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# Evaluation of candidate orange-fleshed sweetpotato clones for nutritional traits

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**ABSTRACT**
Information on the nutrient contents of newly developed orange-fleshed sweetpotato (OFSP) varieties is required for recommendations to growers and the food industry. Therefore, the objectives of this study were to determine the nutritional value of newly developed OFSP clones and to establish the associations between β-carotene content and micro-nutrients for targeted large scale production to alleviate nutrient deficiencies. Seventeen OFSP and eight white/cream-fleshed sweetpotato clones were evaluated across six diverse environments (Halaba, Kokate, Areka, Arbaminch, Hawassa and Dilla) in southern Ethiopia in 2014 using a 5 × 5 simple lattice design. Nutritional traits data were collected on dry-weight basis and subjected to analysis of variance and correlation analyses. Environment, genotype, and genotype × environment interaction effects were highly significant ($p < 0.01$) for all parameters measured. A newly developed genotype, designated G8, had the highest contents of β-carotene (20.01 mg 100 $g^{-1}$), protein (7.08%), iron (2.55 mg 100 $g^{-1}$), zinc (1.42 mg 100 $g^{-1}$), fructose (4.45%), glucose (5.34%) and sucrose (16.20%). Genotypes G15 and G19 also performed relatively well for the above nutritional traits. The three genotypes, G8, G15 and G19 had mean fresh root yield of 23.5,13.7 and 21.3 $tha^{-1}$, respectively. These genotypes had root dry matter content of 26.99%, 25.23% and 33.09%, respectively. Β-carotene content had significant positive correlations with iron, zinc, fructose, glucose and sucrose content. This reflects the potential to breed for OFSP varieties enriched with the important micro-nutrients. Overall, the candidate OFSP clones, G8 (Resisto × PIPI-2), G15 (Resisto × Temesgen-23) and G19 (Resisto × Ogansagen-23) were good sources of nutritional traits such as vitamin A, iron, zinc, protein, sucrose, glucose and fructose. The selected genotypes can be recommended for large-scale production, food processing or further sweetpotato improvement to alleviate nutrient deficiencies in Ethiopia or similar environments in sub-Saharan Africa.

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β-carotene; correlation analysis; micro-nutrients; nutrient deficiencies; OFSP

## Introduction

Micronutrient deficiency is a global health problem, especially in low income countries of the world, affecting the health of the poor communities (Welch 2002; Knez & Graham 2013). Deficiency of micro-nutrients such as vitamin A and minerals, especially iron (Fe) and zinc (Zn), affects nearly two billion people worldwide (Allen et al. 2006; Tulchinsky 2010). The deficiencies increase susceptibility to other diseases. Pregnant and lactating mothers, and young children, are greatly affected by nutrient deficiencies since they need relatively high levels of vitamins and minerals (Nabakwe & Ngare 2004; WHO 2009b). Vitamin A deficiency is the major health problem worldwide that leads to blindness, retarded growth and death, particularly in developing countries. It largely affects pre-school children, pregnant and lactating mothers, and the rural poor (WHO 2009a). Fe deficiency is another global health problem with approximately two billion people in the world being reported to be anemic (Frossard et al. 2000; WHO 2009b; Singh et al. 2013). Fe is required for proper functioning of the immune system, the blood system, protein synthesis, cell reproduction and wound healing. Furthermore, this micro-nutrient plays a major role in fertility and conception (Singh et al. 2013). Zn is another essential element. Over one-third of the world's population is estimated to have Zn deficiency (|WHO 2009b, 2011, 2012). Nearly 800,000 and 700,000 deaths per year can be attributed to Fe and Zn deficiencies, respectively and more than 2% of global disease problems are attributable to vitamin A, Fe and Zn deficiencies (Black 2003).

