	42 d-g	92 cd	-	59
SS 49	48 bc	96 bc	-	65
SS 52	58 a	91 c-e	-	67
TZSMN 11-5	45 c-e	86 d-g	86 d-f	69
TZSMN 52-3	-	-	86 de	85
TZSMN 55-3	43 d-f	81 gh	87 c-e	67
UGNS 3	-	-	81 hi	78
MW 25	46 cd	89 c-f	-	61
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	37 h	657 i	86 def	60
NS3CR2	39 f-h	101 ab	-	60
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	38 gh	101 ab	77 j	67
RC 18	38 gh	92 cd	-	55
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	38 gh	92 cd	80 i	64
RC 1	-	-	83 gh	79
F-test	***	***	***	-
CV (%)	5.7	4.3	1.6	-

Table 2 (Cont.)

Line	Plant height at maturity (cm)			
	Season 1	Season 2	Season 3	Mean
S. scabrum **(Hexaploid; 2n = 6x =72)**				
BG 4	98 e-g	112 c-f	88 b	99
BG 7	90 g-i	88 g-i	54 gh	78
BG 8	99 ef	67 ij	54 gh	73
BG 9	104 de	66 ij	63 ef	77
BG 11	88 h-j	117 b-e	-	103
BG 13	109 cd	95 e-h	-	102
BG 14	124 a	142 a	101 a	122
BG 16	117 b	97 e-g	59 f-h	91
BG 17	-	-	68 de	68
BG 21	101 ef	78 g-i	74 cd	84
BG 22	87 h-j	143 a	63 ef	98
BG 24	94 f-h	82 g-i	65 ef	80
BG 26	100 ef	111 c-f	60 f-h	90
BG 29	97 e-g	72 h-j	61 e-g	77
SS 04.2	105 de	116 c-e	-	110
SS 40	114 bc	130 a-c	-	122
SS 49	115 bc	112 c-f	-	114
SS 52	78 l	130 a-c	-	104
TZSMN 11-5	86 h-k	77 ghi	66 ef	76
TZSMN 52-3	-	-	46 i	46
TZSMN 55-3	100 ef	51 j	46 i	66
UGNS 3	-	-	77 c	77
MW 25	120 ab	140 ab	-	130
S. sarrachoides **(Diploid; 2n = 2x =24)**				
NSR23B	88 hij	98 d-g	59 f-h	82
NS3CR2	85 i-l	91 f-h	-	88
S. villosum **(Tetraploid; 2n = 4x = 48)**				
BG 27	93 f-i	116 c-e	52 hi	87
RC 18	81 j-l	121 a-d	-	101
S. americanum **(Diploid; 2n = 2x =24)**				
BG 1	77 l	127 a-c	76 c	93
RC 1	-	-	58 f-h	58
F-test	***	***	***	
CV (%)	4.6	11.9	6.4	

*** highly significant (p<0.001). Means within the same column followed by the same letter(s) are not significantly different at p<0.00 based on DMRT

practices, insect pest management, harvesting and data collection were carried out as detailed for the on-station trials.

Matrix ranking was used during PVS. Varieties were assessed based on farmer-agreed criteria that included branching, leaf size, pest and disease tolerance (particularly *Fusarium solani*), flowering time, potential marketability and taste. The evaluation panellists varied from 30 to 150 depending on the location and whether evaluation was done on-farm or on-station. A scale of 1 to 5 was used to rank the lines on the basis of the six criteria above, where 1 = poor, 2 = fair, 3 = good, 4 = very good and 5 = excellent (de Boef and Thijssen 2007). Participating panellists discussed and agreed on traits they considered critical for choosing a good African nightshade variety in the field and arranged the traits in order of priority. Before making any scores, the stakeholders walked around the field for a while to get a feel of the differences in the varieties based on the discussed traits. The lines were then scored based on the top five traits using maize seeds where 1 seed corresponded to a poor score and 5 seeds corresponded to an excellent score. Scoring was done one trait at a time, beginning with the most critical in order of priority. For each trait, the stakeholders established the 1 (for example the latest maturing variety) and the 5 (the earliest maturing) first, then the rest easily fell in between. Beyond the field evaluation, samples of the lines were subjected to organoleptic tests. The leaves were boiled without additives to give as much of the natural flavour as possible. To avoid biases, the samples were numbered differently from the labels as in the field. Mean scores were used to rank varieties.

RESULTS

During the initial evaluation testing in season 1, line BG 16 took longest to reach 50% flowering followed by SS 49 while BG 21 and BG 1 took the shortest time (**Table 2**). In season 2, BG 16 again took the longest to reach 50% flowering followed by SS 52, while line RC 18 took the shortest time. This was replicated again in season 3, where BG 16 took longest to reach 50% flowering while the earliest to flower were BG 17, BG 22 and BG 27. As expected, a similar trend was followed in fruit set with the lines taking longest to reach 50% flowering in each season also taking longest to reach 50% fruit-set, while those that flowered early also set fruit early (**Table 2**).

Line BG 16 had longest and broadest leaves in all the three seasons, while most early flowering and fruiting lines such as BG 4 had among the narrowest and shortest leaves (**Table 3**). Generally, the *S. scabrum* lines had less branching and fewer but larger leaves. These characteristics seem to be important criteria in participatory selection, as farmers prefer lines with broader and longer leaves; they associate this with higher leaf yield potential, and shy away from early flowering, heavy fruiting lines that are likely to produce less leaf yield. The *S. americanum* and *S. sarrachoides* lines had much more branching and more leaves per plant, but smaller leaf sizes. *S. villosum* lines had small leaves, few branches early flowering and heavy fruit set.

Line BG 16 also had the longest and broadest fruits in all the three seasons, while the early flowering lines with prolific fruit production had the smallest fruits (**Table 4**). Again, most *S. scabrum* lines had relatively larger fruits than those of other species. It is also noteworthy that the berries of *S. scabrum* lines did not abscise at maturity nor were they eaten by birds, as the case was with *S. villosum* and *S. americanum* lines.

The fresh leaf yield differences between lines evaluated in the three experimental seasons were highly significant (**Table 5**). In the first trial line SS 52 had the highest mean

Table 3 Mean leaf length and width of genetically diverse African nightshade lines evaluated in in Arusha, Tanzania in three seasons.

