Evaluation of Dry Matter, Protein, Starch, Sucrose, β -carotene, Iron, Zinc, Calcium, and Magnesium in East African Sweetpotato [*Ipomoea batatas* (L.) Lam] Germplasm

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Abstract. The present study evaluated selected East African (EA) sweetpotato varieties for storage root dry matter and nutrient content and obtained information on the potential contributions of the varieties to alleviate vitamin A and mineral deficiencies. Roots obtained from 89 farmer (white- and orange-fleshed) varieties and one introduced variety ('Resisto') were analyzed for storage root quality using near-infrared reflectance spectroscopy technology. Location differences were only significant for starch content. The σ_G^2 variance was significant ($P < 0.01$) for all the traits except sucrose content. Overall, the farmer varieties had higher dry matter, higher starch, and lower sucrose contents than the control clone, 'Resisto'. It is these qualities that make sweetpotato attractive as a starchy staple in EA. A low population's mean β -carotene content (19.0 ppm) was observed. However, deep orange-fleshed farmer varieties, 'Carrot_C', 'Ejumula', 'Carrot Dar', 'Mayai', and 'Zambezi', had β -carotene content that can meet 350% or greater of recommended daily allowance (RDA) with 250-g serving to a 5- to 8-year-old child. More but light orange-fleshed farmer varieties 'K-118', 'K-134', 'K-46', 'KMI61', 'MLE162 Nakahi', 'PAL161', 'Sowola6', 'Sponge', 'SRT34 Abuket2', 'SRT35 Anyumel', 'SRT52', and 'Sudan' can provide 50% to 90% RDA of pro-vitamin A for the child. The root minerals' content was generally low except for magnesium whose content can meet 50% or greater RDA in many farmer varieties. However, in areas with high sweetpotato consumption, varieties 'Carrot_C', 'Carrot Dar', 'KRE nylon', 'MLE163 Kyebandula', and 'SRT49 Sanyuzameza' can make good intakes of iron, zinc, calcium, and magnesium. In conclusion, some EA farmer varieties can contribute greatly to alleviation of vitamin A deficiency and substantial mineral intakes.

Sweetpotato [*Ipomoea batatas* (L.)] ranks fifth in importance for its caloric contribution in developing countries after rice, wheat, maize, and cassava (CIP, 2005). In some areas of EA,

the crop has become a staple (Scott et al., 2000). For example, in Uganda, the daily intake of sweetpotato is estimated to be 240 g·d⁻¹ per person (FAOSTAT, 2007). Information about

quality attributes of African sweetpotato germplasm is very limited. The average storage root dry matter (DM) of the cultivated sweetpotato clones of the world is $\approx 30\%$ (Bradbury and Holloway, 1988; Woolfe, 1992). Two main taste groups can be distinguished: 1) white- and cream-fleshed sweetpotatoes usually with DM contents of $\approx 25\%$ to 35% ; and 2) orange-fleshed sweetpotatoes (OFSP) with DM of $\approx 20\%$ to 30% and high provitamin A carotenoids (Grüneberg et al., 2009; Martin and Jones, 1986). The taste preference in sub-Saharan Africa is clearly the dry and low sweet type, which is nearly exclusively white-fleshed.

Carotenoid pigments provide OFSP storage roots the orange flesh color. More than 60 mg total carotenoids in 100 g DM have been reported (Woolfe, 1992). A constant high proportion ($\approx 90\%$) of β -carotene in relation to total carotenoids in OFSP has been known for decades (Ezell and Wilcox, 1958; Hagenimana et al., 1999; Purcell, 1962; Purcell and Walter, 1968), and currently OFSP is considered a complementary food approach to alleviate vitamin A deficiency (VAD) in the world (Low et al., 2001, 2007). Modern OFSP varieties that are more adapted to African consumer preferences than traditional moist and sweet OFSP have been bred and released in Uganda (Mwanga et al., 2007, 2009). Also, OFSP farmer varieties that meet local consumer preferences have been found in EA (CIP, 2005; Tumwegamire et al., 2004). Approximately 80% to 90% of sweetpotato storage root DM is made up of carbohydrates, mainly starch ($\approx 60\%$ to 70% of DM) and sugars ($\approx 15\%$ to 20% of DM) with a wide range from $\approx 5\%$ to 40% of DM), and lesser amounts of pectins, hemicelluloses and cellulose (Woolfe, 1992). Usually white- and cream-fleshed varieties have higher starch ($\approx 50\%$ to 80% of DM) and lower sugar contents ($\approx 5\%$ to 15% of DM) compared with OFSP genotypes, which have lower starch ($\approx 45\%$ to 55% of DM) and higher sugar contents ($\approx 10\%$ to 20% of DM) (Woolfe, 1992). Additionally, the storage root of sweetpotato also contains reasonable amounts of protein [$\approx 5\%$ of storage root DM] (Woolfe, 1992). Studies on sweetpotato storage root mineral contents (especially trace minerals) are limited, particularly for African sweetpotato germplasm. Bradbury and Holloway (1988) reported storage root mineral content ranges of ≈ 75 to 740 ppm calcium, ≈ 180 to 350 ppm magnesium, ≈ 1.6 to 9.4 ppm iron, and ≈ 2.7 to 18.9 ppm zinc in sweetpotato accessions from the South Pacific. Courtney (2007) observed up to ≈ 10 ppm iron and ≈ 6.4 ppm zinc in fresh storage roots for North American breeding material.

The provitamin A and minerals (iron, zinc, calcium, and magnesium) are critical and deficient in human food supply (Frossard et al., 2000; Munoz et al., 2000). In Uganda, $\approx 20\%$ of children and 19% of women are vitamin A-deficient and 73% of children and 49% of women are anemic (Uganda Bureau of Statistics and Macro International Inc., 2007). The levels of anemia are higher among pregnant (64%) and breast-feeding (53%) mothers. Worldwide, 127 million preschool children

and more than 7.2 million pregnant women in developing countries suffer from VAD (Bouis, 2003; West, 2002) and approximately two billion people are anemic (Frossard et al., 2000). Another 13.5 million pregnant women have low vitamin A status (West, 2002). Globally, 800,000 and 700,000 deaths per year are attributed to iron (Fe) and zinc (Zn) deficiencies, respectively (Black, 2003). According to Black (2003), 2.4%, 1.8%, and 1.9% of the global disease burden is attributable to Fe deficiency, vitamin A deficiency and Zn deficiency, respectively. OFSPs have been demonstrated to have a great potential to alleviate VAD around the Lake Victoria region and East African highlands (Low et al., 2001). However, the majority of sweetpotato varieties consumed in EA are white-fleshed. Also, the traditional OFSP with their moist and sweet taste are unlikely to be accepted on a broad basis in EA. Fortunately, African OFSP farmer varieties and modern breeding lines have been identified and are currently being promoted by CIP and Harvest-Plus in Uganda and Mozambique (Mwanga et al., 2009). The present study evaluated selected East African sweetpotato accessions for storage root quality (DM, protein, starch, sucrose, β -carotene, Fe, Zn, calcium, and magnesium) and obtained information on the potential contributions of the accessions to alleviate vitamin A and mineral deficiencies in the EA region.

Materials and Methods

Ninety sweetpotato accessions were used in this study (Table 1). All varieties were farmer varieties from EA, except the modern variety 'Resisto' from the United States. Non-Ugandan accessions had been introduced in Uganda for regional trials during early 2005 in the frame of the sweetpotato biofortification project of the International Potato Center funded by the HarvestPlus Program. The variety, 'Resisto', was used in this study as a control to compare OFSP varieties of African origin with the typical moist and sweet OFSP type of non-African origin. It should be noted that several nutritional studies have used 'Resisto' to

investigate effects on human vitamin A status resulting from OFSP consumption (Low et al., 2007; van Jaarsveld et al., 2005). Thirty-two of the farmer varieties were OFSP cultivars with varied intensities of orange flesh color. One cultivar, Kwezikumwe, was purple-fleshed. The remaining accessions were cream-, white-, or yellow-fleshed varieties. Sixty-five farmer varieties were from Uganda, 19 from Kenya, four from Tanzania, and one from Zambia.

