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**ARTICLE**

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## Full length Research Paper

# Analysis of micronutrients variations among sweet potato (*Ipomoea batatas* [L.] Lam) genotypes in Malawi

Felistus Chipungu<sup>1,2</sup>, Wisdom Changadeya<sup>2\*</sup>, Aggrey Ambali<sup>3</sup>, John Saka<sup>4</sup>, Nzola Mahungu<sup>5</sup> and Jonathan Mkumbira<sup>6</sup>

<sup>1</sup>Bvumbwe Agricultural Research Station, P. O. Box 5748, Limbe, Malawi.

<sup>2</sup>Molecular Biology and Ecology Research Unit (MBERU) DNA Laboratory, Department of Biological Sciences, Chancellor College, University of Malawi, P.O. Box 280, Zomba, Malawi.

<sup>3</sup>NEPAD African Biosciences Initiative, Policy Alignment and Programme Development Directorate, NEPAD Agency, C/O CSIR Building 10F, Meiring Naude Road, Brummeria, Pretoria, Republic of South Africa, 0001, South Africa.

<sup>4</sup>University of Malawi, University Office, P. O. Box 278, Zomba, Malawi.

<sup>5</sup>The International Institute of Tropical Agriculture (IITA), Central Africa Hub, 4163, Avenue Haut-Congo, Commune de la Gombe, Kinshasa, Democratic Republic of Congo (DRC), Congo.

<sup>6</sup>Tea Research Foundation of Central Africa, P. O. Box 51, Mulanje, Malawi.

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Sweet potato (*Ipomoea batatas* [L.] Lam) is an important root crop in Malawi and Sub-Saharan Africa where micronutrient deficiency is an eminent health problem. Using 15 sweet potato genotypes grown in a randomized complete block design at Bvumbwe Research Station, a study was undertaken to determine the extent of variability of selected micronutrients in the genotypes as influenced by storage root age and peeling. Analysis of variance (ANOVA) showed significant ( $p \leq 0.01$ ) variability among genotypes for dry matter,  $\beta$ -carotene, ascorbic acid levels and reduction of  $\beta$ -carotene due to peeling across all ages. Significant ( $p \leq 0.05$ ) variations in zinc, iron and copper were also observed among all genotypes. Peeling reduced  $\beta$ -carotene, ascorbic acid levels, iron, zinc and copper content while late harvesting resulted in low iron, zinc and copper. Therefore, 5 months after planting (MAP) and 4 MAP are recommended for high levels of  $\beta$ -carotene and ascorbic acid and iron, zinc and copper, respectively. Ten genotypes exhibited acceptable levels of dry matter of  $\geq 30\%$ . Zondeni (10.9 mg/100 g, WW) and Babache (23.84 mg/100 g, WW) had highest levels of  $\beta$ -carotene and ascorbic acid, respectively. Mzungu displayed the highest levels of Iron (0.67 mg/100 g, DW) and zinc (0.63 mg/100 g, DW) while Yoyera (0.61 mg/100 g, DW) had the highest levels of copper. Variations of various traits entail potential to breed for higher levels of micronutrients.

**Key words:** Sweet potato, genotypes,  $\beta$ -carotene, ascorbic acid, iron, zinc, copper, peeling, storage root age.

## INTRODUCTION

Approximately one billion (795 million) people from developing countries suffer from hunger, malnutrition and poverty (FAO, 2015). Various reasons including climate change, environmental degradation, dwindling of natural resources and an ever increasing population have been

implicated. In 2015, global population was estimated at 7.3 billion and was expected to climb up to about 9.7 billion in 2050 when nearly 90% of the population will be in resource poor developing countries of Asia, Africa and Latin America (James, 2015). The UN population

projection shows that the trend will continue until the end of this century when the global population will reach 10.8 billion or more (UN DESA, 2015). Such increases in global population will result in ever increasing number of food in-secure people, who by definition are people with no physical and economic access to enough safe and nutritious food which meets their dietary needs at all times (FAO, 1996).

However, over 3 billion people suffer from a different, sneakier form of hunger than the simple lack of sufficient quantities of foodstuffs referred to as micronutrient malnutrition or “hidden hunger” which is caused by a lack of food of sufficient dietary quality (Kennedy et al., 2003; FAO, 2013). Monotonous diets which are a hallmark of Sub-Saharan countries, based on cereals and other starchy staple foods frequently fail to deliver sufficient quantities of essential minerals and vitamins like Iodine, Iron, Zinc and Vitamin A (Demment et al., 2003). Such diets predisposed communities to micronutrient deficiencies resulting in micronutrient malnutrition (FAO/WHO, 2002). Generally, such deficiencies result in increased chances of infectious and non-infectious disorders which include impaired vision, measles, diarrhoea, pneumonia and malaria (World Health Report, 2004). Young children, pregnant and lactating women are particularly at risk because they have a higher need for minerals and vitamins (Nabakwe and Ngare, 2004). In order to address the prevalent micronutrient deficiencies directly, the conventional approach is supplementation, food fortification, dietary diversification and nutrition education (Laurie and Faber, 2008). Food based approaches to nutrition improvement are well documented worldwide (Musunguzi et al., 2006; Nawiri et al., 2012) and in such methods, choice of candidate crops is critical. Sweet potato is a logical choice for such interventions as the crop is nutrient rich and widely cultivated ranking second after cassava in area and production in the tropical and sub-tropical regions (FAOSTAT, 2012; Boney et al., 2014). In the Sub-Saharan Africa (SSA), the crop is farmed on more than 3 million hectares with estimated yield of 13 million tons annually (Low and Van Jaarsveld, 2008).

In Malawi, sweet potato is the second most widely grown root crop after cassava. Since the crop is highly tolerant to drought and poor soil conditions, frequent droughts in Malawi have led to increased sweet potato cultivation as evidenced by production increase of 370% from 1995 to 2006 (FEWS/MoAFS, 1995, 2006).

There is an emergent recognition of sweet potato as a cheap produce for combating food insecurity and micronutrient malnutrition worldwide (Yamakawa and Yashimoto, 2002; Hotz et al., 2012; Girard et al., 2017)

because sweet potato is a renowned important source of carbohydrates, vitamins (A, C, D and E), fiber, iron, potassium, zinc, copper and protein (Woolfe, 1992; Low et al., 2009; Sreekanth et al., 2010; Hotz et al., 2012). However, variability of micronutrients with genotypes of sweet potato has been reported widely (Woolfe, 1992; Abubakar et al., 2010; Meludu, 2010; Sunette, 2010), therefore there is need to ascertain the levels of various micronutrients in different genotypes grown by farmers in Malawi. Hence the study was conducted to identify mineral and vitamin rich sweet potato genotypes and quantify variations of different nutrients in different genotypes in order to recommend right genotypes which can assist in addressing different micronutrient deficiencies (iron, zinc, copper, vitamins A and C) in Malawi.