Different strategies have been used to combat the problem of nutrient deficiencies. One of the strategies is multiple vitamin and mineral supplements for pregnant and lactating mothers, and for young children aged below 5 years. However, this approach is not sustainable. It is expensive, and also difficult to deliver to all mothers and children that are at risk, especially in

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remote rural areas (Anderson et al. 2007). Therefore, consumption of food items naturally rich in vitamins and minerals is a more reliable strategy. The food items are vegetables such as kale, tomatoes, yellow pepper, carrot, broccoli, Swisschard, squash and pumpkin, fruits such as cantaloupe, apricot, mango and papaya, and root crops such as orange-fleshed sweetpotato (Toenniessen 2000; Mwanga et al. 2003; Kapinga et al. 2005; Anderson et al. 2007; Gurmu et al. 2015). Among these food items, sweetpotato is the cheapest food source that is rich in many of the macro and micro-nutrients (Woolfe 1992; Courtney et al. 2008; Grüneberg et al. 2009a; Waized et al. 2015).

Sweetpotato is an important food crop that is grown primarily by smallholder farmers of the developing countries. The crop is used as a staple or secondary staple or as a substitute for starchy staples such as rice, wheat, maize and potato and is mainly consumed by poor communities. Sweetpotato storage roots are important sources of a significant level of carbohydrates, vitamins C and B6, minerals such as copper, potassium, iron, and other nutrients and fiber (Woolfe 1992). It also contains moderate quantities of zinc, sodium, magnesium and manganese (Suda et al. 1999; Antia et al. 2006; Burri 2011) .

Some sweetpotato varieties, especially those with orange and purple flesh, are rich in β-carotene, anthocyanins, phenolics, dietary fiber, vitamin C, folic acid and minerals (Woolfe 1992; Bovell-Benjamin 2007; Burri 2011). OFSP is an effective, low-priced, sustainable source of β-carotene (pro-vitamin A) (Low et al. 2001; Mwanga et al. 2003; Tumwegamire et al. 2004; Gurmu et al. 2015).β-carotene is converted to vitamin A in the human body (Low et al. 2001; Mwanga et al. 2003; Kapinga et al. 2005). Some dark-orange-fleshed sweetpotato varieties can contain up to 20,000 μg 100 $g^{-1}$ of β-carotene on a fresh weight basis (Woolfe 1992; Takahata et al. 1993; Kapinga et al. 2010). The leaves of sweetpotato also serve as nutritious vegetable for humans (Woolfe 1992). Sweetpotato leaves are good sources of protein, β-carotene, some of the B vitamins, iron, and other minerals. Therefore, using sweetpotato as a dietary source to combat nutrient deficiencies related health problems is a key strategy, especially for smallholder and poor communities.

Twenty four candidate sweetpotato clones with improved root dry matter, β-carotene content, and fresh root yield were selected from a family of crosses constituting seven parents. Information on the nutrient contents of the newly developed OFSPs is required for recommendations to growers, the food industry or to government or non-government scientists. Therefore, the objectives of this study were to determine the nutritional value of newly developed OFSP clones and to establish the associations between β-carotene content and micronutrients for targeted large scale production to alleviate nutrient deficiencies in Ethiopia.

## Materials and methods

### Study sites

The study was conducted during the 2014 cropping season in six sites with varying climatic conditions. The sites were Arbaminch, Areka, Dilla, Halaba, Hawassa and Kokate, situated in the Southern Nations, Nationalities and Peoples' Region (SNNPRS) of Ethiopia (Table 1).

### Plant materials, experimental design and field establishment

The study used 25 sweetpotato genotypes: 24 were F1 clones selected recently with one check variety currently grown in Ethiopia (Table 2). Among these genotypes, 17 were OFSPs and eight were white/cream-fleshed sweetpotato clones. A 5×5 simple lattice design was used for the plant layout with four rows per plot of 3 m for each genotype. The spacing between rows and plants was 0.60 and 0.30 m, respectively. This resulted in a total of 10 plants per row and 40 plants per plot. The spacing between blocks and replications was 1 and 2 m, respectively. At all the sites, the experiment was conducted under rain fed condition and did not receive irrigation. Fertilizer was not applied at all the test sites.