The field trials were planted at the National Crops Resources Research Institute at Namulonge close to lake Victoria (1150 m.a.s.l.), and Kachwekano Zonal Agricultural Research Institute (2220 m.a.s.l.) in the southwestern highlands of Uganda (Table 2). Namulonge has a bimodal rainfall pattern of 1270 mm per year, annual mean temperature of 22.2 °C (mean maximum temperature, 28.4 °C; mean minimum temperature, 15.9 °C), ferrallitic soils (red sandy clay loams), and soil pH 4.9 to 5.0. Kachwekano has a bimodal rainfall of 1319 mm per year, annual mean temperature of 18.0 °C, latosolic soils (sandy clay loam), and soil pH 5.8 to 6.2. During the second rain season of 2005 (starting in October), each landrace was planted on two-row plots using 20 vines placed 30 cm apart. The rows were 1 m apart and each variety was planted with two plot replications in a randomized complete block design. The plots were kept weed-free and no fertilizer or other agrochemicals were applied. Harvest was carried out 5 months after planting at Namulonge and 7 months after planting at Kachwekano using the local practice of sweetpotato crop duration in these different ecogeographic zones.

Plots were harvested by uprooting the center of each row, leaving a plant at both ends of each row. The harvested roots were collected into a composite pile and a sample of five roots each between 100 and 300 g weight was taken for DM, protein, starch, sucrose, β -carotene, Fe, Zn, calcium, and magnesium determination. The roots were washed of soil particles and rinsed with abundant tap water, peeled, and each root cut longitudinally into four sections. Two opposite sections of each of the sectioned roots were taken to prepare a 100-g compound sample that was placed in transparent polythene bags and freeze-dried at -31 °C for 72 h. Dry samples were weighed, milled into flour in a stainless steel mill, and stored in Kraft paper bags.

Percent root DM was calculated from flesh and dry weight estimates. Near-infrared reflectance spectroscopy (NIRS) technology (Shenk and Westerhaus, 1993) was used to determine protein, starch, sucrose, β -carotene, Fe, Zn, calcium, and magnesium in milled samples of freeze-dried storage root samples. NIRS technology has been used to screen for macronutrients in root and tuber crops (Haase, 2006; Mehrübeoglu and Côté, 1997; Young et al., 1997;), including sweetpotato (Lebot et al., 2009; Lu et al., 2006), and has been tested for minerals in agricultural commodities (Cozzolino and Moron, 2004; Halgerson et al., 2004). Also the technology has become a standard fast screening method for micronutrients (provitamins A, Fe, and Zn) (Pfeiffer and McClafferty,

2007; Zum Felde et al., 2009). Each milled sample material (two times 3 g) was analyzed by NIRS within the range of 400 to 2500 nm on a NIRS monochromator model 6500 (NIR-Systems, Inc., Silver Springs, MD) using small ring cups with a sample autochanger. Near-infrared spectra of each sample were stored in a computer file and in 2009 these spectra were again used to determine protein, starch, sucrose, β -carotene, Fe, Zn, calcium, and magnesium with the latest calibration version for sweetpotato freeze-dried samples (Zum Felde et al., 2009). In this version, the correlations in cross-validation between standard laboratory reference methods and NIRS are 0.95, 0.96, 0.80, 0.97, 0.80, and 0.89 for protein, starch, sucrose, β -carotene, Fe, Zn, respectively (Zum Felde et al., 2009) and 0.92 and 0.78 for calcium and magnesium, respectively (Zum Felde, personal communication). The reference methods to develop the NIRS calibration were Dumas according to Sweeney and Rexroad (1987) for crude protein, polarimetrically by hydrochloric acid dissociation according to ICC No. 123/1 (ICC, 1994) for starch, high-performance liquid chromatography according to Rodriguez-Amaya and Kimura (2004) for β -carotene, inductively coupled plasma argon optical emission spectrometer, according to Bridger and Knowles (2000), and reviewed by Aceto et al. (2002) for Fe, Zn, calcium, and magnesium. For sucrose determination, we used a procedure in which a water extract of the freeze-dried samples (0.1 g in 100 mL) was used: 1) the samples were incubated in a water bath at 60 °C for 1 h and afterward, they were treated with each 0.2-mL Carrez I and Carrez II solution to remove proteins; and 2) samples were purified by centrifugation (Sorvall RC-5B Refrigerated Superspeed; GMI, Ramsay, NJ) for 10 min at 20 °C with 10000 rpm, total sugars were determined from the membrane-filtered supernatant (pores size 0.45 μ m), and sucrose, glucose, fructose, maltose, and galactose were separated using a LiChrospher 100 NH₂ (5 μ m) 4 $\times$ 4 mm pre-column in combination with a LiChrospher 100 NH₂ (5 μ m) 4 $\times$ 250 mm separation column (Merck KGaA, Darmstadt, Germany) and an acetonitrile-pure water solution (80:20 v/v) as a mobile phase (flow rate 1.0 mL·min⁻¹) at 20 °C and an injection volume of 20 μ L. Sugars were detected with a Knauer differential refractometer 198.00 (Knauer, Berlin, Germany).

Statistical analyses were conducted using PLABSTAT (Plant Breeding Statistical Program) computer package (Utz, 2001) and SAS 6.12 (SAS Institute Inc., 1988, 1997). Data were classified relative to varieties or genotypes (G), locations (L), and blocks or replications (R). In an analysis of variance (ANOVA), each trait x_i (namely, protein, starch, sucrose, β -carotene, Fe, Zn, calcium, and magnesium) was analyzed from each experimental site separately to determine outliers, experimental means, coefficients of variation, and minimum and maximum values using the SAS procedure GLM and the model statement $x_i = G + R$, which corresponds to the statistical model:

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Table 1. List of sweetpotato varieties used for quality characterization at Namulonge and Kachwekano in Uganda during 2005–2006.