## MATERIALS AND METHODS

### Study genotypes

The study used fifteen sweet potato genotypes from different sources (Table 1) comprising four released genotypes, two local bred elite clones, two elite introductions and seven landraces. The sweet potato genotypes were chosen on the basis of their status (Table 1) and were maintained at Bvumbwe Agricultural Research Station for one season following standard procedures that included randomized complete block design (RCBD) experimental plots replicated thrice. A gross plot consisted of two ridges (4.8 m long) spaced at 90 × 90 cm apart and planting stations of 30 × 30 cm apart. The sweet potato cuttings were planted at 30 cm apart within ridges. The seven landraces represented low to high yielding, early to late maturing, good to bad taste, texture, varying flesh colour, flavour and susceptibility and resistance to weevil attack as described by farmers using their knowledge (Indigenous Knowledge Systems). Released genotypes, locally bred clones and introductions represented breeders’ selections. Sampling for analysis started at four months after planting (MAP) and continued in the fifth and seventh MAP. Generation of soil analysis, dry matter and micronutrients data was done in the Bvumbwe Agricultural Research Station laboratories.

### Bvumbwe Agricultural Research Station field soil analysis

Top and sub soil samples (30 cm deep) from the experimental plots were collected and analyzed for pH, zinc, iron and copper following standard protocols as prescribed by the Association of Official Analytical Chemistry (AOAC, 2000) in order to compare the mineral results in the genotypes with respect to those of the top and sub soils on the planting day.

### Determination of dry matter content

Dry matter content was measured by random sampling of five storage roots of a genotype from each plot and chopped into 2 cm thick strips. Two hundred grams of the chopped samples in three

\*Corresponding author. E-mail: wchanga@cc.ac.mw.

**Table 1.** Origin and status of the study genotypes.

Genotype	Origin	Status
Zondeni	Landrace	Wide spread, low to medium yield and maturity
LU96/374	DARS bred	Elite clone, high yield, early maturing
Yoyera	Landrace	Being eroded due to very low yields and late maturing,
Kamchiputu	Landrace	Being eroded due to very low yields and late maturing,
Tainung (Taiwan 57)	AVRDC <sup>a</sup>	Released in 1999, low adoption, early maturing
Pepu	Landrace	High yield, not widely grown
Babache	Landrace	Grown in Lower Shire, Medium yield, late maturity
Mfumu	Landrace	Grown in Lower Shire, Medium yield, medium maturity
LU96/303	DARS bred	Elite clone, high yield and early maturity
Kenya (Kemb 10)	Tanzania	Wide spread, released 1988, high yield, early maturity
Lunyangwa	DARS bred	Released in 1990, high yield, early maturity, low adoption
Semusa (Cemsa 74-228)	CIP <sup>b</sup>	High yield, early maturity, released 1999 increased adoption
A45	RSA <sup>c</sup>	Preliminary evaluation trials, high yield, medium maturity
Mzungu	Landrace	High yield, early maturity
Mafutha	RSA	Promising genotype, high yield and early maturity

<sup>a</sup> =Asian Vegetable Research and Development Center; <sup>b</sup> = International Potato Centre; <sup>c</sup> =Republic of South Africa  
DARS= Department of Agricultural Research Services.

replicates were oven-dried at 105°C until weight remained constant (Carey and Reynoso, 1999; AOAC, 2000). Percentage dry matter was calculated as:

$$\%DM = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100 \quad (1)$$

#### Preparation of samples for nutrient analysis

Mature storage roots from six randomly selected plants of a genotype were harvested at 4, 5 and 7 MAP with each sample split into two batches. One batch was washed, chopped into 1-cm cubes, mixed, packed in well-sealed plastic bags and stored at -20°C until extraction time. The second batch was peeled (by removing the epidermis and cortex) and preserved like batch one. Analysis of nutrients was undertaken within 2 months of harvesting.

#### Determination of $\beta$ -carotene

##### Preparation of $\beta$ -carotene standard stock and working solutions ( $1.7695 \times 10^{-3}M$ )

$\beta$ -carotene (0.100 g, 95%) was dissolved in petroleum ether and diluted to the mark in a volumetric flask (100 ml). Aliquots of this stock solution (0.1, 0.2, 0.3, 0.4 and 0.5 ml) were pipetted into a set of 50-ml amber volumetric flasks and diluted to give a set of standard solutions with absorbance readings between 0 and 1.0. The absorbances of the standard solutions were determined at 450 nm in a spectrophotometer.

##### $\beta$ -carotene extraction and determination

Beta-carotene content was determined spectrophotometrically as described by Imungi and Wabule (1990). Fresh peeled and unpeeled samples were initially homogenized using a blender. Exact portions (2.00 g) in duplicates were weighed in a 50-ml extraction conical centrifuge tube and mixed with cold acetone (40 ml). The samples were centrifuged for 60 s before filtering with

suction through a Buchner funnel. The flask and residues were washed with acetone while receiving the washing in the funnel. The filtered residues were white in colour which indicated that all  $\beta$ -carotene had been extracted. Petroleum ether (40 ml) was put in a separator funnel. The resultant acetone extract was then added into the separator funnel. Distilled water was slowly added while letting it flow along the walls of the funnel. The mixture was not shaken to avoid formation of an emulsion. The two phases were allowed to separate and the lower aqueous acetone phase was discarded. The resultant was washed first with distilled water (300 ml) and three times with distilled water (200 ml) to remove the acetone completely. The petroleum ether phase was collected in a 50-ml volumetric flask. The ethereal extract was made to pass through the funnel containing filter paper and anhydrous sodium sulphate. The washing solvent was also collected into the volumetric flask and the volume was made to the mark. The absorbance of the  $\beta$ -carotene ethereal extract was read at 450 nm in a UV/VIS spectrophotometer.  $\beta$ -carotene content was calculated using the following formula:

$$\mu\text{g/g} = (A \times \text{Volume} \times 10^4) / (2592 \times \text{Sample weight}) \quad (2)$$

where A= Absorbance.