	Leaf length (cm)			
Lines	**Season 1**	**Season 2**	**Season 3**	**Mean**
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	5.9 o	7.2 l	6.1 g	6.4
BG 7	9.9 hi	9.6 fg	10.5 cd	10.0
BG 8	11.4 e	8.2 jk	10.4 cd	10.0
BG 9	10.2 gh	10.0 f	10.1 de	10.1
BG 11	8.4 k-m	8.0 kl	-	8.2
BG 13	8.6 kl	9.8 fg	-	9.2
BG 14	7.9 mn	10.1 ef	8.2 f	8.7
BG 16	17.7 a	14.8 a	16.5 a	16.4
BG 17	-	-	6.2 g	6.2
BG 21	15.8 b	9.5 f-h	11.3 b-d	12.2
BG 22	12.9 d	11.8 c	5.5 g	10.1
BG 24	9.9 hi	8.2 jk	12.0 b	10
BG 26	13.5 d	10.8 de	10.5 cd	11.6
BG 29	10.3 gh	9.8 fg	11.7 bc	10.6
SS 49	14.3 c	10.9 de	-	12.6
SS 40	10.1 gh	13.7 b	-	11.9
SS 52	16.1 b	11.3 cd	-	13.7
SS 04.2	11.1 ef	11.0 cd	-	11.1
TZSMN 11-5	9.5 ij	8.0 kl	11.1 b-d	9.5
TZSMN 52-3	-	-	9.0 ef	9.0
TZSMN 55-3	10.7 fg	9.0 g-j	8.6 f	9.4
MW 25	10.2 gh	9.6 fg	-	9.9
UGNS 3	-	-	10.0 de	10.0
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	9.3 ij	8.4 i-k	6.4 g	8.0
NS3CR2	8.8 jk	8.7 h-k	-	8.7
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	8.0 l-n	8.0 kl	10.5 cd	8.9
RC 18	7.5 n	9.3 f-i	-	8.4
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	9.7 h-i	9.2 f-i	5.5 g	8.1
RC 1	-	-	5.3 g	5.3
F-test	***	***	***	-
CV (%)	3.3	4.9	8.0	-

	Leaf width (cm)			
Lines	**Season 1**	**Season 2**	**Season 3**	**Mean**
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	5.0 lm	6.1 jk	4.6 gh	5.2
BG 7	8.7 fg	8.3 de	9.2 b-d	8.7
BG 8	9.6 de	7.3 f-i	9.0 cd	8.6
BG 9	8.8 f	8.3 de	8.7 c-e	8.6
BG 11	7.6 hi	7.7 e-h	-	7.7
BG 13	7.1 i	8.1 ef	-	7.6
BG 14	5.7 kl	6.6 ij	5.4 g	5.9
BG 16	15.7 a	12.8 a	13.1 a	13.9
BG 17	-	-	3.3 hi	3.3
BG 21	12.9 c	8.3 de	8.8 c-e	10.0
BG 22	10.0 d	9.0 b-d	3.5 hi	7.5
BG 24	8.8 fg	6.9 h-j	10.4 b	8.7
BG 26	9.9 d	7.6 e-h	8.9 cd	8.8
BG 29	9.2 ef	8.5 c-e	10.0 bc	9.2
SS 49	9.8de	6.8 h-j	-	8.3
SS 40	6.4 j	9.4 b	-	7.9
SS 52	14.3 b	9.3 bc	-	11.8
SS 04.2	6.2 jk	7.1 g-i	-	6.7
TZSMN 11-5	8.1 gh	7.0 g-i	9.3 b-d	8.1
TZSMN 52-3	-	-	7.2 f	7.2
TZSMN 55-3	9.4 def	7.8 e-g	7.4 ef	8.2
MW 25	7.6 hi	7.1 g-i	-	7.4
UGNS 3	-	-	8.2 d-f	8.2
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	4.7 mn	5.2 l	3.4 hi	4.4
NS3CR2	5.0 lm	5.8 kl	-	5.4
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	4.3 no	4.2 m	9.0 b-d	5.8
RC 18	4.0 o	5.1 l	-	4.5
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	5.6 kl	5.7 kl	3.1 i	4.8
RC 1	-	-	3.4 hi	3.4
F-test	***	***	***	-
CV (%)	4.9	6.4	10.2	-

** highly significant ($p<0.001$). Means within the same column followed by the same letter(s) are not significantly different at $p<0.05$ based on DMRT

Table 4 Mean fruit length and width of genetically diverse African nightshade lines evaluated in Arusha, Tanzania in three seasons.

Line	Fruit length (mm)			
	Season 1	**Season 2**	**Season 3**	**Mean**
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	11.4 d-g	11.4 b-d	11.0 ab	11.3
BG 7	10.4 de-g	11.1 b-e	10.7 a-c	10.7
BG 8	13.4 abc	12.4 b	10.2 a-c	12.0
BG 9	10.0 fg	9.7 e-g	10.2 a-c	10.0
BG 11	12 b-e	12.0 bc	-	12.0
BG 13	11.6 c-f	11.6 b-d	-	11.6
BG 14	9.8 fgh	9.1 g	10.7 a-c	9.9
BG 16	14.5 a	14-4 a	11.9 a	13.6
BG 17	-	-	6.0 f	6.0
BG 21	13.6 ab	14-5 a	10.6 a-c	12.9
BG 22	11.4 d-g	11-4 b-d	7.0 ef	9.9
BG 24	13.7 ab	14.1 a	8.8 cd	12.2
BG 26	9.6 gh	9.2 g	10.8 a-c	9.9
BG 29	11.7 c-f	11.3 b-d	10.5 a-c	11.2
SS 04.2	10.0 fg	10.0 d-g	-	10.0
SS 40	10.2 efg	10.9 b-f	-	10.6
SS 49	8.1 hi	9.5 fg	-	8.8
SS 52	12.3 bcd	11.5 b-d	-	11.9
TZSMN 11-5	11.2 d-g	9.5 fg	9.0 b-d	9.9
TZSMN 52-3	-	-	11.4 a	11.4
TZSMN 55-3	9.6 gh	9.3 fg	10.1 a-c	9.7
MW 25	12.1 b-d	10.7 c-g	-	11.4
UGNS 3	-	-	5.2 f	5.2
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	5.8 j	5.8 hi	6.9 ef	6.2
NS3CR2	7.0 ij	5.6 hi	-	6.3
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	6.3 j	6.5 h	10.8 a-c	7.9
RC 18	3.8 k	4.5 i	-	4.2
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	2.9 k	4.6 i	8.2 de	5.2
RC 1	-	-	6.8 ef	6.8
F-test	***	***	***	-
CV (%)	9.91	8.57	11.1	-