### Data collection

All the data were collected from two replicates. Fresh root yield (t $ha^{-1}$) was measured from two central rows and expressed as harvested fresh root weight in kg per plot and converted to tones per hectare. For root dry matter content, 100–200 g samples were taken from roots of sampled plants in the plot and the samples were dried in an oven at 80°C for 48 h. The results were expressed as percentage of root dry weight (g) to fresh root weight (g).For the nutritional analysis, roots from the two central rows of each plot were harvested and representative samples of five medium sized roots were taken from each plot. The roots were washed with tap water, peeled, and each root was cut longitudinally into four sections. Two opposite sections of each of the sectioned roots were taken to prepare a 100 g composite sample that was placed in a transparent polythene bag and freeze-dried at −31°C for 72 h, following the method described by Tumwegamire et al. (2011). The freeze dried samples were kept in light proof black

**Table 1.** Description of the experimental sites.

| Location | Code | Altitude (masl)[a] | Agro-ecological zones | Coordinates | Annual rainfall (mm) | Mean annual temperature (°C) | | RH (%) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Min | Max | |
| Arbaminch | AM | 1400 | sub-moist warm | 06°03′N, 37°33′E | 940.9 | 17.4 | 30.6 | 55.9 |
| Areka | ARE | 1752 | moist-cool | 07°03″N, 37°42′E | 1499.8 | 13.2 | 27.9 | 60.8 |
| Dilla | DIL | 1519 | sub-moist cool | 06°22′N, 38°18′E | 1354.6 | 12.9 | 28.1 | 65.0 |
| Halaba | HAL | 1772 | sub-moist cool | 07°18′N, 38°05′E | 928.8 | 14.6 | 28.6 | 58.3 |
| Hawassa | HAW | 1700 | sub-moist cool | 07°03′5N, 38°28′E | 1046.3 | 13.3 | 27.6 | 62.1 |
| Kokate | KOK | 1854 | moist- cool | 06°49′N, 37°44′′′E | 1352.9 | 12.7 | 25.5 | 63.1 |

[a]masl = meter above sea level, RH = relative humidity.
Source: National Meteorological Agency, Hawassa Main Branch.

polythene bags and sent to the International Potato Center (CIP)-Uganda for analysis. Eight nutritional traits were analysed namely, β-carotene content (expressed in mg 100 $g^{-1}$), protein (expressed in %), iron (mg 100 $g^{-1}$), zinc (mg 100 $g^{-1}$), starch (%), glucose (%), fructose (%) and sucrose (%) using near infrared spectrometry (NIRS).

## *Statistical analyses*

### *Analysis of variance*

ANOVA of the data across environments was conducted using GenStat 14th edition (Payne et al. 2011) and SAS version 9.3 (SAS Institute Inc. 2003) statistical packages.