#### Extraction and determination of ascorbic acid

A 5 g of sample was homogenised in a solvent system (100 ml) for two minutes at medium speed, and allowed to stand for 30 min in a refrigerator for the supernatant to settle before determination. Ascorbic acid was determined according to AOAC (2000). The 2,6 dichlorophenolindophenol titrimetric (0.250 g) method described in AOAC was used for determination of the acid. The dye was standardized by titrating it against ascorbic acid standard (2.0 ml) in solvent system (5.0 ml) before determination. The supernatant (10.0 ml) was transferred in a well-rinsed and dried conical flask, titrated in triplicate against 2,6 -dichlorophenolindophenol until end point (pink coloration). Blank determinations were done to correct sample and standard titre values. Ascorbic acid concentration (mg/100 g) was calculated using the equation:



$$\text{Concentration of ascorbic acid (mg/100 g)} = (X - B) \times (F/E) \times (V/Y) \times 100 \quad (3)$$

Where X= average ml for sample titration, B = average ml for sample blank titration, F = mg ascorbic acid equivalent to 1.0 ml indophenol standard solution, E = number of grams, V = initial volume of assay solution and Y = volume of sample aliquot titrated.

#### Extraction and determination of metals (Zn, Fe and Cu)

Extraction of Zn, Fe and Cu was done as described in AOAC (2000). Sweet potato chips (1.00 g) were dried in an oven (110°C) for 12 h and the dried material was ashed in a furnace for 5 h at 500°C. The samples were cooled to room temperature in desiccator and subsequently weighed using an analytical balance. To the ash, some deionised water (10 drops) and nitric acid (5.85 M, 4 drops) were added as the excess acid evaporated in the oven (110°C) for 30 min. The residues in crucibles were ashed for an additional 1 h at 500°C, cooled and ash taken up in hydrochloric acid (5.09 M, 10.0 ml). The resultant mixture was diluted to the mark in a 50.0-ml volumetric flask with de-ionized water. Standard solutions (50.0 ml; 0.0, 0.05, 0.10, 0.20, 0.30, 0.40 and 0.5 ppm) of each sample were prepared and their absorbances read at 422.7, 248.3 and 213.9 nm for copper, iron and zinc, respectively in a UV/VIS spectrophotometer. The absorbance of sample solutions was read immediately after each standard and their concentration C (ppm) was calculated from standard calibration plot as follows:

$$C \text{ for Iron} = \text{Absorbance} - (0.001/0.023) \quad (4)$$

$$C \text{ for Zinc} = \text{Absorbance} - (0.0077/0.1098) \quad (5)$$

$$C \text{ for Copper} = \text{Absorbance} - (0.0042/0.0413) \quad (6)$$

$$\text{Concentration of metal (mg/100 g)} = \frac{C \times 100 (\mu\text{g})}{\text{Sample weight (g)}} \quad (7)$$

#### Determination of sweet potato genotypes' loss/gain of $\beta$ -carotene and ascorbic acid

Loss or gain in  $\beta$ -carotene and ascorbic acid among unpeeled sweet potato genotypes was determined by calculating the difference among  $\beta$ -carotene and ascorbic acid readings at 4, 5 and 7 MAP for each genotype. The results were converted into percentages and assigned a negative or positive sign representing loss or gain of  $\beta$ -carotene and ascorbic acid, respectively. The percentages were plotted into graphs.

#### Data analysis

Agronomic traits and micronutrients data were subjected to ANOVA using AGROBASE software (Agrobases, 1999) in order to determine differences among genotypes, months of harvest (4, 5 and 7 MAP) and preparation form (peeled and unpeeled). Genotypes were assumed to be fixed, with time of harvesting and sample type effects as random. Least significant difference ( $p < 0.05$ ) was used to compare means.

## RESULTS AND DISCUSSION

### Dry matter content of 15 genotypes

The dry matter (DM) content of sweet potato storage

roots at 4, 5 and 7 MAP are presented in Table 2. The DM results demonstrated significant variation among the genotypes within the three MAP at  $p \leq 0.01$ . Variations in percentage DM content across harvesting times and in both sample types, peeled and unpeeled, were not significant at  $p \leq 0.05$ . Across the harvesting times, genotype Yoyera a landrace, exhibited the highest DM content (36.25%) followed by two other landraces; Babache and Kamchiputu (36%). Mzungu (23.33%) and A45 (25.17%) were relatively low in percent DM content. Acceptable levels of dry matter content in preferred genotypes in Malawi are  $\geq 30\%$  (Chipungu et al., 1999) and Kamchiputu and Yoyera are among the best genotypes. Genotypes with high dry matter are preferred because they are usually low in sugar (Baafi et al., 2016a). Determination of dry matter is important since % DM is among key component traits that contribute to total root yield (TRY), others being large root yield (LRY), number of large root per plant (NLR/P), root dry matter yield (RDMY) and harvest index (HI) (Amoatey et al., 2016).

### Variation in $\beta$ -carotene content

ANOVA results on  $\beta$ -carotene content in 15 sweet potato genotypes, harvested at three different times (MAP) and in two sample type (peeled and unpeeled), are presented in Table 3. The variables under study; genotype, harvesting times and sample type results and their first order interactions; genotype  $\times$  storage root age, genotype  $\times$  sample type and storage root age  $\times$  sample type and second order interactions (genotype  $\times$  storage root age  $\times$  sample type) were all highly significant at  $p \leq 0.01$ .

### Effect of genotype and flesh colour on $\beta$ -carotene content

Using unpeeled storage roots at 5 MAP, which is the recommended MAP in Malawi (Chipungu et al., 1999), the results showed high and significant variations in  $\beta$ -carotene content ( $p \leq 0.01$ ) among the genotypes (Table 3). This is probably due to the wide spectrum of storage root colour where carotenoids are responsible for the yellow, orange and red colours roots (Rodriguez-Amaya, 1993). Zonden, an orange fleshed genotype provided the highest  $\beta$ -carotene content (13.93 mg/100 g) followed by A45 (4.39 mg/100 g) which is also an orange fleshed genotype. There was a usual general downward trend in  $\beta$ -carotene levels in the genotypes from orange, pale orange to yellow storage root flesh colour registering colour category means of  $7.47 \pm 5.60$ ,  $2.76 \pm 0.44$  and  $1.65 \pm 0.66$  mg/100 g, respectively. Very low  $\beta$ -carotene levels were registered in unpeeled white/cream genotypes where genotype Yoyera (0.13 mg/100 g) registered the lowest levels. These observations agree