Variety name	CIP code	Plant type	Country of origin	Cultivar type	Storage root		
					Flesh color	Skin color	Form
Obuogo1	IP	NA	Kenya	FV	Cream	Cream	NA
KBL640 Africare	No	Semi-erect	Uganda	FV	LO	Cream	Long elliptic
APA343	No	Semi-erect	Uganda	FV	LO	Cream	Round elliptic
APA348 Liralira	No	Semi-erect	Uganda	FV	Cream	Purple–red	Elliptic
APA352 Oketodede	IP	Semi-erect	Uganda	FV	Cream	Cream	Round elliptic
APA365 Anam Anam	IP	Erect	Uganda	FV	Cream	Cream	Elliptic
ARA208 Ombivu	IP	Semi-erect	Uganda	FV	Cream	Purple–red	Round elliptic
ARA214	IP	Semi-erect	Uganda	FV	LO	Cream	Round elliptic
ARA244 Shinyanga	IP	Semi-erect	Uganda	FV	LO	Cream	Long elliptic
Bunduguza	IP	Spreading	Uganda	FV	Cream	Purple–red	Round elliptic
Bungoma	No	Semi-erect	Uganda	FV	Cream	Purple–red	Elliptic
Carrot_C	IP	Spreading	Tanzania	FV	DO	Cream	Long irregular
Carrot Dar	IP	Semi-erect	Tanzania	FV	DO	Cream	Long elliptic
Dimbuka	No	Semi-erect	Uganda	FV	Cream	Cream	Obovate
Ejumula	No	Spreading	Uganda	FV	DO	Cream	Long irregular
HMA490 Kawogo	No	Semi-erect	Uganda	FV	Cream	Brown	Ovate
HMA493 Tanzania	IP	Spreading	Uganda	FV	LO	Cream	Long elliptic
IGA963 Nyongerabarenzi	No	Erect	Uganda	FV	Cream	Cream	Round elliptic
K-118	IP	Semi-erect	Kenya	FV	LO	Cream	Long elliptic
K-134	No	Erect	Kenya	FV	LO	Purple–red	Round elliptic
K-207	No	NA	Kenya	FV	Yellow	Cream	NA
K-37	IP	NA	Kenya	FV	LO	Cream	Elliptic
K-46	IP	Semi-erect	Kenya	FV	Orange	Purple–red	Round elliptic
KBL627 Mukazi	IP	Spreading	Uganda	FV	Cream	Cream	Long elliptic
KBL632 Nyinakamanzi	No	Spreading	Uganda	FV	Cream	Purple–red	Round
KMI56 Opira	No	Erect	Uganda	FV	Cream	Brown	Long irregular
KMI59 Kampala	IP	Semi-erect	Uganda	FV	Cream	Purple–red	Long elliptic
KMI61	IP	Semi-erect	Uganda	FV	Orange	Cream	Long elliptic
KMI78 Osukari	No	Semi-erect	Uganda	FV	Cream	Purple–red	Obovate
KMI81 Ikala	IP	Semi-erect	Uganda	FV	LO	Cream	Round elliptic
KMI83 Ikala2	IP	Semi-erect	Uganda	FV	LO	Cream	Elliptic
KML883 Silkempya	No	Semi-erect	Uganda	FV	White	Cream	Elliptic
KRE716 nylon	No	Spreading	Uganda	FV	Cream	Cream	Ovate
KRE726 Kwezikumwe	No	Semi-erect	Uganda	FV	Purple	Purple–red	Elliptic
KRE733 Kitambi	IP	Spreading	Uganda	FV	Cream	Purple–red	Round
KSR673Mabereikumi	IP	Semi-erect	Uganda	FV	Cream	Cream	Ovate
KSR652 Mugumire	IP	Semi-erect	Uganda	FV	Cream	Cream	Long elliptic
KSR662 Kakoba	IP	Semi-erect	Uganda	FV	Yellow	Purple–red	Elliptic
KSR664 Muleraabana	No	Semi-erect	Uganda	FV	Cream	Pink	Long elliptic
KSR675 NoraII	IP	Semi-erect	Uganda	FV	Cream	Cream	Round
Kunyubiongo	No	Erect	Kenya	FV	Cream	Purple–red	Elliptic
Kyabafuriki	No	Spreading	Uganda	FV	Cream	Cream	Round elliptic
LIR257 Otada	No	Semi-erect	Uganda	FV	Cream	Cream	Round elliptic
LIR296	IP	Semi-erect	Uganda	FV	PY	Purple–red	Round elliptic
Mayai	No	Semi-erect	Tanzania	FV	DO	Cream	Long elliptic
MBR 539 Kitekamaju	IP	Semi-erect	Uganda	FV	White	Cream	Elliptic
MBR524 Nkwasaahansi	IP	Semi-erect	Uganda	FV	Cream	Purple–red	Long irregular
MBR536 Karebe	IP	Semi-erect	Uganda	FV	Cream	Cream	Elliptic
MBR552 Kahungezi	No	Semi-erect	Uganda	FV	Cream	Purple–red	Ovate
MBR560 Mugurusi	No	Semi-erect	Uganda	FV	Cream	Cream	Long irregular
MBR580 nylon	No	Semi-erect	Uganda	FV	Cream	Purple–red	Long elliptic
MBR600 Kisakyabikiramaria	No	Semi-erect	Uganda	FV	Cream	Cream	Long elliptic
MLE166	No	Semi-erect	Uganda	FV	LO	Purple–red	Round
MLE162 Nakahi	No	NA	Uganda	FV	LO	Cream	NA
MLE163 Kyebandula	IP	Semi-erect	Uganda	FV	Cream	Cream	Long elliptic
MLE165 Namafumbiro	No	Semi-erect	Uganda	FV	Cream	Cream	Elliptic
MLE173 Kijovu	IP	Semi-erect	Uganda	FV	Cream	Purple–red	Long irregular
MLE184 Manafayereta	No	Semi-erect	Uganda	FV	White	Pink	Long irregular
MSK1025 Bitambi	IP	Erect	Uganda	FV	Cream	Brown	Long irregular
MSK1047 Bwanjire	IP	Semi-erect	Uganda	FV	White	Purple–red	Long irregular
Nyaguta	IP	NA	Kenya	FV	Cream	Pink	Long elliptic
Nyandere	IP	NA	Kenya	FV	PY	Purple–red	Elliptic
Nyathiodiewo	No	Spreading	Kenya	FV	LO	Purple–red	Round
Nyatonge	IP	NA	Kenya	FV	Cream	Cream	NA
Obuogo2	No	NA	Kenya	FV	White	Purple–red	NA
Oguroiwe	IP	Semi-erect	Kenya	FV	Cream	Cream	Long elliptic
PAL153 Abukoki	IP	Semi-erect	Uganda	FV	Cream	Cream	Elliptic
PAL161	IP	Semi-erect	Uganda	FV	LO	Cream	Elliptic
Pipi	IP	NA	Tanzania	FV	LO	Cream	NA
Resisto	440001	Semi-erect	USA	MV	DO	Brown	Ovate
Sowola (389A)	No	Semi-erect	Uganda	FV	Cream	Brown	Elliptic
Sowola_6	No	Semi-erect	Uganda	FV	LO	Cream	Long irregular
Sponge	No	Semi-erect	Kenya	FV	LO	Purple–red	Round elliptic

(Continued on next page)

Table 1. (Continued) List of sweetpotato varieties used for quality characterization at Namulonge and Kachwekano in Uganda during 2005–2006.

Variety name	CIP code	Plant type	Country of origin	Cultivar type	Storage root		
					Flesh color	Skin color	Form
SRT14 Nora	No	Erect	Uganda	FV	Cream	Purple–red	Elliptic
SRT01 Osapat	IP	Erect	Uganda	FV	Yellow	Cream	Obovate
SRT02 Araka White	IP	Semi-erect	Uganda	FV	Cream	Cream	Ovate
SRT30 Nyara	No	Semi-erect	Uganda	FV	LO	Cream	NA
SRT33 Abuket1	IP	Semi-erect	Uganda	FV	Orange	Pink	Long elliptic
SRT34 Abuket2	IP	Semi-erect	Uganda	FV	LO	Cream	Elliptic
SRT35 Anyumel	No	Erect	Uganda	FV	LO	Cream	Round elliptic
SRT39 Rwanda	No	Semi-erect	Uganda	FV	Orange	Cream	Round elliptic
SRT40 Mary	No	Semi-erect	Uganda	FV	Cream	Cream	Long elliptic
SRT49 Sanyuzameza	No	Erect	Uganda	FV	Yellow	Purple–red	Long oblong
SRT52	No	Erect	Uganda	FV	Orange	Cream	Oblong
Sudan	No	Spreading	Uganda	FV	LO	Cream	Long elliptic
Tororo 3	IP	Semi-erect	Uganda	FV	Cream	Cream	Long elliptic
Ukerewe	IP	Semi-erect	Tanzania	FV	Yellow	Purple–red	Elliptic
Wagaborige	IP	Spreading	Uganda	FV	Cream	Cream	Round
Wera	IP	NA	Kenya	FV	Yellow	Cream	NA
Zambezi	IP	Semi-erect	Zambia	FV	DO	Purple–red	Round elliptic

IP = designation of CIP code in process; No = no acquisition from the gene bank at CIP; FV = farmer variety; MV = modern variety; DO = deep orange; LO = light orange; PY = pale yellow; NA = not applicable.

$$Y_{ijl} = \mu_i + g_{ij} + bl_{il} + \varepsilon_{ijl},$$

where Y_{ijl} is the plot value of the i th trait of the j th genotype and the l th block, μ_i is the trial mean of the i th trait, g_{ij} is the effect of genotypes, bl_{il} is the effect of blocks, and ε_{ijl} is the plot error. For the analysis across locations an ANOVA was carried out for each trait x_i using PLABSTAT with the model statement $x_i = G + L + EL + R:L + RLG$, which corresponds to the statistical model:

$$Y_{ijkl} = \mu_i + g_{ij} + l_{ik} + gl_{ijk} + bl(l)_{il(k)} + \varepsilon_{ijkl}$$

where l_{ik} and gl_{ijk} are the effects of locations and genotype–location interactions, respectively, and other effects as designated previously. In the first analysis, all effects were considered random to use the ANOVA to estimate the magnitude and significance of variance components for σ_G^2 , σ_L^2 , σ_{GL}^2 , and σ_ε^2 . In the second analysis, the effects g_{ij} , l_{ik} , and gl_{ijk} were considered as fixed to estimate the least significant difference (LSD) to compare means among varieties and locations for each trait.