Line	Fruit width (mm)			
	Season 1	**Season 2**	**Season 3**	**Mean**
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	13.8 ab	12.5 bc	12.0 a-c	12.8
BG 7	11.8 b-d	12.3 bc	12.1 a-c	12.1
BG 8	14.4 ab	13.5 ab	11.3 b-d	13.1
BG 9	10.0 d-f	10.0 e	-	10.0
BG 11	12 b-d	12.0 b-d	-	12.0
BG 13	12.4 a-d	12.4 bc	-	12.4
BG 14	13.0 a-c	11.8 b-d	11.7 a-d	12.2
BG 16	15.2 a	14.7 a	13.3 a	14.4
BG 17	-	-	6.2 f	6.2
BG 21	13.1 a-c	12.5 bc	12.3 a-c	12.6
BG 22	12.4 a-d	12.3 bc	6.8 f	10.5
BG 24	13.3 a-c	12.7 bc	10.3 de	12.1
BG 26	14.2 ab	11.8 b-d	12.3 a-c	12.8
BG 29	13.7 a-c	12.7 bc	11.7 a-d	12.7
SS 04.2	10.0 d-f	10.0 e	-	10.0
SS 40	10.9 c-e	11.9 b-d	-	11.4
SS 49	8.9 ef	10.3 de	-	9.6
SS 52	12.5 a-d	12.4 bc	-	12.5
TZSMN 11-5	13.2 a-c	11.5 c-e	11.2 b-d	12.0
TZSMN 52-3	-	-	12.6 ab	12.6
TZSMN 55-3	12.2 b-d	11.9 b-d	10.7 cd	11.6
MW 25	10.9 c-e	11.5 cde	11.5 b-d	11.3
UGNS 3	-	-	6.0 f	6.0
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	4.8 g	4.8 f	6.9 f	5.5
NS3CR2	8.0 f	4.6 f	-	6.3
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	4.9 g	5.0 f	12.2 a-c	7.4
RC 18	5.2 g	5.8 f	-	5.5
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	4.5 g	4.2 f	9.2 e	6.0
RC 1	-	-	7.3 f	7.3
F-test	***	***	***	-
CV (%)	13.11	8.65	8.19	-

** highly significant ($p<0.001$). Means within the same column followed by the same letter(s) are not significantly different at $p<0.05$ based on DMRT

Table 5 Mean leaf (t/ha) and seed (kg/ha) yield of genetically diverse African nightshade lines evaluated in Arusha, Tanzania in three seasons.

Line	Leaf yield (t/ha)			
	Season 1	**Season 2**	**Season 3**	**Mean**
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	12 de	5.3 g	7.5 e	8.3
BG 7	12.8 de	6.3 fg	11.3 b-e	10.1
BG 8	17.6 cde	8.2 d-g	10.9 b-e	12.3
BG 9	18.7 b-e	9.6 de	10.3 cde	12.9
BG 11	21.9 a-e	8.2 d-g	-	15
BG 13	21.8 a-e	9.1 def	-	15.5
BG 14	11.2 e	8.3 d-g	8.3 de	9.2
BG 16	30.1 ab	16.7 a	24.2 a	23.7
BG 17	-	-	9.3 cde	9.3
BG 21	23.3 a-e	9.2 def	15 b	15.8
BG 22	20.5 b-e	13.5 bc	11.9 bcd	15.32
BG 24	16.9 cde	9.1 def	12.7 bc	12.9
BG 26	23.8 a-d	10.2 de	12.5 bc	15.5
SS 04.2	22.7 a-e	9.8 de	-	16.2
SS 40	23.2 a-e	11.3 cd	-	17.3
SS 49	21. 5 a-e	7.4 efg	-	14. 5
SS 52	32.8 a	14.4 ab	-	23.6
BG 29	19.7 b-e	7.1 efg	12.6 bc	13.2
TZSMN 11-5	19.1 b-e	9.1 def	10.8 b-e	13
TZSMN 52-3	-	-	11.2 b-e	11.2
TZSMN 55-3	27.7 abc	8 efg	12.1 bcd	15.9
UGNS 3	-	-	13. 6 bc	13.6
MW 25	20.8bcde	13. 2 bc	-	16.9
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	22.7a-e	7.2 efg	1.9 f	10.6
NS3CR2	18.6b-e	8.1 d-g	-	13.3
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	12.8de	7.9 efg	12.7 bc	11.1
RC 18	12.3de	7.5 efg	-	9. 9
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	14.9de	8.1 d-g	8 de	10.33
RC 1	-	-	11.7 b-e	11.7
F-test	**	***	***	-
CV (%)	30.7	17.7	19.0	-

Line	Seed yield (kg/ha)			
	Season 1	**Season 2**	**Season 3**	**Mean**
***S. scabrum* (Hexaploid; 2n = 6x =72)**				
BG 4	1871.3 ab	1516.3 bc	2116.9 a	1834.8
BG 7	954.9 a-f	870.1 d-h	809.4 e-i	878.2
BG 8	895.5 a-f	723.9 e-i	1440.9 a-e	1020.1
BG 9	977.1 a-f	806.1 d-h	1299.7 b-f	1027.7
BG 11	982.8 a-f	573.8 g-j	-	778.4
BG 13	1614.9 ab	1064.2 c-g	-	1339.5
BG 14	1567.9 ab	1111.9 b-f	968.1 d-h	1215.9
BG 16	2078.9 a	2036.3 a	1828.2 abc	1981.2
BG 17	-	-	300.5 hij	300.5
BG 21	809.2 b-f	519.5 h-k	1889.9 ab	1072.8
BG 22	1803.4 ab	1580.4 b	451.2 g-j	1278.4
BG 24	787.5 b-f	649.5 f-i	1335.8 b-f	924.34
BG 26	1429.3 abc	1264.8 bcd	1591.7 a-d	1428.6
SS 04.2	1367 a-e	1150 b-e	-	1258.5
SS 40	1407.3 a-d	1194.8 b-e	-	1301.1
SS 49	1411. 1 a-d	1202. 3 b-e	-	1306. 7
SS 52	1212.6 a-f	1190.8 b-e	-	1201.7
BG 29	2119.3 a	1490.4 bc	1486.2 a-e	1698.6
TZSMN 11-5	1221.7 a-f	1028.5 c-g	1499.4 a-e	1249.9
TZSMN 52-3	-	-	708.5 f-j	708. 5
TZSMN 55-3	1837.1 ab	1203.1 b-e	1098.8 c-g	1379.7
UGNS 3	-	-	381.5 g-j	381.5
MW 25	1525.8 ab	1555.1 b	-	1540. 5
***S. sarrachoides* (Diploid; 2n = 2x =24)**				
NSR23B	168.9 def	75.1 k	-	121.9
NS3CR2	91.7 f	61.3 k	-	76.5
***S. villosum* (Tetraploid; 2n = 4x = 48)**				
BG 27	137.9 ef	104.6 jk	1592.7 a-d	611.7
RC 18	236.3 c-f	133. 3 jk	-	184.8
***S. americanum* (Diploid; 2n = 2x =24)**				
BG 1	1697.9 ab	280.6 ijk	186.1 ij	721.5
RC 1	-	-	160.1 ij	160.1
F-test	**	***	***	-
CV (%)	25.4	28.3	36.4	-

** highly significant ($p<0.001$). Means within the same column followed by the same letter(s) are not significantly different at $p<0.05$ based on DMRT

Table 6 Yield (t/ha) of African nightshade tested in multilocational trials in four agro-ecological zones in 2008/2009 and 2009/2010.