**Table 2.** Dry matter content (%) of 15 sweet potato genotypes at 4, 5 and 7 MAP.

Genotype	4 MAP	5 MAP	7 MAP	Mean
Yoyera	35.50	36.50	36.00	36.25
Kamchiputu	35.50	36.50	36.00	36.00
Babache	36.50	36.50	35.00	36.00
Kenya	33.00	35.00	34.00	34.00
LU96/303	31.50	32.00	33.00	32.17
Semusa	32.00	33.50	31.00	32.17
Zondoni	31.50	32.50	30.00	31.33
Lunyangwa	33.00	32.50	28.50	31.33
Mfumu	30.50	32.00	31.50	31.33
LU96/374	30.00	32.00	31.50	31.17
Pepu	27.50	30.50	31.00	29.67
Tainung	27.50	28.50	27.00	27.67
Mafutha	27.00	27.00	27.00	27.00
A45	25.00	26.00	24.50	25.17
Mzungu	22.50	23.50	24.00	23.33
Coefficient of Variation (%)	6.60	7.48	7.77	5.36
Least Significant Difference	3.52	4.40	4.15	2.37
Genotype	***	***	***	***
Peeled	ns	ns	Ns	ns
Unpeeled	ns	ns	Ns	ns
MAP	ns	ns	Ns	ns

ns= Not significant, \*\*\*= Significant at  $p \leq 0.01$ .

with Stathers et al. (2005) and Mbwaga et al. (2007) findings which showed low beta carotene levels in white/cream genotypes but are contrary to other studies that concluded that white/cream genotypes have absolutely no beta carotene (Van Jaarsveld et al., 2005; Ingabire and Vasanthakalam, 2011).

The findings also reinforced the fact that root fresh colour is an indicator of relative  $\beta$ -carotene levels with orange and cream showing highest and lowest levels, respectively. The results complement findings by K'osambo et al. (1998), Picha (1985) and Huang et al. (1999) which revealed that  $\beta$ -carotene are largely responsible for the orange flesh colour in sweet potato. Level of  $\beta$ -carotene in genotype Zondoni (13.93 mg/100 g at 5 MAP) is comparatively among the highest in eastern and southern Africa Region (K'osambo et al., 1998; Carey et al., 1999; Manrique and Herman, 2000). Andrade et al. (2009) showed in their study that there is a strong negative correlation between dry matter and  $\beta$ -carotene content in sweet potato; however, Zondoni (31.33%), in this study had fairly high and acceptable levels of dry matter (Table 1). Yield stability studies done in different sites in Malawi also showed that Zondoni was the most stable genotype across all sites (Kathabwalika et al., 2013) implying that it can be grown successfully across the country. However, levels of  $\beta$ -carotene in Zondoni, A45 and other orange fleshed genotypes in the

study (Table 3), fall far short of what is considered high by the International Potato Centre (CIP, 2005) (100 g/1 g of fresh tissue). Nevertheless, the genotypes can make considerable contribution towards addressing vitamin A deficiency (VAD) whose incidences are worrisome in Africa including Malawi (Hotz et al., 2011; Shisana et al., 2013; Girard et al., 2017). Isolation and identification of genotypes with high level of  $\beta$ -carotene is important for effective choice of parents in breeding improved varieties with higher  $\beta$ -carotene levels (Vimala et al., 2012; Kiarie et al., 2016; Naidoo et al., 2016).

#### **Effect of peeling on $\beta$ -carotene content at 5 MAP**

Table 3 reveals that on average, at all MAP, peeling of sweet potato root samples significantly ( $p \leq 0.01$ ) reduced  $\beta$ -carotene levels in most genotypes. However, variation in gain or loss resulting from peeling was mainly observed at 5 MAP where some genotypes such as Kenya, Yoyera, LU96/303, Lunyangwa and Semusa gained while the rest lost  $\beta$ -carotene (Data not shown). In this study, peeling of storage roots generally resulted in  $\beta$ -carotene loss averaging 28.7, 46.7 and 39.1% at 4, 5 and 7 MAP, respectively inferring that sweet potato peels contain substantial amounts of  $\beta$ -carotene. This observation concurs with findings by Akoetey et al. (2017)