Correlations among traits were carried out by SAS procedure CORR and the optional statement PEARSON. The correlations were calculated for each location and replication separately followed by calculating the average correlation between each trait pair across locations and replications using the statement BY in SAS procedure CORR. These correlations are still phenotypic correlations but can be considered as a good approximation of genotypic correlation estimates (Hill et al., 1998).

In the final analysis, the contribution of sweetpotato to the RDA for β -carotene, Fe, Zn, calcium, and magnesium was calculated by assuming an intake of 250 g fresh sweetpotato storage root per day (comparable to the consumption estimates for Uganda). The RDAs for school-aged children from 5 to 8 years were based on the Institute of Medicine in the United States (National Academy of Sciences, 2004) statistics. These RDA per day are: 400 μ g retinol, which corresponds to 4.8 mg β -carotene, 10 mg Fe, 5 mg Zn, 800 mg calcium, and 130 mg magnesium. For each, β -carotene, Fe, Zn,

Table 2. Description of locations used for the evaluation of farmer varieties.

Location	Ecogeographic region	Soil types	Altitude (m.a.s.l.)	Rainfall ² (mm)	Temperature ² (°C)	
					Mean	Range
Namulonge	Tropical rain forest	Sandy clay soils (pH 4.9 to 5.0)	1150	359.0	23.1	16.1–30.1
Kachwekano	Tropical mountain region	Sandy clay Loam (pH 5.8 to 6.2)	2220	423.1	18.1	11.9–24.2

²Rainfall (mm) and temperature experienced during the crop growing period: Oct. 2005 to Feb. 2006 at Namulonge and Oct. 2005 to Apr. 2006 at Kachwekano.

Table 3. Experimental means ($\bar{x}$), cv (cv %), minimum (min), and maximum (max) genotypic values for observed traits at locations.

Trait	Namulonge				Kachwekano			
	$\bar{x}$	cv %	Min	Max	$\bar{x}$	cv %	Min	Max
Storage root yield, t·ha ⁻¹	7.5	47.8	0	18.1	10.0	56.0	0.2	21.3
Dry matter content of storage roots, %	32.3	5.5	19.4	38.3	31.7	6.8	20.8	36.7
Protein content of storage roots, % DM	6.8	13.4	4.0	9.2	6.5	16.0	3.8	9.5
Starch content of storage roots, % DM	60.5	3.2	30.1	68.2	68.2	3.2	62.2	73.4
Sucrose content of storage roots, % DM	11.4	14.6	4.3	48.7	9.4	18.0	4.7	13.8
β -carotene content of storage roots, ppm DM	36	40.6	0	338	24	65.9	0	295
Iron content of storage roots, ppm DM	23.7	8.9	17.3	33.2	19.5	11.1	14.7	26.9
Zinc content of storage roots, ppm DM	12.3	11.0	9.5	17.8	9.5	12.1	5.9	12.7
Calcium content of storage roots, ppm DM	1980	21.2	929	4411	1880	18.0	1029	3795
Magnesium content of storage roots, ppm DM	569	25.4	169	1416	676	25.12	363	1392

DM = dry matter.

calcium, and magnesium data value, the corresponding percent RDA was calculated by: % RDA = nutrient content in 250 g fresh weight basis (fwb)/RDA*100. To compare varieties for their value in RDA contribution, the LSDs were calculated for percent RDA as described for other traits previously mentioned.

Results

Differences in the experimental means between locations were not large for all the traits, except storage root starch content (Table 3). Storage root yield means were 7.5 t·ha⁻¹ for

Namulonge and 10.0 t·ha⁻¹ for Kachwekano. However, some accessions had higher storage root yields than respective means at both locations. At Kachwekano, storage root starch and sucrose contents were, respectively, higher and lower than at Namulonge (Table 3). The lowest root sucrose contents for farmer varieties were 4.3% and 4.7% at Namulonge and Kachwekano, respectively. At Namulonge, means for protein, β -carotene, Fe, Zn, and calcium were slightly higher than at Kachwekano. Maximum values for β -carotene were high at both locations, whereas the mean values for β -carotene were low (approximately two-thirds

of the farmer varieties used in the study were white-fleshed). The cv (cv given as a percentage) values for observed traits were low to moderate, except storage root yield and β -carotene content (greater than 30%).

The σ_G^2 variance component was significant ($P < 0.01$) for all traits, except sucrose content (Table 4). For several observed traits, the σ_L^2 variance component was not significant ($P > 0.05$), except starch, β -carotene, Fe, and Zn. In contrast, the σ_{GL}^2 variance component was significant ($P < 0.01$) for all traits. The σ_G^2 : σ_{GL}^2 ratios were high (1:0.1 for β -carotene content) to extremely low (1:9.32 for sucrose content). It should be noted that the σ_G^2 : σ_{GL}^2 ratio for sucrose is extreme for a quality trait. Mainly as a result of the magnitude of σ_G^2 : σ_{GL}^2 ratios within the interval 1:0.5 and 1:3.0 for most traits as well as the number of locations (2), the operational broad sense heritabilities (h^2) were moderate (0.3 to 0.6) for most traits and only high for β -carotene content (0.94).

The population means (across varieties, locations, and replications) for storage root yield were low (8.6 t·ha⁻¹) (Table 5) but higher than the national average of 4.2 t·ha⁻¹ (Yanggen and Nagujja, 2006). Compared with averages given for cultivated sweetpotato clones of the world, higher population means for DM (32.1%) and starch content (64.4%) were observed. In contrast, sucrose population mean (10.3%) was clearly low. The population means observed for Fe, Zn, calcium, and magnesium were 21.6 ppm, 10.9 ppm, 1950 ppm, and 626 ppm, respectively. However, an important finding was that nearly all light to deep OFSP farmer varieties clearly contain provitamin A β -carotene. For the OFSP control ('Resisto'), a β -carotene content of 271 ppm was observed. Several OFSP farmer varieties, namely 'Carrot_C' (259 ppm), 'Carrot Dar' (272 ppm), 'Ejumula' (240 ppm), 'Mayai' (264 ppm), and 'Zambezi' (233 ppm), exhibited similar or slightly different β -carotene contents as the control. For these OFSP accessions, high DM contents ($\approx 33\%$), elevated starch contents ($\approx 58\%$ to 66.6% dry weight basis), and low to moderate sucrose contents ($\approx 9.8\%$ and 13.7% dry weight basis) were also observed. However, low sucrose contents (6.4% to 7.4%) were also observed in several white-fleshed varieties such as 'Bungoma', 'K-207', 'K-37', and 'KBL632 Nyinakamanzi'. Two OFSP varieties ('Rwanda' = 169 ppm; 'Abu-

ket1' = 159 ppm) were observed with moderately high β -carotene contents. It should be noted that for these two varieties, only low to medium DM contents were observed [in the case of 'Rwanda' significantly ($P < 0.05$) lower than 'Resisto']. An additional 12 farmer varieties ('K-118', 'K-134', 'K-46', 'KMI61', 'MLE162 Nakahi', 'PAL161', 'Sowola6', 'Sponge', 'SRT34 Abuket2', 'SRT35 Anyumel', 'SRT52', and 'Sudan') were observed with significant but low β -carotene contents (33 to 82 ppm) and high to very high DM contents (30.6% to 35.5%). Relatively high values for minerals were observed in OFSP (e.g., 'Carrot Dar' with values that correspond to 8.8 ppm Fe, 4.5 ppm Zn, 695 ppm calcium, and 305 ppm magnesium on a fwb) as well as white-fleshed farmer varieties (i.e., 'MBR580 nylon' with values that correspond to 7.5 ppm Fe, 4.1 ppm Zn, 901.5 ppm calcium, and 315.6 ppm magnesium on a fwb).