Line	Cool highland wet tropics (Iringa)			Hot dry medium altitude tropics (Dodoma)		
	'08/ '09	'09/ '10	Rating	'08/ '09	'09/ '10	Rating
BG 14	36.4	8.4	5	49.2	33.6	1
BG 16	41.2	10.9	5	52.1	37.7	5
BG 23	35.1	9.8	5	29.2	33.7	1
Ex-Hai	32.6	7.3	3	43.6	24.4	4
SS 04.2	36.3	9.9	5	51.1	34.8	5
SS 49	47.6	14.7	5	67.8	42.6	5
SS 52	38.3	11.3	5	55.8	36.6	5
TZSMN55-3	27.3	8.2	3	24.2	23.9	1
F- test	*	ns		*	Ns	
$LSD_{0.05}$	9.8	5.3		21.9	19.6	

Line	Hot humid low altitude (Bagamoyo)			Cool medium altitude wet tropics (Arusha)		
	'08/ '09	'09/ '10	Rating	'08/ '09	'09/ '10	Rating
BG 14	18.7	23.5	4	30.0	17.4	3
BG 16	28.4	29.6	3	30.3	22.6	5
BG 23	20.4	22.3	3	28.0	24.6	3
Ex-Hai	13.0	21.2	5	25.8	15.9	3
SS 04.2	17.4	21.1	3	29.5	18.2	3
SS 49	22.9	22.8	3	42.4	25.9	5
SS 52	20.4	23.5	4	28.4	24.4	4
TZSMN55-3	9.2	13.2	5	26.4	12.4	3
F-test	*	*		**	*	
$LSD_{0.05}$	9.1	7.6		9.9	9.3	

*Mean separation is based on $LSD_{0.05}$

leaf yield followed by line BG 16. Lines BG 14 and BG 4 had the lowest leaf yields respectively. In the second season, line BG 16 had the highest mean leaf yield followed by line SS 52. Lines BG 4 and BG 7 were the least yielding. In the third season, the line BG 16 had the highest leaf yield while line NSR23B gave the lowest leaf yield. Overall, BG 16 had the highest mean leaf yield while BG 4 had the lowest (**Table 5**).

Differences between lines in seed yield were also highly significant for all the three seasons (**Table 5**). In trial 1 line BG 29 had the highest mean seed yield followed by BG 16, while lines NS3CR2 and NSR23B were the lowest yielding. In the second trial, line BG 16 had the highest mean seed yield followed by BG 22. Lines NS3CR2 and NSR23B had the lowest seed yield. In the third season trial, line BG 4 had the highest seed yield followed by BG 21 and BG 16 while line RC 1 had the lowest seed yield. Overall, line BG 16 had the highest mean seed yield followed by BG 4 while NS3CR2 had the lowest mean seed yields (**Table 5**).

Evaluations carried out at multiple locations showed that line SS 49 had the highest leaf yield in Iringa, Dodoma and Arusha while BG 16 had the highest yield in Bagamoyo in both years (**Table 6**). The generally low yields observed at Iringa in 2009/2010 were due to spider mite attack that reduced harvest duration to 2 instead of the 4 harvests the previous year. The most acceptable lines in Bagamoyo were Ex-Hai and TZ SMN 55-3, while in Iringa all lines were highly acceptable except Ex-Hai and TZ SMN 55-3. In Dodoma, SS 49, SS 52, BG 16 and BG 04.2 were all highly acceptable. The two most acceptable lines in Arusha were SS 49 and BG 16 (**Table 6**). Following the yield and acceptability results, African nightshade lines SS 49 and BG 16 were nominated and proposed for release in all agroecological zones except in the coastal areas represented by Bagamoyo where line Ex-Hai was proposed on the basis of its popularity.

DISCUSSION

The lines that consistently recorded the highest leaf and seed yields when they were included in the trials were from the S. *scabrum* group. Generally, *S. scabrum* lines have large leaves, and only primary and secondary branches, thereby attaining high leaf area index by maximizing the size of individual leaves and thereby attaining very high leaf yields (Manoko 2007; Manoko *et al*. 2007; Mwai 2007; Mwai *et al*. 2007; Manoko *et al*. 2008, 2012). Some *S. scabrum* lines performed very poorly in terms of flowering time, leaf and seed yields, indicating a high level of genetic variability among lines within this species and in agreement with the previous findings (Manoko 2007; Mwai 2007; Mwai *et al*. 2007; Manoko *et al*. 2008; Volis *et al*. 2009).

S. sarrachoides, and *S. americanum* lines have much smaller leaves compared to *S. scabrum* but branch profusely, attaining a bushy growth habit, by initiating a large number of small leaves borne on numerous lateral shoots. However, they flower and fruit early, thereby reducing their leaf yields. *S. villosum* lines form compact plants with primary and secondary branches only. With neither the advantage of large leaves nor many branches/leaves, these species are unable to attain photosynthetic efficiencies as high as *S. scabrum* and hence produce lower leaf yields.

Generally high leaf yields in some *S. scabrum* lines might be attributed to their characteristic late flowering and fruiting, large leaves and ability to sprout leaves fast after harvest. *S. scabrum* lines have been reported in earlier variety evaluation trials to have higher leaf yields than lines in other species (Mwai 2007; Mwai *et al*. 2007, 2009a, 2009b). At the onset of reproductive growth, dry matter partitioning is directed more to pollen, seed and fruit formation and development at the expense of leaf emergence and expansion. Deflowering was reported to increase leaf yields by 40% (Mwafusi 1992). Elimination of the suppressing effect of flowers and fruits could account for such increases. Deflowering is not a sustainable approach due to high cost of labour and time investment involved. Development of new varieties with late flowering habits or whose leaf yields are least affected by the reproductive function is potentially more economically viable and technically feasible (Ojiewo *et al*. 2005).

In Eastern Africa, the most commonly grown and consumed African nightshade landraces belong to the *S. villosum* group. This species exhibits one of the earliest and most prolific flowering habits, which severely limits its leaf yields. Working with *S. villosum*, Ojiewo *et al*. (2009) induced male sterility and studied its effect on dry matter distribution. While the male sterile mutant, T-5 allocated a mean of 2% of the total plant biomass to the reproductive function, the wild-type plants allocated a mean of 37% (Ojiewo *et al*. 2009). T-5 allocated a mean of 29% of the total plant matter to leaves while the wild type allocated 19%. These results were attributed to elimination of the suppressing effects of fruits and seeds on vegetative growth.