**Table 3.** Effect of genotype and age on  $\beta$ -carotene values (mg/100 g fresh tissue).

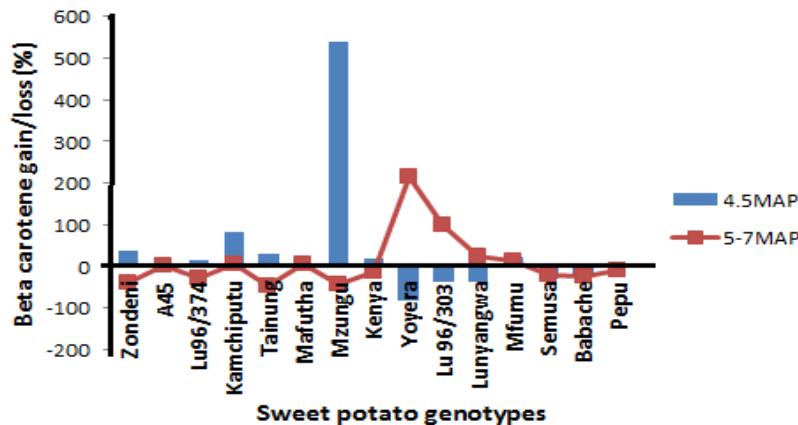
Genotype	Flesh colour	Unpeeled root samples				Peeled root samples				Grand Mean
		4 MAP	5 MAP	7 MAP	Mean	4 MAP	5 MAP	7 MAP	Mean	
Zondeni	Orange	10.29	13.93	8.49	10.90	7.73	6.59	6.07	6.80	8.85
A45		4.32	4.39	4.38	4.36	3.26	3.49	2.36	3.04	3.70
LU96/374		3.62	4.09	2.92	3.54	2.36	2.16	1.93	2.15	2.85
<b>Mean <math>\pm</math>SD</b>		<b>6.08<math>\pm</math>3.67</b>	<b>7.47<math>\pm</math>5.60</b>	<b>5.26<math>\pm</math>2.89</b>	<b>6.27<math>\pm</math>4.03</b>	<b>4.45<math>\pm</math>2.88</b>	<b>4.08<math>\pm</math>2.27</b>	<b>3.45<math>\pm</math>2.28</b>	<b>3.99<math>\pm</math>2.47</b>	<b>5.13<math>\pm</math>3.25</b>
Kamchiputu	Pale orange	1.26	2.29	2.38	1.98	1.02	1.57	1.24	1.28	1.63
Tainung		2.18	2.83	1.49	2.17	1.81	1.87	0.98	1.55	1.86
Mafutha		3.44	3.17	3.39	3.33	2.15	2.96	3.15	2.75	3.04
<b>Mean <math>\pm</math>SD</b>		<b>2.29<math>\pm</math>1.09</b>	<b>2.76<math>\pm</math>0.44</b>	<b>2.42<math>\pm</math>0.95</b>	<b>2.49<math>\pm</math>0.73</b>	<b>1.66<math>\pm</math>0.58</b>	<b>2.13<math>\pm</math>0.73</b>	<b>1.79<math>\pm</math>1.18</b>	<b>1.86<math>\pm</math>0.78</b>	<b>2.18<math>\pm</math>0.76</b>
Mzungu	Yellow	0.33	2.11	1.19	1.21	0.23	0.27	0.28	0.26	0.74
Kenya		1.01	1.18	1.03	1.07	1.45	2.16	0.89	1.50	1.29
<b>Mean <math>\pm</math>SD</b>		<b>0.67<math>\pm</math>0.48</b>	<b>1.65<math>\pm</math>0.66</b>	<b>1.11<math>\pm</math>0.11</b>	<b>1.14<math>\pm</math>0.10</b>	<b>0.84<math>\pm</math>0.86</b>	<b>1.22<math>\pm</math>1.34</b>	<b>0.59<math>\pm</math>0.43</b>	<b>0.88<math>\pm</math>0.88</b>	<b>1.01<math>\pm</math>0.39</b>
Yoyera		0.74	0.13	0.41	0.43	0.47	0.33	0.44	0.41	0.42
LU96/303	White/cream	0.61	0.39	0.77	0.59	0.63	0.89	0.96	0.83	0.71
Lunyangwa		0.44	0.28	0.35	0.36	0.31	0.43	0.21	0.32	0.34
Mfumumu		0.62	0.76	0.86	0.75	0.59	0.45	0.81	0.62	0.68
Semusa		0.63	0.45	0.35	0.48	0.44	0.50	0.19	0.38	0.43
Babache		0.23	0.19	0.14	0.19	0.10	0.15	0.06	0.10	0.15
<b>Mean <math>\pm</math>SD</b>		<b>0.55<math>\pm</math>0.18</b>	<b>0.37<math>\pm</math>0.23</b>	<b>0.48<math>\pm</math>0.28</b>	<b>0.46<math>\pm</math>0.19</b>	<b>0.42<math>\pm</math>0.20</b>	<b>0.46<math>\pm</math>0.25</b>	<b>0.45<math>\pm</math>0.37</b>	<b>0.44<math>\pm</math>0.25</b>	<b>0.45<math>\pm</math>0.21</b>
Pepu	Purple	0.93	0.94	0.86	0.91	0.67	0.16	0.24	0.36	0.63
<b>Mean</b>		<b>1.99</b>	<b>2.45</b>	<b>1.85</b>	<b>2.07<math>\pm</math>0.31</b>	<b>1.53</b>	<b>1.58</b>	<b>1.32</b>	<b>1.47<math>\pm</math>0.14</b>	<b>1.77</b>
CV %		16.36	21.56	19.97	13.25	10.25	21.81	15.87	12.58	21.42
LSD		0.89	0.91	0.46	0.86	0.34	0.63	0.38	0.82	0.64
Genotype (C)		***	***	***	***	***	***	***	***	***
Sample type (S)										***
MAP (T)					***				***	***
S $\times$ T										***
C $\times$ T					***				***	***
C $\times$ S										***
C $\times$ T $\times$ S										***

CV%= Coefficient of variation; LSD= least significance difference, \*\*\*= Significant at  $p \leq 0.01$ .

which showed that sweet potato peels are a good source of micronutrients including  $\beta$ -carotene.

Rodriguez-Amaya (1993) also reported that most fruits and vegetables have higher carotenoid levels

in the peel than the pulp. However, the increases in  $\beta$ -carotene levels after peeling in Yoyera, Kenya,



**Figure 1.** Gain/loss (%) in  $\beta$ -carotene content in unpeeled samples of storage roots of 15 sweet potato genotypes due to plant age.

LU96/303 and Lunyangwa presents a challenge to scientists that would be solved by a proper understanding of responsible genes and the dynamics of their expression. A study done by Baafi et al. (2016b) showed that genetic variability for the traits that control expression of micronutrients ( $\beta$ -carotene, iron and zinc) in sweet potato are mostly controlled by additive gene effect and the study found significant heterosis suggesting that levels of micronutrients could be improved through breeding.

#### **Effect of root age on $\beta$ -carotene content in unpeeled samples**

Figure 1 shows that except for Kamchiputu and Mafutha, all orange, pale orange and yellow fleshed genotypes gained and lost  $\beta$ -carotene as the roots aged from 4 to 5 MAP and 5 to 7 MAP, respectively in unpeeled samples. In general, the opposite was observed in white/cream fleshed genotypes where losses and gain in  $\beta$ -carotene was observed as the roots aged from 4 to 5 MAP and 5 to 7 MAP, respectively in unpeeled samples. This observation suggests that various genotypes would have various recommended time of harvesting for maximum use of the micronutrient. However, it is well established that plant age affects the composition of food nutrients including  $\beta$ -carotene levels. Carey et al. (1999) reported increasing  $\beta$ -carotene levels with age; the values peaked at 5 MAP and declined thereafter. Also, in leafy vegetables, the  $\beta$ -carotene content of mature leaves of lettuce (12  $\mu\text{g/g}$ ) and endive (14  $\mu\text{g/g}$ ) were nearly three times higher than those of the young leaves (Ramos and Rodriguez-Amaya, 1987).

#### **Percent contribution of variables to the total sum of squares**

Since all the variables and their interactions under study

showed significant ( $p \leq 0.01$ ) contributions to  $\beta$ -carotene content as presented in Table 3, an estimate of the contribution of each variable to the total sum of squares (TSS) of  $\beta$ -carotene content was conducted to isolate determinant variables of  $\beta$ -carotene in sweet potato genotypes (Table 4).

The results revealed that genotypes'  $\beta$ -carotene content was largely due to genetic variability which accounted for 47.23% of the TSS (Table 4). This means that  $\beta$ -carotene content could be shared among genotypes through breeding since it is genes-based. The second variable of importance was sample type (peeled or unpeeled), which contributed 20.56% to the TSS; unpeeled sample being superior in  $\beta$ -carotene content. This is not surprising since peels are known to contain more carotenoids than the pulp (Rodriguez-Amaya, 1993). The contribution of harvesting time and other interactions to TSS was less than 10% and therefore regarded as less important in determining  $\beta$ -carotene.