Moderate to high positive correlations were observed between trait pairs for DM and starch ($r = 0.620$), protein and Fe ($r = 0.810$), protein and Zn ($r = 0.796$), Fe and Zn ($r = 0.859$), Fe and magnesium ($r = 0.633$), and calcium and magnesium ($r = 0.837$) in storage roots on basis of all accessions ($N = 90$) used in the study (Table 6). A high negative correlation was observed for starch and sucrose ($r = -0.885$) on the basis of all accessions used in the study. A separate analysis with only OFSP varieties ($N = 32$ clones) revealed that there are positive correlations between β -carotene and mineral (Fe $r = 0.446$; Zn $r = 0.379$; magnesium $r = 0.374$; calcium $r = 0.428$), and sucrose ($r = 0.470$) contents, although these are not strong (Table 6). Also, a moderate negative correlation between β -carotene and starch ($r = -0.521$) was observed.

The %RDA under the condition of a high intake (250 g fresh storage roots) and consumers 5 to 8 years old was high for β -carotene (350 to 450) in deep OFSP farmer varieties (i.e., 'Carrot_C', 'Carrot Dar', 'Ejumula', 'Mayai', and 'Zambezi'). It should be noted that the estimated %RDA β -carotene for the control clone ('Resisto') was 350%. Estimates of $\approx 50\%$ (results not presented) for %RDA β -carotene were obtained with small intakes ≈ 30 g fresh storage roots per day) of deep OFSP farmer varieties (variety names given previously). Many OFSP farmer varieties with light orange color and high DM and starch

contents were observed with %RDA β -carotene estimates of 50% to 90% ('Shinyanga', 'HMA493 Tanzania', 'K-118', 'K-134', 'K-46', 'PAL161', 'Sowola6', 'SRT52', and 'Sudan'). On average, low to medium %RDA was observed for Fe and Zn (17.5%), calcium (20%), and magnesium (40%) (Table 7). Several accessions were observed with %RDA between 20% and 22% for Fe and Zn, 25% to 33% for calcium, and 50% to 66% for magnesium, which were significantly different from accessions below the population mean (LSD test).

Discussion

Our study focused on β -carotene, DM, sucrose, protein, starch, and mineral contents against the background of the contribution of sweetpotato to the food supply in EA. Whereas levels of root β -carotene and DM contents are fairly well documented for African germplasm, other quality traits are not, thus making results of this study the first of its kind. The more pronounced differences between locations for starch content in our study (Table 3) extend our knowledge by documenting the magnitude of this variability (Grüneberg et al., 2005; Saad, 1996). The cv for all traits at both locations were low (Table 3), except storage root yields and β -carotene contents. High cv values for storage root yield have been previously reported for sweetpotatoes (Grüneberg et al., 2005) but could have also resulted from small plots used in the present study. Experiments with large plots would be needed to generate reliable data for root yield performance of the accessions. The high cv values for β -carotene contents in this study can be explained by the low population mean (for all accessions including white- and cream-fleshed), whereas mean estimates for β -carotene contents varied considerably between accessions. The variance component σ_{GL}^2 was unexpectedly higher for starch and sucrose contents (Table 4). However, cv values for both traits at each location were low. The locations belong to distinct agroecological zones that differ greatly in altitude and crop duration for harvest (Table 2), which probably explains the high σ_{GL}^2 estimates for starch (Grüneberg et al., 2005) and sucrose. Such extreme locations are most useful in testing accessions' adaptability and resistance to pest and diseases but less useful for nutritional quality breeding (Grüneberg

Table 4. Estimated variance components, variance component ratios in brackets, and operational broad-sense heritabilities of observed traits.^z

Trait	σ_G^2	σ_L^2	σ_{GL}^2	σ_e^2	h^2
Storage root yield, t·ha ⁻²	8.01** (1)	-4.56 (-0.56)	4.83* (0.60)	22.05 (2.75)	0.50
Dry matter content of storage roots, %	4.94** (1)	-0.97 (-0.20)	3.62** (0.73)	3.89 (0.79)	0.64
Protein content of storage roots, % DM	0.32** (1)	0.06 (0.18)	0.34** (1.05)	0.94 (2.94)	0.44
Starch content of storage roots, % DM	5.31** (1)	29.78** (5.61)	13.88** (2.62)	4.24 (0.80)	0.40
Sucrose content of storage roots, % DM	1.30 (1)	1.86* (1.44)	12.09** (9.32)	2.81 (2.16)	0.16
β -carotene content of storage roots, ppm ² DM	4362** (1)	60** (0.01)	430** (0.10)	183 (0.04)	0.94
Iron content of storage roots, ppm ² DM	1.97** (1)	8.72** (4.42)	2.63** (1.33)	4.54 (2.30)	0.45
Zinc content of storage roots, ppm ² DM	0.81** (1)	3.80** (4.70)	0.64** (0.79)	1.59 (1.97)	0.53
Calcium content of storage roots, ppm ² DM	52643* (1)	-23551 (-0.45)	137272** (2.61)	145497 (2.76)	0.33
Magnesium content of storage roots, ppm ² DM	15008** (1)	4306 (0.29)	15355** (1.02)	24607 (1.64)	0.52

* Significant at the 0.05 level.

** Significant at the 0.01 level.

^zVariance components: σ_G^2 = genotypes; σ_L^2 = locations; σ_{GL}^2 = genotype–location interactions; σ_e^2 = error; h^2 = operational broad-sense heritability. DM = dry matter.

Table 5. Clone means of farmer varieties for observed traits across locations.