Developing flowers and fruits are strong enough sinks, to mobilize stored photosynthates and mineral nutrients from vegetative parts and induce leaf senescence by decreasing the amounts of assimilates present in the leaves (Wada *et al*. 1993). In tomato, 72% of the total above-ground dry matter production is distributed to the fruits (de Koning 1993). Male-sterile *Sidalceae oregano* plants allocate more biomass, nitrogen, phosphorus, and potassium to leaves than male-fertile ones (Ashman 1994). Two thirds of the total flower dry mass is allocated to stamens and pollen, the regenerative parts of the flower in *Plantago lanceolata* (Poot 1997). Similarly, allocation of large portions of the flower biomass to stamens and pollen has been reported in *Curcubita foetidissima* (Kohn 1989) and *Hebe subalpina* (Delph 1990). Pollen production is associated with relatively high respiratory costs. The tapetum contains a very high concentration of mitochondria, showing that pollen production requires high energy (Bedinger 1992). The high % N of the stamens relative to that of the other plant parts suggests the relatively high cost of protein construction (De Visser *et al.* 1992). In this study, low yields in lines such as RC 18, BG 1, BG 22, BG 27 and TZSMN 55-3 could be accounted for in part by early flowering and early fruiting that suppressed emergence of new leaves, reduced leaf expansion rates, and induced early leaf senescence.

The high yields of *S. scabrum* lines could also be attributed to the higher ploidy level, which would be expected to confer larger plant dimensions to this hexaploid species compared with diploids and tetraploids (de Jesus 2003; Mwai 2007; Mwai *et al*. 2007; Manoko 2007; Manoko *et al*. 2008). Octoploids induced from *S. villosum* (tetraploid) have been shown to have larger stomata and larger pollen as well as large dark leaves (Ojiewo *et al*. 2006). By increasing their ploidy level through successive rounds of DNA replication, plant cells commonly enlarge to hundreds or even thousands of times their original size. Polyploidy affects genetic mechanisms that control the size of plants, plant organs and plant cells (Kondorosi *et al*. 2000) and polyploid plants have been reported to give better yields than diploid ones (Ojiewo *et al*. 2007, 2013).

Higher seed yields observed in *S. scabrum* lines could be attributed to large fruit size and numbers. Although the seed size was not measured, the seeds were observed to be larger than in other lines. Within plants, there is a constant interplay between structures that provide the plant with nutrients or photosynthates and structures that import nutrients and photosynthates for their own growth or storage (Marcelis 1996). Resource supply from sources may control formation of new sinks (Kaitaniemi *et al*. 1999), thus explaining why BG 16 with large leaves, potentially high leaf area index, and prolonged vigorous vegetative growth could accumulate more photo-assimilates for later reproductive growth, leading to high seed yields. Low seed yields observed from lines NS3CR2, NSR23B and RC 18 might be attributed to their characteristic small fruit sizes and fruit abscission at ripening coupled with bird damage. Besides competing against the leaves, developing flowers and fruits also compete against themselves for photosynthates and mineral nutrients as the numbers increase over time (Wada *et al*. 1993). This explains why lines with early heavy flowering and fruiting end up with small fruits with poor fruit/seed set with a consequence of fairly low seed yields.

In fruit, pod, and seed vegetables a large reproductive: vegetative ratio may be desirable to increase yields, but vegetative organs must develop sufficiently enough to intercept light and accumulate water and nutrients. In leafy vegetables such as African nightshade, fruit and seed formation is desirable only for propagation purposes; over-bearing or early flowering may be undesirable if there is evidence of leaf suppression. From this study, lines with high leaf and seed yields were identified with a potential to become major leafy vegetables, and they already attract interest from seed companies for commercialization. The high-yielding lines selected on station were subjected to further multi-location evaluation along with multi-stake-holder participatory variety evaluation and selection and proposed for official release and registration. As a result, lines BG 16 and SS 49 were officially released and registered in Tanzania as "Nduruma" and "Olevolosi", respectively (MAFSC 2012). Line Ex-Hai was declined on the basis of its overall poor performance despite its popularity at the Coast. Coastal communities in Tanzania prefer slightly bitter taste that Ex-Hai offers. However, the line flowers and fruits very early, bearing lots of berries, thereby limiting its leaf yield.

One of the most common leafy vegetable harvesting practices in Tanzania is clear harvesting by uprooting. With this practice, Weinberger and Msuya (2004) reported that the mean yields of African nightshade in Tanzania is 3.8 t/ha. Given the susceptibility to spidermites and also early flowering and prolific fruiting habits of African nightshade and the concomitant suppression of leaf formation and expansion, it is justifiable that farmers should clear harvest at maturity and re-plant. However, the practice is not only labour-intensive, but also costly in terms of farm inputs. In addition, most small-scale commercial farmers practice crop specialization and mono-cropping without crop rotation, thereby accumulating soil borne pathogens. The two new varieties can be harvested continually with a cumulative yield potential of about 30-40 t/ha after 4-6 harvests. Continuous harvesting involves less labour in land preparation and is less costly in terms of farm inputs. Furthermore, it can be practiced sustainably on a small piece of land. If the farmers opt for clear harvesting, the new varieties are ready for harvest in just 21-28 days.

Tastes and preferences vary from one locality to another even within the same country. While in some parts of Tanzania, people associate bitter taste with medicinal properties of African nightshade (Ojiewo *et al*. 2013), in other parts of the country, and in Kenya particularly, mild or sweet taste is preferred. "Nduruma" from BG 16 is sweet tasting while "Olevolosi" from SS 49 is slightly bitter. Therefore, these two varieties meet a wider range of tastes and preference than the commonly cultivated *S. villosum* group, which are generally bitter. Furthermore, earlier characterization, evaluation and selection trials indicate that the varieties are more resistant to *Fusarium* wilt that is very devastating to *S. villosum* (PRONIVA 2006).

CONCLUSION

Most African seed companies prefer to import seed from Europe and Asia rather than develop cultivars locally. This is caused by strict regulation of the variety release, registration and certification process, making it long, cumbersome and very expensive. Besides, there is a fairly long lag time between investment in research and development and income from sales of new varieties. These notwithstanding, only registered varieties can be legally traded in. Indigenous vegetables are the immediate casualty of this strict regulation, causing a deficit of certified seed of improved varieties. The development, official release and registration of "Nduruma" and "Olevolosi" is expected to make a major contribution to revolutionizing the formal seed supply system of African nightshade once commercialized by seed companies and adopted by farmers. This in turn will ease off the current discrepancy between demand and supply of African nightshade, especially in the urban and peri-urban markets. Commercialization of the two varieties is poised to take off with increasing demand in line with a previous experience in Kenya. In Kenya, line SS52 has been registered and officially released as "Giant Nightshade". The line is commercialized in Kenya by Simlaw Seed Company.