#### **Ascorbic acid (Vitamin C) content in sweet potato genotypes**

The levels of ascorbic acid in 15 genotypes assessed at 4, 5 and 7 MAP in unpeeled and peeled storage root samples of sweet potato are provided in Table 5.

#### **Genotypic variability of ascorbic acid content**

At 5 MAP and in unpeeled samples, the results in Table 5 showed that significant ( $p \leq 0.01$ ) variation in ascorbic acid content existed among the genotypes. Genotypic variability contributed the highest percent to the TSS (36.32%) followed by sample type (26.35%; unpeeled). For instance, genotype Semusa (22.43 mg/100 g; fresh weight; 5 MAP) gave the highest ascorbic acid content and was not significantly different from Mfumu (22.42

**Table 4.** Contribution of variables to total sum of squares (TSS) of  $\beta$ -carotene content in sweet potato.

Source	Degrees of freedom	% Contribution to TSS
Genotype, G	14	47.23
Sample type, S	1	20.56
GxS	14	7.12
MAP T	2	8.11
GxT	28	5.39
TxS	2	4.14
GxTxS	28	3.84
REP (GxS)	12	2.52
Error	84	1.09

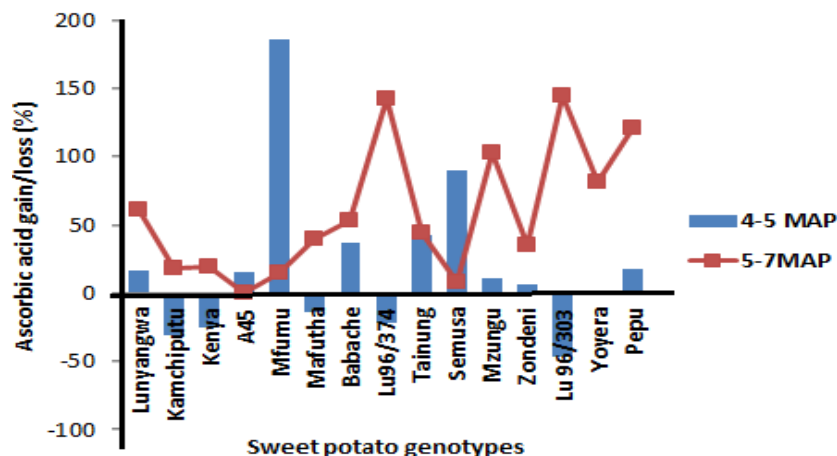
**Table 5.** Effect of genotype and age on ascorbic acid values (mg/100 g fresh tissue).

Genotype	Unpeeled root samples				Peeled root samples				Contribution to TSS (%)
	4 MAP	5 MAP	7 MAP	Mean	4 MAP	5 MAP	7 MAP	Mean	
Babache	15.99	21.88	33.64	23.84	7.27	16.73	21.21	15.07	
Mzungu	16.01	17.79	36.18	23.33	5.82	13.41	13.28	10.84	
Kamchiputu	24.69	17.24	20.45	20.79	11.63	11.72	15.18	12.84	
Zondeni	17.45	18.61	25.16	20.41	5.82	10.04	21.22	12.36	
Lunyangwa	14.39	16.83	27.23	19.48	10.94	15.41	11.64	12.66	
Kenya	21.81	16.41	19.67	19.30	11.63	13.39	11.93	12.32	
A45	17.01	19.64	19.67	18.77	9.73	10.79	14.56	11.69	
Mfumu	7.85	22.42	25.73	18.67	9.73	9.25	15.99	11.66	
Yoyera	16.01	16.41	29.86	20.76	5.81	11.71	10.60	9.37	
Semusa	11.77	22.43	24.21	19.47	6.08	12.32	11.63	10.01	
LU96/303	20.36	10.94	26.74	19.35	5.82	10.04	13.26	9.71	
Pepu	11.64	13.67	30.25	18.52	4.86	11.71	14.58	10.38	
LU96/374	14.38	11.21	27.21	17.60	6.08	13.86	13.09	11.01	
Tainung	11.78	16.83	24.22	17.61	6.08	9.24	14.54	9.95	
Mafutha	13.09	11.22	15.74	13.35	9.72	7.71	11.65	9.69	
Mean	15.62	16.90	25.73	19.42	7.80	11.82	14.29	11.30	
CV %	11.23	14.72	13.96	11.03	10.28	10.85	11.18	13.68	
LSD	1.73	1.98	2.65	1.98	1.17	1.58	1.66	1.77	
Genotype (G)	***	***	***	***	***	***	***	***	36.32
Sample type S)									26.35
MAP (T)				***				***	18.96
S x T									6.35
G x T				***				***	3.27
G x S									1.27
G x T * S									2.11

CV%= Coefficient of variation; LSD= least significance difference.

mg/100 g; 5 MAP) and Babache (21.88 mg/100 g; 5 MAP) ( $p \leq 0.01$ ) while the least was LU96/303 (10.94 mg/100 g; 5 MAP). On average, across harvesting times and sample types, different genotypes exhibited different rankings for ascorbic acid content. For instance, in unpeeled samples, Babache (23.84 mg/100 g) ranked

highest while Mafutha was lowest (13.35 mg/100 g). In the peeled samples, Babache (15.07 mg/100 g) was the highest and Yoyela (9.37 mg/100 g) was the lowest. The mean level of ascorbic acid from unpeeled samples across all MAP (19.42 mg/100 g) was lower than (26.35 mg/100 g) reported by Bradbury and Singh (1986) from



**Figure 2.** Gain/loss (%) in ascorbic acid amounts in unpeeled storage root samples of 15 sweet potato genotypes due to age variation.

**Table 6.** Status of Fe, Zn and Cu at Bvumbwe Research Station during the study.

Soil sample	Analyte (PPM)				Soil type
	Fe	Zn	Cu	pH	
Top soil	8.27	9.96	1.52	5.56	Sandy clay loam
Sub soil (30 cm deep)	6.35	8.08	1.28	5.78	
Mean	7.31	9.02	1.40	5.67	

four Solomon Island sweet potato genotypes.