Farmer variety	Observed traits ^c									
	YLD (t·ha ⁻¹)	DM (%)	PRO (%)	STA (%)	SUC (%)	BC (ppm)	Fe (ppm)	Zn (ppm)	Ca (ppm)	Mg (ppm)
APA343	5.3	32.5	5.7	63.9	11	12	19.7	9.7	1582	523
APA348 Liralira	11.2	39.0	6.8	69.9	—	0	20	9.7	1748	607
APA352 Oketodede	13.9	32.4	5.9	65.8	10.1	0	19.6	10.3	1587	478
APA365 Anam Anam	12.3	33.0	5.7	67.1	8.9	0	20.1	10.4	1789	540
ARA208 Ombivu	12.2	29.6	8.2	66.3	9.9	0	23.2	12.4	1550	401
ARA214	8.4	31.9	6.2	64.3	9.6	27	19.9	10.3	1500	520
ARA244 Shinyanga	14.3	24.7	5.3	57.7	14	64	20.2	9.3	1685	561
Bunduguza	5	35.3	6	66.6	10.7	0	19.8	8.6	2033	660
Bungoma	11.9	33.4	6.2	67.5	6.4	0	20.8	10.1	1699	644
Carrot_C	5.5	33.2	8.2	58.7	13.7	259	26.1	12.7	2591	924
Carrot_Dar	7.8	31.1	8	58.2	13.7	272	28.4	14.4	2232	981
Dimbuka	16.8	32.2	7.5	67.1	8.3	0	21.2	11.3	1778	539
Ejumula	8.4	32.7	7.4	58	13.4	240	23.8	11.4	2263	848
HMA 490 Kawogo	1.3	32.6	6.1	65.5	8.6	0	20.1	10.4	1709	456
HMA493 Tanzania	1.8	33.4	6.1	65.8	8.4	29	20.2	9.7	1996	682
IGA963 Nyongerabarenzi	15.5	30.7	6.6	66.2	9.5	1	20.6	10.8	1525	374
K-118	5.5	30.7	7.2	62.8	11.6	38	21.4	11.5	1350	470
K-134	10.3	31.9	6.7	64.5	10.5	40	21.1	11.1	1885	616
K-207	5.8	37.4	5.8	67.5	7.4	0	20.4	9.7	2888	857
K-37	2.8	34.1	4.7	66.6	7.4	25	18	8.2	2426	665
K-46	4.5	33.7	6.6	62.9	11.3	48	21.3	10.7	2522	730
KBL627 Mukazi	8.1	35.8	6.6	64.4	12.4	0	22.7	10.9	2053	747
KBL632 Nyinakamanzi	7.1	31.3	6.6	68	7.4	1	20.9	11.4	2128	694
KBL640 Africare	15.3	30.2	6.5	63.6	11.4	15	20.2	9.9	1392	467
KMI56 Opira	10.6	31.3	6.8	65	9.5	0	22.9	11.2	1978	763
KMI59 Kampala	11.6	32.6	7.1	63.8	9.8	0	22.9	10.1	1904	651
KMI61	7.9	33.4	7.4	64.4	10.5	75	23	11.3	1333	496
KMI78 Osukari	6.5	31.5	8.4	66.1	8.6	0	22	11.8	1543	531
KMI81 Ikala	11.7	25.6	7.3	60	12.1	28	22.7	12.6	1594	495
KMI83 Ikala2	11.9	29.9	7.4	63.2	11.7	11	21.2	10.8	1620	507
KML883 Silkempya	13.8	35.1	6.2	68.7	8	0	20.1	9.4	1931	485
KRE716 nylon	2.5	36.1	6.9	66.7	8.3	-1	22.8	11.6	2569	816
KRE726 Kwezikumwe	16.6	31.7	5.9	69.3	8.3	9	19.2	10.7	1426	445
KRE733 Kitambi	3.8	35.2	6.3	66.4	8.6	0	21.9	11	1977	661
KSR673 Maberekumi	6.6	33.5	6.2	67.4	7.5	0	21.1	11.3	1505	365
KSR652 Mugumire	1.9	34.9	7.5	66.9	8.9	1	21.1	10.9	2029	412
KSR662 Kakoba	7.5	32.7	4.8	68	7.9	1	18.3	9.6	2313	568
KSR664 Mulrerabana	5.8	31.4	7.5	66.8	8.4	1	22.7	10.9	2056	738
KSR675 Nora II	7.2	33.2	6.9	64.7	10.5	0	24	11.1	1897	730
Kunykubiongo	15	29.3	6.2	63.4	10.1	0	21.3	10.2	1866	565
Kyabafuriki	10.3	27.4	7.5	63.4	10.2	0	22.8	12.4	1969	492
LIR257 Otada	11.7	32.7	6.7	67.8	6.7	0	20.3	9.5	1810	582
LIR296	15.5	32.6	6.5	63.2	11.6	0	19.4	9.7	1742	564
Mayai	6.8	33.2	7.3	66.6	9.8	264	22.5	10.8	2177	761
MBR 539 Kitekamaju	6.5	32.5	6.7	69.3	5.6	1	20.8	11.5	1934	530
MBR524 Nkwahansi	1.1	31.5	7.5	62.1	12.1	1	25.2	11.7	1904	639
MBR536 Karebe	15	31.3	5.1	65.3	10.7	0	19.4	10.7	2120	633
MBR552 Kahungezi	9.3	33.9	7.3	66.8	9.8	0	21.2	11.2	1986	644
MBR580 nylon	4.8	27.4	6.5	58.4	13.7	0	27.4	14.8	3290	1152
APA343	5.3	32.5	5.7	63.9	11	12	19.7	9.7	1582	523
MBR600 Kisakyabikiramaria	5.8	30.9	7.7	65.5	9.5	0	23.5	12.3	1611	520
MLE 166	6	35.3	5.9	69.2	7.6	5	21.3	10.7	2212	733
MLE162 Nakahi	10.2	32.9	6.5	64.9	10.1	45	20.7	10.1	1801	611
MLE163 Kyebandula	9.5	36.6	8	66.6	8.6	-1	24.4	12	2382	863
MLE165 Namafumbiro	5.9	30.7	6.2	64.7	10.2	0	21.8	11.5	2337	755
MLE173 Kijovu	5.3	29.7	7.4	64.5	9.8	-1	23.7	11.4	1855	506
MLE184 Manafayereta	6.4	32.3	8.1	64.7	9.9	0	23.3	13.5	1814	415
MSK1025 Bitambi	5.4	34.3	5.9	68.3	7.7	0	19.9	10.5	2588	775
MSK1047 Bwanjire	6.6	30.7	6.8	65	9.2	0	22.2	11.1	1651	438
Nyaguta	5.4	33.2	7.1	62.7	10.9	0	24.8	11.3	2659	1046
Nyandere	14.2	34.9	6.2	66.2	8.9	0	19.5	10.5	1527	473
Nyathiodiewo	16.2	30.2	6.2	64.8	9.6	0	19.7	10.1	1650	566
Nyatonge	8.4	33.4	5.9	67.8	9.2	0	19.5	9.9	2003	632
Obuogo1	3.7	36.3	7.3	64	11.2	0	22.8	10.1	2073	780
Obuogo2	4.1	34.5	6.9	67.7	8	0	22	9.8	1755	657
Oguroiwe	6.6	33.8	6	67.5	9.6	0	19.8	10.4	1226	358
PAL153 Abukoki	7.7	29.7	4.3	67	8.9	-1	16.6	9	1639	309
PAL161	6.8	35.5	6.8	65.2	9.3	33	20.2	10.5	1609	602
Pipi	7.7	33.2	6.4	65	10.2	13	19	10	1903	602
Resisto	7.8	24.8	7.6	53.5	15.7	271	24.1	12.7	1821	646
Sowola (389 A)	13.2	33.3	7.2	66.4	9.8	0	21.1	11.1	1603	469
Sowola_6	9.9	30.6	8	62.2	10.3	54	24.6	12.5	2302	770
Sponge	11.4	32.4	6	65.1	10	48	19.7	10.2	2039	595

(Continued on next page)

Table 5. (Continued) Clone means of farmer varieties for observed traits across locations.

Farmer variety	Observed traits ^z									
	YLD (t·ha ⁻¹)	DM (%)	PRO (%)	STA (%)	SUC (%)	BC (ppm)	Fe (ppm)	Zn (ppm)	Ca (ppm)	Mg (ppm)
SRT 14 Nora	14.1	32	6.6	62.8	11.7	0	21.2	9.5	2156	593
SRT01 Osapat	9.5	33.6	6.2	66.8	9.6	0	19.5	10	1660	525
SRT02 Araka white	10.3	33	7.3	65.8	9.6	0	22.5	11.5	1608	440
SRT30 Nyara	13.9	29	7.6	58.3	13.8	22	22.9	11.7	1891	644
SRT33 Abuket1	11.6	27.7	7.1	58.2	14.6	159	23.1	12.4	1938	670
SRT34 Abuket2	13.2	31	6.6	59.5	14.5	51	20.3	10.1	1762	587
SRT35 Anyumel	9.4	31.6	6.9	63.8	10.6	82	22.7	11.2	1871	636
SRT39 Rwanda	12.2	20.1	5.4	51.1	17	169	22.7	10.7	2179	771
SRT40 Mary	10.6	35.9	6.4	64.7	10.7	-1	22.1	10.8	2916	918
SRT49 Sanyuzameza	5.8	35.3	8	65.7	9.3	0	24.3	12.3	2414	976
SRT52	4.1	32.5	7.5	64.2	11	35	23.4	11.7	2644	892
Sudan	6.1	32.2	6.3	64.6	10.6	44	20.6	10.2	1571	646
Tororo3	5.1	32.9	5.2	65.2	9.3	0	18.1	7.9	2238	537
Ukerewe	13.7	34.6	5.7	65.7	11.2	0	18.4	9.6	1536	421
Wagaborige	7.3	32.2	6	65.2	11.9	0	19.9	8.7	1493	498
Wera	4.2	29.9	7	50.1	28.5	1	26.1	13.1	2544	1004
Zambezi	6.7	29.5	7	62	11.1	233	22.9	12.9	2631	884
Least significant difference (0.05)	6.6	2.8	1.4	2.9	2.5	19	3.0	1.8	534	219
Population mean	8.6	32.1	6.7	64.4	10.3	30.6	21.6	10.9	1950	628

^zObserved traits: YLD = storage root yield, t·ha⁻¹; DM = dry matter content of storage roots, %; PRO = protein content of storage roots, % DM; STA = starch content of storage roots, % DM; SUC = sucrose content of storage roots, % DM; BC = β -carotene content of storage roots, ppm DM; Fe = iron content of storage roots, ppm DM; Zn = zinc content of storage roots, ppm DM; Ca = calcium content of storage roots, ppm DM; Mg = magnesium content of storage roots, ppm DM.