ACKNOWLEDGEMENTS

This study was carried out under the sponsorship of BMZ/GTZ funded project No: 05.7860.9–001.00 "Promotion of Neglected Indigenous Leafy and Legume Vegetable Crops for Nutritional Health in Eastern and Southern Africa (ProNIVA)"; and the Bill and Melinda Gates Foundation funded project "Vegetable Breeding and Seed Systems for Poverty Reduction in Africa (vBSS)" awarded to AVRDC-The World Vegetable Center.

Table 7 Weather patterns in various locations during the three years of multilocational and on-farm trials in Tanzania.

Year	Element	Jan	Feb	Mar	Apr	May	Jun	Jul
Bagamoyo								
2008	Mean T ºC	28.1	27.3	27.4	25.1	25.5	24	23.7
	Max T ºC	32.5	31.7	32.7	29.5	30.6	29.4	29.5
	Min T ºC	24.6	22.8	23.2	22.4	21.4	19.1	18.5
	Mean RH %	77.9	78.8	79.4	89.4	82	76.7	78
	Rainfall (mm)	53.6	34.79	158.24	414	63.75	12.7	7.11
2009	Mean T ºC	28.3	27.8	27.4	26.3	25.8	25.3	24.1
	Max T ºC	33.1	33.3	32.8	31	30.8	31	30
	Min T ºC	24.9	24.1	23.2	22.6	21.7	20.9	19.5
	Mean RH %	75.2	78.9	81.7	84.3	80.9	77.4	73.9
	Rainfall (mm)	26.66	59.95	130.54	580.64	26.93	18.03	3.06
2010	Mean T ºC	28.4	29.1	28.8	27.2	26.4	25.4	24
	Max T ºC	32.6	33.7	32.9	31.7	30.8	30.2	29.6
	Min T ºC	25.6	24.9	25	23.9	23	20.7	19.6
	Mean RH %	74.3	73.3	77.5	84.2	82.7	77.1	76.1
	Rainfall (mm)	11.42	68.06	110.24	74.42	17.02	3.56	5.08
Dodoma								
2008	Mean T ºC	23.9	22.5	22.9	22.1	21.7	20.1	19.8
	Max T ºC	29.8	28.4	28.7	27.8	28	26.8	26.5
	Min T ºC	19.2	18.3	18.4	17.8	16.1	14.1	14.2
	Mean RH %	67.1	75.4	73.6	72.4	64.5	58.8	57.4
	Rainfall (mm)	43.2	176.53	207.81	9.65	0	0	0
2009	Mean T ºC	25	23.2	24.5	23.1	22.7	21.7	20.3
	Max T ºC	31.5	28.8	30.3	29.2	28.9	27.8	26.3
	Min T ºC	19.5	18.5	19.2	18.2	17.1	16	13.9
	Mean RH %	60.4	70.1	65.9	67.7	61.1	61.1	54.9
	Rainfall (mm)	41.91	179.07	42.17	130.81	0	0	0
2010	Mean T ºC	23.8	24	24.5	24	22.9	21.9	20.5
	Max T ºC	29	29.8	30.3	30.1	29	27.5	26.4
	Min T ºC	19.3	19.3	19.6	18.9	18	15.9	14.6
	Mean RH %	70.9	70.9	68	64	61.2	56	54.7
	Rainfall (mm)	76.97	107.45	25.91	4.57	0	0	0
Arusha								
2008	Mean T ºC	22.2	21.3	21.4	19.5	18.7	16.9	16.5
	Max T ºC	28.1	27	26.1	23.3	22.5	20.8	20.5
	Min T ºC	15.5	15.8	17.3	16.4	15.7	14.1	13.2
	Mean RH %	63.6	69.2	73.4	82	78.4	77.4	75.2
	Rainfall (mm)	19.2	37	208.2	458.6	99.5	42.8	28.8
2009	Mean T ºC	22.4	22	23.1	21.6	19.9	18.9	18.5
	Max T ºC	28	27.6	29.1	25.9	23.6	22.9	22.2
	Min T ºC	15.5	16	16.9	17.5	16.6	15.5	14.3
	Mean RH %	62.7	66.2	64.4	76.4	79.6	78	70.3
	Rainfall (mm)	19.1	93.7	42	106.5	236.9	67.2	2.03
2010	Mean T ºC	25.2	26.1	25.8	24.1	23	21.3	20.6
	Max T ºC	32	33.9	33.5	29.1	27.8	26.3	25.9
	Min T ºC	19.2	20	20.1	20.7	19.8	17.3	15.3
	Mean RH %	63.8	61.5	62.9	78.7	77.5	75.7	67.5
	Rainfall (mm)	64	24.5	58.8	212	64	17.81	16.6
Iringa								
2008	Mean T ºC	21.3	20.7	21.2	20.5	20.3	19	18.5
	Max T ºC	26.3	25.6	26.2	25.1	25.7	24.7	24.2
	Min T ºC	16.7	15.5	15.5	15.3	13.1	11.9	11.9
	Mean RH %	75.4	76.8	74	71.8	61.9	56.3	54.3
	Rainfall (mm)	271.8	198.62	109.48	32.25	0	0	0
2009	Mean T ºC	22.7	21.2	21.7	21.4	21.8	20.5	18.5
	Max T ºC	28.1	25.7	26.4	26.3	27.3	26.3	24.7
	Min T ºC	15.9	16.1	15.8	15.7	14.3	13.1	12.7
	Mean RH %	64.8	73.8	74.5	69.3	60.3	56.9	55.3
	Rainfall (mm)	45.98	170.43	151.12	102.88	251.71	2.03	0
2010	Mean T ºC	21.9	21.8	22.1	22.5	22.1	19.9	18.8
	Max T ºC	26.8	27.3	28.1	28.1	26.4	25.2	23.7
	Min T ºC	16.6	16.7	16.4	16.2	15.7	14	13.3
	Mean RH %	74.4	74.8	75.1	64.6	57.8	56.6	53
	Rainfall (mm)	198.64	211.32	47.49	8.13	0	0	0

Table 7 Cont. Weather patterns in various locations during the three years of multilocational and on-farm trials in Tanzania.