### Effect of age on ascorbic content

The performance of 15 genotypes in ascorbic acid content as affected by delayed harvesting in unpeeled samples is presented in Figure 2. A one month delay (4 to 5 MAP) in harvesting resulted in the accumulation of ascorbic acid levels in 10 out of the 15 genotypes with highest accumulation percent in genotype Mfumu (185.6%) and Semusa (90.6%).

The genotype LU96/303 (-46.27%) experienced the highest percent loss at 5 MAP followed by Kamchiputu (-30.17%). An average accumulation of 42.6% was observed due to age from 4 to 5 MAP. A two months delay from 5 to 7 MAP resulted in further accumulation of ascorbic acid in all genotypes. The genotype LU96/303 which experienced the highest loss due to one month delay in harvesting from 4 to 5 MAP, showed the highest percentage gain (144.42%) in ascorbic acid due to two months delay from 5 to 7 MAP followed by LU96/374 (142.73%). The lowest percentage gain was exhibited by A45 (0.15%). A two months delay from 5 to 7 MAP gave an average percent increase in ascorbic acid of 59.3%. Generally, delayed harvesting of sweet potato roots resulted in increased ascorbic acid content due to

increased size of storage root which is directly associated with increased levels of water soluble ascorbic acid (Rukundo et al., 2013). Lanier and Sistrunk (1979) showed that ascorbic acid levels vary with size of storage roots. This study also corroborated findings from elsewhere that showed that sweet potato is a good source of vitamin C (Low et al., 2009; Sreekanth et al., 2010; Hotz et al., 2012).

### Mineral content (Iron, Zinc and Copper)

Table 6 presents the status of soil mineral composition at the planting of study genotypes at Bvumbwe Agricultural Research Station. Iron (Fe), zinc (Zn) and copper (Cu) contents in peeled and unpeeled sweet potato samples at 4, 5 and 7 MAP are presented in Tables 7, 8 and 9, respectively. The sweet potato genotypes exhibited significant ( $p \leq 0.05$ ) variations in the three mineral elements at 4, 5 and 7 MAP and sample types (peeled and unpeeled). This can be attributed to dynamics in soil mineral content and interaction between minerals and genotypes (Woolfe, 1992; Ingabire and Vasanthakalam, 2011; Ukom et al., 2011). Zhang et al. (2003) and Laurie et al. (2012) showed that sweet potato is rich in various minerals including K, Ca, Fe, P, Se, Cu and Zn. Iron, zinc and copper are usually present in the soil in adequate to

**Table 7.** Iron content (mg/100 g) of 15 sweet potato genotypes.

Genotype	Unpeeled root samples			Peeled root samples		
	4 MAP	5 MAP	7 MAP	4 MAP	5 MAP	7 MAP
Babache	0.32	0.09	0.03	0.19	0.08	0.01
Mzungu	0.67	0.06	0.04	0.20	0.06	0.01
Yoyera	0.15	0.06	0.06	0.12	0.03	0.01
Kamchiputu	0.19	0.03	0.03	0.15	0.03	0.01
Kenya	0.21	0.08	0.06	0.17	0.04	0.01
Zonden	0.23	0.04	0.02	0.14	0.04	0.01
LU96/303	0.47	0.04	0.03	0.29	0.04	0.01
Pepu	0.15	0.04	0.02	0.03	0.03	0.01
Mafutha	0.20	0.06	0.02	0.17	0.05	0.01
A45	0.17	0.11	0.04	0.16	0.1	0.02
Lunyangwa	0.16	0.05	0.02	0.09	0.04	0.01
LU96/374	0.46	0.04	0.02	0.16	0.05	0.01
Tainung	0.14	0.05	0.02	0.12	0.05	0.01
Mfumum	0.43	0.07	0.04	0.19	0.04	0.01
Semusa	0.09	0.06	0.03	0.10	0.04	0.01
Mean	0.27	0.06	0.03	0.15	0.05	0.01
CV (%)	25.63	24.23	15.67	21.36	18.91	19.2
Significance	***	**	**	***	**	**
LSD	0.06	0.02	0.01	0.05	0.01	0

CV (%)= Coefficient of variation; LSD= least significance difference.

excess amounts (Table 6) (Laurie et al., 2012), such that deficiencies are due to their presence in unavailable forms rather than their lack. Environmental factors such as leached soils, acid, sandy soils, organic soils, intensively cropped soils, soils with high pH, and eroded soils also affect solubility of micronutrients (Brady and Weil, 2002). However, mineral content variations in genotypes are attributed mainly to differences among genotypes in uptake efficiency and capacity to solubilize non-available nutrients (Rengel, 2001).

#### **Effect of genotype, age and peeling on iron content**

Results in Table 7 indicate that the highest iron content (0.67 mg/100 g) in unpeeled samples was recovered at 4 MAP in genotype Mzungu followed by LU96/374 (0.46 mg/100 g) and Mfumum (0.43 mg/100 g). Unpeeled Semusa at 4 MAP recorded the least iron (0.09 mg/100 g). Upon peeling of samples at 4 MAP, LU96/303 retained the highest amount (0.29 mg/100 g) while Pepu had the least iron (0.03 mg/100 g). Delays in lifting of storage roots reduced iron content in all genotypes and in both peeled and unpeeled samples, with the highest value being unpeeled A45 (0.11 mg/100 g) at 5 MAP. This loss could be due to the sweet potato plant ultimately using up the iron in the storage root. Iron content from all genotypes at average MAP (0.12 mg/100 g) observed in this study is lower than what Sanoussi et

al. (2016) (0.63 mg/100 g), Bradbury and Holloway (1988) (0.93 mg/100 g) and Laurie et al. (2012) (0.995 mg/100 g) reported in Benin, Australia and South Africa, respectively. Thus, Malawian genotypes in the study need to be bred for increased iron levels since lack of iron is the main cause of severe anaemia in children (Sanoussi et al., 2013).