Table 6. Pearson correlation coefficients among observed traits in East African sweetpotatoes.^z

	YLD	DM	PRO	STA	SUC	BC	Fe	Zn	Ca
<i>Estimates based on all farmer varieties (N = 89)</i>									
DM	-0.178								
PRO	-0.095	0.018							
Sta	-0.015	0.620	-0.265						
Suc	-0.023	-0.472	0.147	-0.885					
BC	-0.061	-0.275	0.131	-0.467	0.351				
Fe	-0.188	-0.176	0.810	-0.505	0.368	0.232			
Zn	-0.123	-0.205	0.796	-0.361	0.231	0.205	0.859		
Ca	-0.299	0.088	0.228	-0.214	0.163	0.149	0.428	0.276	
Mg	-0.276	0.067	0.397	-0.301	0.234	0.232	0.633	0.433	0.837
<i>Estimated based on orange-fleshed farmer varieties (N = 32)</i>									
DM	-0.258								
PRO	-0.148	0.064							
Sta	-0.071	0.708	-0.199						
Suc	0.050	-0.586	0.181	-0.917					
BC	-0.188	-0.209	0.213	-0.521	0.470				
Fe	-0.172	-0.205	0.805	-0.493	0.429	0.446			
Zn	-0.140	-0.167	0.855	-0.375	0.325	0.379	0.899		
Ca	-0.355	0.050	0.315	-0.137	0.061	0.374	0.469	0.324	
Mg	-0.350	0.006	0.505	-0.232	0.151	0.428	0.705	0.560	0.857

^zObserved traits: YLD = storage root yield, t·ha⁻¹; DM = dry matter content of storage roots, %; PRO = protein content of storage roots, % DM; STA = starch content of storage roots, % DM; SUC = sucrose content of storage roots, % DM; BC = β -carotene content of storage roots, ppm DM; Fe = iron content of storage roots, ppm DM; Zn = zinc content of storage roots, ppm DM; Ca = calcium content of storage roots, ppm DM; Mg = magnesium content of storage roots, ppm DM.

et al., 2009). The extreme locations result in lower heritabilities for improvement of quality traits, which was also observed in this study (Table 4). This merits further studies with a fraction of the varieties used in this study. Nevertheless, the variance component σ_G^2 was significant ($P < 0.01$) for all the observed traits except storage root sucrose contents, which indicates significant differences between accession means. Owing to the magnitude of $\sigma_{G \times L}^2$ estimates and that locations were in distinct ecogeographical zones, we set genotype and location as fixed factors for a multiple comparison of accessions by the LSD test. Hence, LSD values at the 0.05 level might be underestimated but do not affect the evidence that differences below the LSD values given (Table 5) are not significantly different.

In contrast to germplasm from other regions (Woolfe, 1992), the EA accessions have clearly higher DM ($\approx 32\%$ to 33%), higher starch ($\approx 65\%$ DM), and lower sucrose ($\approx 10\%$ DM) contents. It appears that sweetpotato in EA has on average a moderate sweetness and several accessions such as 'Bungoma', 'K-207', 'K-37', and 'KBL632 Nyinakamanzi' have very low sucrose ($\approx 7.5\%$ DM) content. These quality attributes make the crop more attractive to be used as a starchy staple in EA compared with such other regions of the world as South Asia and Central and South America where sweetpotato is consumed in low amounts. However, sweetness after cooking or boiling is also determined by enzymatic conversion of starch to maltose (Kays et al., 2005) and not only

by the sucrose content we observed in fresh storage roots.

The study found five OFSP farmer varieties ('Carrot_C', 'Carrot Dar', 'Ejumula', 'Mayai', and 'Zambezi') with high β -carotene contents similar to the control variety 'Resisto' (Table 5). The β -carotene estimates compare well with those reported for OFSP accessions with low storage root DM (Grüneberg et al., 2005; Purcell, 1962; Purcell and Walter, 1968). β -carotene content of 'Resisto' in the present study is lower than previous estimates (Laurie, 2008). The variety 'Resisto' is typical for the taste group "OFSP moist and sweet" (Martin and Jones, 1986) and had a storage root DM content of 24.8% and a storage root starch content of 53.5% (Table 5). Varieties such as 'Carrot_C', 'Carrot Dar', 'Ejumula', 'Mayai', and 'Zambezi' cannot be classified as "OFSP moist and sweet" but rather propose to be designated as "OFSP dry and starchy." These five OFSP farmer varieties all had DM content greater than 29.5% and starch content greater than 62.0%. These estimates compare well with those obtained for many white-fleshed African farmer varieties in the same study. OFSP varieties with high DM and high starch contents make OFSP attractive to a much wider range of taste preferences. The 12 light OFSP accessions ('K-118', 'K-134', 'K-46', 'KMI61', 'MLE162 Nakahi', 'PAL161', 'Sowola6', 'Sponge', 'SRT34 Abuket2', 'SRT35 Anyumel', 'SRT52', and 'Sudan') with meaningful β -carotene (Table 5) are also important. The storage root DM and starch contents of these accessions were high, whereas sucrose contents were low and thus have attributes close to those of white-fleshed farmer varieties.

The results of this study are the first description of OFSP accessions that are high in DM and starch contents. This leads to the question where these "OFSP dry and starchy" are coming from in crop evolution. A molecular characterization of this material (Tumwegamire et al., 2011) has shown closer clustering of

African OFSP with their sister WFSP accessions and clear genetic distances between African OFSP and non-African OFSP germplasm. Breeders in Africa have observed that open-pollinated white-fleshed accessions result in segregation of OFSP at low frequencies (Mwanga et al., 2003).

The potential to alleviate VAD through use of deep OFSP accessions like 'Carrot_C', 'Carrot_Dar', 'Ejumula', 'Mayai', and 'Zambezi' is possibly very high in Uganda and other areas where daily sweetpotato consumption is high. These accessions showed at least 350% RDA β -carotene for the children aged 5 to 8 years with routine intake quantities found in Uganda (Table 7). This suggests that these varieties could address VAD in many other areas across the world, including South and East Asia and northeastern states of Brazil where VAD prevalence is high and per-capita consumption of sweetpotato is low. For example, 'Carrot_C' could provide 100% of RDA provitamin A intake with a modest 70 g of cooked roots per day. The potential to alleviate VAD using OFSP has been demonstrated (Low et al., 2001, 2007; van Jaarsveld et al., 2005). However, the challenge has been reluctance by farmers to grow and consume "OFSP moist and sweet" varieties, a situation that should possibly change given the "OFSP dry and starchy" accessions found in this study. Additionally, the light orange-fleshed accessions have been found to contribute significantly to RDA β -carotene in the range between 50% to 90% (Table 7).

The storage root mineral (Fe = 21.6 ppm, Zn = 10.9 ppm, calcium = 1950 ppm, and magnesium = 626 ppm) and protein (6.7%) contents observed in the present study are in the range previously reported by Bradbury and Holloway (1988), Courtney (2007), Grüneberg et al. (2009), and Woolfe (1992). Percent RDA for magnesium is notably higher and approaches 50% of daily needs in many accessions. Iron, Zn, and calcium had mean %RDA of 17.3, 17.4, and 19.6, respectively. In areas with high sweetpotato consumption, farmer varieties like 'Carrot_C', 'Carrot_Dar', 'KRE nylon', 'MLE163 Kyebandula' and 'SRT49 Sanyuzameza' can contribute to the intake of Fe, Zn, calcium, and magnesium (Table 7) but cannot alleviate respective mineral deficiencies at the current storage root concentrations. Breeding efforts, particularly in areas with high sweetpotato consumption, have to double Fe, Zn, and calcium contents in storage roots to reach %RDA of $\approx$ 50% to achieve impact. In regions with low sweetpotato consumption and high VAD, breeders should mainly target high β -carotene content and consumer acceptance.

The correlation matrix (Table 6) is consistent with those reported for sweetpotato (Collins and Walter, 1982; Courtney, 2007; Grüneberg et al., 2009; Saad, 1996). The positive correlations between β -carotene and mineral and sucrose contents suggest the possibility of an indirect improvement of the latter through selection for higher β -carotene (Grüneberg et al., 2009). The challenge, however, is simultaneous improvement of DM and β -carotene

Table 7. Percent recommended daily intake (%RDA) contribution of micronutrients based on 250 g fresh sweetpotato root consumption per day for different farmer varieties.