Year	Element	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Bagamoyo								
2008	Mean T ºC	23.7	24	25	26.4	27.2	28.1	
	Max T ºC	29.5	29.9	30.7	31.9	31.6	32.4	
	Min T ºC	18.5	18.9	19.1	21.3	22.9	24.8	
	Mean RH %	78	78.4	75.2	77.3	81.7	78	
	Rainfall (mm)	7.11	11.18	14.74	78.99	108.21	12.46	969.77
2009	Mean T ºC	24.1	24.2	25	26.5	27.6	28.5	
	Max T ºC	30	30.5	31.5	32.5	32.6	33.2	
	Min T ºC	19.5	19.2	19.5	21.9	23.7	24.8	
	Mean RH %	73.9	78.8	72.7	72.2	74.9	74.9	
	Rainfall (mm)	3.06	8.13	0	38.1	18.8	53.09	963.93
2010	Mean T ºC	24	25.1	24.9	26.4	27.5	28	
	Max T ºC	29.6	30.9	30.5	32.2	32.4	32.5	
	Min T ºC	19.6	19.9	19.8	21.4	23	23.7	
	Mean RH %	76.1	71.7	72.1	75	76.9	76.7	
	Rainfall (mm)	5.08	5.08	45.47	2.54	143.78	84.83	571.5
Dodoma								
2008	Mean T ºC	19.8	20.6	23	24.6	25.3	24.5	
	Max T ºC	26.5	27.2	29.7	31.6	31.7	30.6	
	Min T ºC	14.2	14.8	16	18.1	19.1	19.2	
	Mean RH %	57.4	59	50.3	50.4	56.7	65	
	Rainfall (mm)	0	0	0	0	187.2	72.12	696.51
2009	Mean T ºC	20.3	21	22.7	23.7	24.2	24.7	
	Max T ºC	26.3	27.3	29.8	30.6	30.7	30.9	
	Min T ºC	13.9	15.2	15.5	17	18.8	19.4	
	Mean RH %	54.9	55.9	50.1	52.3	59	61.6	
	Rainfall (mm)	0	59.94	0	0	36.58	337.82	828.3
2010	Mean T ºC	20.5	21.6	22.3	24.2	25.4	24.1	
	Max T ºC	26.4	27.9	28.7	31	32	29.9	
	Min T ºC	14.6	15	15.3	17.5	18.7	18.7	
	Mean RH %	54.7	52.6	49.5	46.3	49.4	65.1	
	Rainfall (mm)	0	0	0	0	6.1	109.23	330.23
Arusha								
2008	Mean T ºC	16.5	18	20.3	22.1	21.9	21.2	
	Max T ºC	20.5	21.9	25.1	27.4	27	26.7	
	Min T ºC	13.2	14	15.1	16.3	15.8	15.3	
	Mean RH %	75.2	73.8	66.4	63.1	68.3	70.9	
	Rainfall (mm)	28.8	9.7	17.7	23.7	103.5	100.1	1148.8
2009	Mean T ºC	18.5	18.7	20.3	21	21.5	24.6	
	Max T ºC	22.2	22.9	25.7	25.7	25.9	31.6	
	Min T ºC	14.3	14.5	13.8	16.4	17	19.4	
	Mean RH %	70.3	68.3	66.3	69.7	75.5	68.8	
	Rainfall (mm)	2.03	5.4	5.3	40.38	95.52	58.16	714.03
2010	Mean T ºC	20.6	21	22.2	24.1	25.1	24.6	
	Max T ºC	25.9	27.4	29	31.2	32.8	32.4	
	Min T ºC	15.3	15.2	15.5	17.5	19.2	18.7	
	Mean RH %	67.5	64.6	60.1	56.9	60.3	62.8	
	Rainfall (mm)	16.6	4.4	0	3.8	49	53.3	568.21
Iringa								
2008	Mean T ºC	18.5	19.6	21.3	23.1	23.3	22.1	
	Max T ºC	24.2	25.5	27.7	29.3	29.5	27.2	
	Min T ºC	11.9	12.5	13.2	15.4	15.9	16	
	Mean RH %	54.3	56.7	48.8	49	52.6	67.4	
	Rainfall (mm)	0	0	0	70.1	9.15	56.89	748.29
2009	Mean T ºC	18.5	19.7	21.7	22.8	22.7	22.1	
	Max T ºC	24.7	25.6	28.2	28.4	28.1	27.5	
	Min T ºC	12.7	13.4	14.4	15.5	16.8	16.6	
	Mean RH %	55.3	52.6	47.4	48.3	60.8	67.4	
	Rainfall (mm)	0	0	0	0	62.99	94.47	881.61
2010	Mean T ºC	18.8	20.7	21	22.6	23.5	22.1	
	Max T ºC	23.7	26.2	27.2	29	30.2	27.9	
	Min T ºC	13.3	14.1	14.3	15.2	16.2	16.3	
	Mean RH %	53	47	47.6	44.8	46.7	61.1	
	Rainfall (mm)	0	0	0	0	7.11	116.09	588.78

Source: http://www.tutiempo.net/en/Climate/Tanzania/TZ.html; Arusha rainfall data obtained from AVRDC weather station.

REFERENCES

Afari-Sefa V, Tenkouano A, Ojiewo CO, Keatinge JDH, Hughes J d'Arros (2012) Vegetable breeding in Africa: Constraints, complexity and contributions toward achieving food and nutritional security. *Food Security* **4**, 115-127

Ashman T (1994) Reproductive allocation in hermaphrodite and female plants of *Sidalcea oregana* ssp. *spicata* (Malvaceae) using four currencies. *American Journal of Botany* **81**, 433-438

Bedinger P (1992) The remarkable biology of pollen. *Plant Cell* **4**, 879-887

Chadha ML, Engle LM, Oluoch MO (2001) Vegetable germplasm conservation and management. In: *Proceedings of a Training Course Held at AVRDC Africa Regional Program*, Arusha, Tanzania, 26 March to 01 April 2000, pp 1-207

Chweya J, Eyzaguirre P (1999) *The Biodiversity of Traditional Leafy Vegetables*, International Plant Genetic Resources Institute (IPGRI), Rome, Italy, 189 pp

CoHort Software (2003) CoStat version 6.204. Monterey CA, USA

D'Arcy W (1991) The Solanaceae since 1976, with a review of its biogeography. In: Hawkes JG, Lester R, Nee M, Estrada RN (Eds) *Solanaceae III: Taxonomy, Chemistry and Evolution*, Academic Press, London, UK, pp 75-137

de Boef SW, Thijssen MH (2007) *Participatory Tools Working With Crops, Varieties and Seeds*, Wageningen International, Wageningen, The Netherlands, 83 pp

de Jesus L (2003) Effects of artificial polyploidy in transformed roots of *Artemisia annua* L. MSc thesis, Worcester Polytechnic Institute, 122 pp

de Koning A (1993) Growth of a tomato crop. Measurements for model validation. *Acta Horticulturae* **328**, 141-146

de Visser R, Spitters C, Bouma T (1992) Energy costs of protein turnover: theoretical calculation and experimental estimation from regression of respiration on protein concentration of full grown leaves. In: Lumbers H, van der Plas L (Eds) *Molecular, Biochemical and Physiological Aspects of Plant Respiration*, SPB Academic Publishing, The Hague, pp 493-508