#### **Effect of genotype, age and peeling on zinc content**

The levels of zinc in the 15 genotypes in the study are provided in Table 8. The highest level of zinc in unpeeled storage roots was registered in genotype Mzungu (0.63 mg/100 g) at 4 MAP followed by Kenya and Kamchiputu (0.59 and 0.58 mg/100 g, respectively). In peeled samples, genotype Mzungu remained the highest (0.62 mg/100 g) followed by Kamchiputu and Lunyangwa (0.53 mg/100 g). Babache is the only genotype that showed an increase in Zn content from 0.16 to 0.60 g/100 g in peeled samples and from 0.23 to 0.36 mg/100 g in unpeeled samples when lifting was delayed by a month (from 4 to 5 MAP). Across genotypes, the results indicated that when storage roots are harvested late and peeled, Zn levels decreases. At 4 MAP, potentially 14 out of 15 unpeeled genotypes in the study (Table 8) have higher zinc levels than that reported by Woolfe (1992) (0.24 mg/100 g), Sanoussi et al. (2016) (0.25 mg/100 g) and comparable with 0.59 mg/100 g reported by

**Table 8.** Zinc content (mg/100 g) of 15 sweet potato genotype.

Genotype	Unpeeled root samples			Peeled root samples		
	4 MAP	5 MAP	7 MAP	4 MAP	5 MAP	7 MAP
Babache	0.23	0.36	-0.3	0.16	0.60	-0.49
Mzungu	0.63	0.07	-0.31	0.62	-0.91	-1.45
Yoyera	0.47	0.16	-0.18	0.43	-0.50	-0.38
Kamchiputu	0.58	0.16	-0.26	0.53	-0.22	-0.38
Kenya	0.59	0.45	-0.31	0.34	-0.21	-0.30
Zondoni	0.35	0.31	-0.12	0.21	-0.27	-0.78
LU96/303	0.43	0.19	-0.26	0.24	-0.29	-0.63
Pepu	0.54	0.24	-0.25	0.23	-0.38	-0.79
Mafutha	0.33	0.35	-0.36	0.29	-0.51	-1.14
A45	0.43	0.39	-0.35	0.17	-0.25	-0.86
Lunyangwa	0.50	0.14	-0.46	0.53	-0.32	-1.06
LU96/374	0.33	0.12	-0.22	0.20	0.11	-0.39
Tainung	0.46	0.19	-0.40	0.31	-0.27	-0.94
Mfumu	0.50	0.23	-0.39	0.42	-0.53	-0.64
Semusa	0.51	0.31	-0.41	0.22	-0.08	-0.47
Mean	0.46	0.24	-0.31	0.33	-0.27	-0.71
CV %	18.24	21.54	22.54	23.17	19.65	19.88
Significance	***	***	**	***	**	***
LSD	0.07	0.01	0.02	0.15	0.05	0.03

CV%= Coefficient of variation; LSD= least significance difference.

Bradbury and Holloway (1988). The levels found by Woolfe (1992) and Sanoussi et al. (2016) are below daily recommended dietary intake in both children and adults (La Frano et al., 2014), hence Malawian genotypes would not necessarily need zinc fortification.

#### **Effect of genotype, age and peeling on copper content**

Highest levels of copper were observed at 4 MAP among unpeeled genotypes ranging from 0.43 to 0.61 mg/100 g (Table 9). A general dwindling trend in copper content from 4 to 5 MAP was exhibited in both preparation methods resulting from age of the storage roots except for Kenya and Semusa (unpeeled samples) and Zondoni and LU96/374 (peeled samples).

Thus peeling of storage roots of some genotypes resulted in total loss of copper at 7 MAP. While Woolfe (1992) reported copper mean value of 0.35 mg/100 g, Kruger et al. (1998) (0.32 mg/100 g), Bradbury and Holloway (1988) (0.16 mg/100 g), Away (2008) (0.42 mg/100 g), mean copper values observed in this study (0.28 mg/100 g; peeled) and (0.40 mg/100 g; unpeeled) are comparably higher. This entails high potential of the Malawian germplasm as a source of dietary copper, which is good for prevention of anemia, low body temperature, bone fractures and osteoporosis (Decuyperes, 2000).

#### **Conclusions**

Sweet potato is a cheap and suitable option for alleviating "hidden hunger" of micronutrients in developing countries owing to its richness in  $\beta$ -carotene, a precursor for pro-vitamin A, ascorbic acid (Vitamin C), iron, zinc and copper. In general, the study revealed that peeling reduces Vitamin A and C, iron, zinc and copper in genotypes while delayed harvesting of sweet potato results in reduced levels of iron, zinc and copper. Harvesting at 5 and 4 MAP gives highest levels of (Vitamin A and C) and (iron, zinc and copper), respectively. The most important determinant of levels of Vitamin A and C is genotype other than sample type or any other interactions. Vitamin A levels generally decrease as genotypes' flesh colour changes from orange, pale orange, yellow to white/cream; thus, sweet potato based VAD programs should target orange fleshed sweet potato.

A total of 10 out of the 15 genotypes in the study exhibited acceptable levels of dry matter of  $\geq 30\%$  and genotypes Kamchiputu, Yoyela and Babache were among the best. Zondoni (10.9 mg/100 g) and Babache (23.84 mg/100 g) are the best genotypes in terms of levels of Vitamin A ( $\beta$ -carotene) and Vitamin C (ascorbic acid) respectively. Genotype Mzungu is the best in iron (0.67 mg/100 g) and zinc (0.63 mg/100 g) levels while Yoyera (0.61 mg/100 g) provides the highest levels of copper.



**Table 9.** Copper content (mg/100 g) of 15 sweet potato genotypes.

Genotypes	Unpeeled root samples			Peeled root samples		
	4 MAP	5 MAP	7 MAP	4 MAP	5 MAP	7 MAP
Babache	0.56	0.44	0.08	0.48	0.21	0.57
Mzungu	0.54	0.19	0.08	0.46	0.28	0.50
Yoyera	0.61	0.51	0.09	0.38	0.19	-0.10
Kamchiputu	0.46	0.43	0.10	0.30	0.17	0.00
Kenya	0.53	0.54	0.06	0.48	0.39	-0.11
Zonden	0.48	0.35	0.18	0.48	0.52	0.27
LU96/303	0.51	0.33	0.57	0.49	0.27	-0.28
Pepu	0.56	0.44	0.26	0.45	0.13	0.49
Mafutha	0.59	0.31	0.31	0.45	0.25	-0.09
A45	0.59	0.37	0.50	0.28	0.60	0.63
Lunyangwa	0.43	0.23	0.31	0.30	0.08	0.53
LU96/374	0.59	0.37	0.34	0.40	0.49	0.05
Tainung	0.53	0.33	0.51	0.36	0.33	-0.08
Mfumu	0.50	0.34	0.64	0.36	0.21	-0.28
Semusa	0.46	0.48	0.40	0.45	0.23	0.23
Mean	0.53	0.38	0.3	0.41	0.29	0.16
CV (%)	15.69	19.63	13.54	21.36	18.97	24.59
Significance	**	**	**	**	**	**
LSD	0.06	0.06	0.02	0.02	0.02	0.04

CV (%) = Coefficient of variation; LSD= least significance difference.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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