Farmer varieties	RDA contribution (%)				
	β -carotene	Iron	Zinc	Calcium	Magnesium
APA343	21	16.0	15.7	16.0	32.7
APA348 Liralira	0	19.5	18.9	21.3	45.5
APA352 Oketodede	0	15.9	16.6	16.1	29.8
APA365 Anam Anam	0	16.6	17.1	18.4	34.3
ARA208 Ombivu	-0.1	17.2	18.4	14.4	22.9
ARA214	44.4	15.8	16.3	14.9	31.8
ARA244 Shinyanga	82.7	12.4	11.5	13.0	26.6
Bunduguza	-0.2	17.5	15.2	22.4	44.8
Bungoma	0	17.3	16.8	17.7	41.3
Carrot_C	447.6	21.6	21.0	26.8	58.9
Carrot_Dar	440.7	22.1	22.4	21.7	58.7
Dimbuka	-0.2	17.1	18.2	17.9	33.4
Ejumula	409.4	19.5	18.7	23.1	53.4
HMA490 Kawogo	0	16.4	16.9	17.4	28.6
HMA493 Tanzania	50.9	16.8	16.2	20.8	43.7
IGA963 Nyongerabarenzi	1.5	15.8	16.6	14.6	22.0
K-118	60.3	16.4	17.7	12.9	27.7
K-134	65.6	16.8	17.7	18.8	37.8
K-207	-0.2	19.0	18.2	33.8	61.7
K-37	45.1	15.4	13.9	25.8	43.5
K-46	83.2	17.9	17.9	26.5	47.3
KBL627 Mukazi	0	20.3	19.5	23.0	51.4
KBL632 Nyinakamanzi	1.5	16.4	17.8	20.8	41.7
KBL640 Africare	23.6	15.2	15.0	13.2	27.1
KMI56 Opira	0	17.9	17.6	19.3	45.9
KMI59 Kampala	0	18.6	16.4	19.4	40.7
KMI61	130.2	19.2	18.8	13.9	31.9
KMI78 Osukari	0.1	17.3	18.6	15.2	32.2
KMI81 Ikala	37.4	14.6	16.1	12.8	24.4
KMI83 Ikala2	16.7	15.8	16.1	15.1	29.1
KML883 Silkempya	0	17.7	16.5	21.2	32.8
KRE716 nylon	-1.7	20.6	20.9	29.0	56.7
KRE726 Kwezikumwe	14.2	15.2	16.9	14.1	27.1
KRE733 Kitambi	0	19.2	19.3	21.7	44.7
KSR673 Mabereikumi	0	17.6	18.8	15.7	23.5
KSR652 Mugumire	1.7	18.4	19.0	22.1	27.6
KSR662 Kakoba	1.7	14.9	15.7	23.6	35.7
KSR664 Mulereabana	1.5	17.8	17.0	20.2	44.6
KSR675 Nora II	0	19.9	18.3	19.7	46.5
Kunyukubiongo	0	15.6	14.9	17.1	31.8
Kyabafuriki	0	15.6	17.0	16.9	25.9
LIR257 Otada	-0.2	16.6	15.4	18.5	36.6
LIR296	0	15.8	15.8	17.7	35.4
Mayai	456.5	18.6	17.9	22.6	48.6
MBR539 Kitekamaju	1.4	16.9	18.6	19.6	33.2
MBR524 Nkwahanshi	1.5	19.8	18.3	18.7	38.7
MBR536 Karebe	0	15.2	16.7	20.7	38.1
MBR552 Kahungezi	0	18.0	18.9	21.0	42.0
MBR560 Mugurusi	0	18.2	18.9	19.0	37.1
MBR580 nylon	-0.1	18.7	20.3	28.1	60.6
MBR600 Kisakyabikiramaria	0	18.1	19.0	15.5	30.9
MLE166	9.8	18.8	18.9	24.4	49.8
MLE162 Nakahi	77.1	17.0	16.6	18.5	38.7
MLE163 Kyebandula	-1.7	22.3	22.0	27.3	60.8
MLE165 Namafumiro	0.1	16.8	17.7	22.4	44.6
MLE173 Kijovu	-1.4	17.6	16.9	17.2	28.8
MLE184 Manafayereta	0	18.8	21.7	18.3	25.7
MSK1025 Bitambi	0	17.1	17.9	27.7	51.1
MSK1047 Bwanjire	0	17.0	17.1	15.8	25.8
Nyaguta	0	20.6	18.8	27.6	66.8
Nyandere	0	17.0	18.2	16.6	31.7
Nyathiodiewo	0	14.8	15.3	15.5	32.8
Nyatonge	0	16.3	16.5	20.9	40.6
Obuogo I	0	20.7	18.3	23.5	54.5
Obuogo II	0	18.9	16.8	18.9	43.6
Oguroiwe	0	16.7	17.6	12.9	23.2
PAL153 Abukoki	-1.4	12.3	13.4	15.2	17.7
PAL161	60.7	17.9	18.7	17.9	41.1
Pipi	22.5	15.8	16.6	19.7	38.4
Resisto	350.1	14.9	15.7	14.1	30.8
Sowola (389A)	0	17.5	18.4	16.7	30.0
Sowola_6	86.3	18.8	19.1	22.0	45.3

(Continued on next page)

Table 7. (Continued) Percent recommended daily intake (%RDA) contribution of micronutrients based on 250 g fresh sweetpotato root consumption per day for different farmer varieties.

Farmer varieties	RDA contribution (%)				
	β -carotene	Iron	Zinc	Calcium	Magnesium
Sponge	80.6	16.0	16.6	20.6	37.1
SRT14 Nora	-0.1	17.0	15.2	21.5	36.5
SRT01 Osapat	0	16.4	16.8	17.4	34.0
SRT02 Araka white	-0.2	18.5	18.9	16.6	27.9
SRT30 Nyara	32.5	16.6	16.9	17.2	35.9
SRT33 Abuket_1	228.8	16.0	17.1	16.7	35.6
SRT34 Abuket_2	82.2	15.7	15.6	17.0	35.0
SRT35 Anyumel	134.7	17.9	17.7	18.4	38.6
SRT39 Rwanda	176.5	11.4	10.7	13.7	29.7
SRT40 Mary	-1.7	19.9	19.3	32.7	63.4
SRT49 Sanyuzameza	0	21.5	21.8	26.7	66.3
SRT52	59.3	19.0	19.0	26.8	55.7
Sudan	72.9	16.6	16.4	15.8	39.9
Tororo3	0.2	14.9	13.0	23.0	33.9
Ukerewe	0	15.9	16.6	16.6	28.0
Wagaborige	0	16.0	14.0	15.0	30.8
Wera	1.4	19.5	19.6	23.8	57.7
Zambezi	357.6	16.9	19.1	24.3	50.2
Least significant difference (0.05)	27.8	2.7	3.0	6.0	14.9
Population mean	47.9	17.3	17.4	19.6	38.9

levels among the sweetpotato germplasm. Whereas starch and DM were positively correlated, they were both negatively correlated to β -carotene content. Similar observations are reported by Grüneberg et al. (2009).

In conclusion, East African sweetpotato germplasm is clearly higher in storage root DM and storage root starch contents and clearly lower in storage root sucrose contents compared with the cultivated sweetpotato of the rest of the world, especially the traditional OFSP. The study revealed that African OFSP farmer varieties such as 'Carrot_C', 'Ejumula', 'Carrot Dar', 'Mayai', and 'Zambezi' contain moderate to high levels of storage root DM and high levels of β -carotene and might be useful for better acceptance of OFSP in Africa as well as other regions of the world. Moreover, sweetpotato significantly adds to the mineral contribution in food supply (i.e., Fe, Zn, calcium, and magnesium) when sweetpotato is consumed frequently. The new OFSP accessions described in this study justify a category (or group) termed "OFSP dry and starchy" and this group may enhance consumer appeal toward a more nutritious sweetpotato, which increases the potential of OFSP to contribute to the alleviation of VAD.

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