Delph L (1990) Sex ratio variation in the gynodioecious shrub *Hebe striticissima* (Scrophulariaceae). *Evolution* **44**, 134-142

Edmonds J, Chweya J (1997) Black Nightshades. *Solanum nigrum* L. and Related Species. Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy, 115 pp

Kaitaniemi P, Neuvonen S, Nyyssonen T (1999) Effects of cumulative defoliations on growth, reproduction, and insect resistance in mountain birch. *Ecology* **80**, 524-532

Kohn J (1989) Sex ratio, seed production, biomass allocation and the cost of male function in *Cucurbita foetidissima* HBK (Cucurbitaceae). *Evolution* **43**, 1424-1434

Kondorosi E, Roudier F, Gendreau E (2000) Plant cell-size control: Growing by ploidy? *Current Opinion in Plant Biology* **3**, 488-492

MAFSC (2012) Ministry of Agriculture Food Security and Cooperatives of Tanzania, Crop Development Department. Variety Release for Tanzania, 2012

Manoko MLK (2007) Systematic study of African *Solanum* L. section *Solanum* (Solanaceae). PhD thesis, University of Nijmegen, The Netherlands, 155 pp

Manoko MLK, van den Berg RG, Feron RMC, van der Weerden GM, Mariani C (2007) AFLP markers support separation of *Solanum nodiflorum* from *Solanum americanum sensu stricto* (Solanaceae). *Plant Systematics and Evolution* **267**, 1-11

Manoko MLK, van den Berg RG, Feron RMC, van der Weerden GM, Mariani C (2008) Genetic diversity of the African hexaploid species *Solanum scabrum* Mill. and *Solanum nigrum* L. (Solanaceae). *Genetic Resources and Crop Evolution* **55**, 409-418

Manoko MLK, van der Weerden GM, van den Berg RG, Mariani C (2012) A new tetraploid species of *Solanum* L. sect. *Solanum* (Solanaceae) from Tanzania. *PhytoKeys* **16**, 65-74

Marcelis L (1996) Sink strength as a determinant of dry matter partitioning in the whole plants. *Journal of Experimental Botany* **47**, 1281-1291

Muenyi P, Poubom C, Oluoch M (2006) Morphological Characterization and yield evaluation of exotic nightshade lines in the forest region of Cameroon. *Cameroon Journal of Agricultural Science* **2**, 1-8

Mwafusi C (1992) Effects of propagation method and deflowering on vegetative growth, leaf yield; phenolic and glycoalkaloid contents of three black nightshade selections used as vegetables in Kenya. MSc thesis, University of Nairobi, Nairobi, Kenya, 96 pp

Mwai GN, Abukutsa-Onyango MO, Onyango JC, Chadha ML, Oluoch MO (2009a) Effect of N-fertilization on yield components of nightshade. *Acta Horticulturae* **806**, 727-732

Mwai GN, Abukutsa-Onyango MO, Onyango JC, Chadha ML, Oluoch MO (2009b) Effect of planting density on yield components of nightshade. *Acta Horticulturae* **806**, 733-739

Mwai GN (2007) Morphological and molecular characterization and yield evaluation of vegetable African nightshades (*Solanum* L. section *Solanum*) under varying cultural practices. PhD thesis, Maseno University, Maseno, Kenya, 217 pp

Mwai GN, Onyango JC, Abukutsa-Onyango MO (2007) Taxonomic identification and characterization of African nightshades (*Solanum* L. section *Solanum*). *African Journal of Food, Agriculture, Nutrition and Development* **7 (4)**, 1-17

Ojiewo CO, Agong SG, Murakami K, Masuda M (2006) Chromosome duplication and ploidy level determination in African nightshade [*Solanum nigrum* L. ssp. *villosum* (L) Ehrh]. *Journal of Horticultural Science and Biotechnology* **81**, 183-188

Ojiewo CO, Agong SG, Murakami K, Tanaka A, Hase Y, Masuda M (2005) Male sterility induced by gamma-ray irradiation of African nightshades (*Solanum nigrum* L. ssp. *villosum*) seed. *Journal of Horticultural Science and Biotechnology* **80**, 699-704

Ojiewo CO, Murakami K, Masinde PW, Agong SG (2007) Mutation breeding in African nightshade (*Solanum* section *Solanum*). *Fruit, Vegetable and Cereal Science and Biotechnology* **1**, 39-52

Ojiewo CO, Murakami K, Masuda M, Agong SG (2009) Induced male-sterility alters dry matter distribution in African nightshade. *Acta Horticulturae* **806**, 571-578

Ojiewo CO, Mwai GN, Abukutsa-Onyango MO, Agong SG, Nono-Womdim R (2013) Exploiting the genetic diversity of vegetable African nightshades. *Bioremediation, Biodiversity and Bioavailability* **7 (1)**, 22-32

Poot P (1997) Reproductive allocation and resource compensation in male sterile and hermaphroditic plants of *Plantago lanceolata* (Plantaginaceae). *American Journal of Botany* **84**, 1256-1265

ProNIVA (2006) Promotion of Neglected Indigenous Vegetable Crops for Nutritional Health in Eastern and Southern Africa, Phase I (ProNIVA I). Project Final Report, March 2003 – Feb 2006

ProNIVA (2010) Promotion of Neglected Indigenous Vegetable Crops for Nutritional Health in Eastern and Southern Africa, Phase II (ProNIVA II). Project Final Report, March 2006 – September 2009

SADC-ICART Project (1999) *Marketing Indigenous Leafy Vegetable and how Small Scale Farmers Income can be Improved in the SADC Region (Tanzania, Zambia And Botswana).* Southern Africa Development Community-Implementation and Coordination of Agricultural Research and Training (SADC-ICART). Gaborone, Botswana, 16 pp

Schippers R (2000) *African Indigenous Vegetables*, An Overview of the Cultivated Species Natural Resources Institute, Chatham, UK, 214 pp

Volis S, Shulgina I, Mendlinger S, Oluoch M (2009) Genetic structure in two African vegetable nightshade species. *International Journal of Plant Breeding* **3**, 81-85

Wada Y, Miura K, Watanabe K (1993) Effect of source-to-sink ratio on carbohydrate production and senescence of rice flag leaves during the ripening period. *Japanese Journal of Crop Science* **62**, 547-553

Weinberger K, Msuya J (2004) Indigenous vegetables in Tanzania. Significance and prospects. Technical Bulletin no. 31. AVRDC publication 04-600, 70 pp

Weinberger K, Pasquini M, Kasambula P, Abukutsa-Onyango M (2011) Supply chains for indigenous vegetables in urban and peri-urban areas of Uganda and Kenya: a gendered perspective. In: Waibel H, Mithöfer D (Eds) *Vegetable Production and Marketing in Africa*, CABI, Nairobi, Kenya, pp 169-181