**Table 2.** Description of sweetpotato genotypes used for the study.

| No | Genotypes | Genotypes ID | Predominant flesh color | | RDMC |
|---|---|---|---|---|---|
| | | | Code[a] | Color | |
| 1 | Ukrewe×Ejumula-10 | G1 | 7 | IO | 31.8 |
| 2 | Ukrewe×Ejumula-13 | G2 | 7 | IO | 32.4 |
| 3 | Ukrewe × PIPI-1 | G3 | 2 | CM | 40.9 |
| 4 | Ukrewe × Naspot-1 | G4 | 2 | CM | 41.0 |
| 5 | Ukrewe × Ogansagan-5 | G5 | 7 | IO | 32.2 |
| 6 | Resisto × Ejumula-7 | G6 | 7 | IO | 34.1 |
| 7 | Resisto × PIPI-1 | G7 | 7 | IO | 31.3 |
| 8 | Resisto × PIPI-2 | G8 | 8 | DO | 29.1 |
| 9 | Resisto × × PIPI-4 | G9 | 2 | CM | 38.4 |
| 10 | Resisto × PIPI-14 | G10 | 2 | CM | 39.8 |
| 11 | Resisto × Temesgen-10 | G11 | 2 | CM | 40.2 |
| 12 | Resisto × Temesgen-12 | G12 | 7 | IO | 31.4 |
| 13 | Resisto × Temesgen-14 | G13 | 7 | IO | 31.7 |
| 14 | Resisto × Temesgen-17 | G14 | 7 | IO | 36.0 |
| 15 | Resisto × Temesgen-23 | G15 | 8 | DO | 28.9 |
| 16 | Resisto × Ogansagen-5 | G16 | 4 | PY | 36.8 |
| 17 | Resisto × Ogansagen-16 | G17 | 8 | DO | 29.7 |
| 18 | Resisto × Ogansagen-20 | G18 | 2 | CM | 38.4 |
| 19 | Resisto × Ogansagen-23 | G19 | 7 | IO | 30.5 |
| 20 | Ejumula × PIPI-10 | G20 | 7 | IO | 31.3 |
| 21 | Ejumula × PIPI-18 | G21 | 8 | DO | 26.2 |
| 22 | Ejumula × PIPI-19 | G22 | 8 | DO | 28.2 |
| 23 | Ejumula × Temesgen-15 | G23 | 2 | CM | 32.5 |
| 24 | Ejumula × Ogansagen-17 | G24 | 7 | IO | 30.2 |
| 25 | Tula | G25 | 6 | PO | 28.5 |

ID = identification, IO = intermediate orange, CM = cream, DO = dark orange, PY = pale yellow, PO = pale orange, RDMC = root dry matter content.
[a]The flesh colour was coded using a scale of 1–9 as described by Huaman (1991) and (1999), where 1 = white, 2 = cream, 3 = dark cream, 4 = pale yellow, 5 = dark yellow, 6 = pale orange, 7 = intermediate orange, 8 = dark orange, 9 = strongly pigmented with anthocyanin.

The following statistical model was used for combined analysis of variance over environments:

$$Y_{ijkl} = \mu + G_i + E_j + GE_{ij} + R_{k(j)} + B_{l(k)} + \varepsilon_{ijkl}$$

where: $Y_{ijkl}$ is observed value of genotype $i$ in block $l$ and replication $k$ of environment $j$, $\mu$ is grand mean, $G_i$ is effect of genotype $i$, $E_j$ is environment or location effect, $GE_{ij}$ is the interaction effect of genotype $i$ with environment $j$, $R_{k(j)}$ is the effect of replication $k$ in environment $j$, $B_{l(k)}$ is the effect of block $l$ in replication $k$, $\epsilon_{ijkl}$ is error (residual) effect of genotype $i$ in block $l$ and replication $k$ of environment $j$.

### *Correlation analysis*

Correlation analyses were performed to describe the pattern of association between the nutritional traits. Correlation coefficients were determined using the Pearson's procedure in the SAS program (SAS Institute Inc. 2003).

## Results

### *Variation in sweetpotato genotypes for nutritional traits*

All the results are presented on dry weight basis. The combined ANOVA indicated that environment, genotype, and genotype×environment interaction effects were highly significant ($p < 0.01$), influencing all the traits studied (Table 3).

The performance of the clones for the eight nutritional traits is presented in Table 4. The mean β-carotene content of the genotypes ranged between 0.0 and 20.01 mg 100 $g^{-1}$. Genotype G8 expressed the highest β-carotene content of 20.01 mg 100 $g^{-1}$, whilst eight genotypes, G3, G4, G9, G10, G11, G16, G18 and G23, had no β-carotene. For protein content, the lowest mean was recorded for genotype G12, with 5.06%. The highest protein content was recorded for genotype G18 at 7.83%. Six genotypes, G1, G5, G8, G14, G18 and G19, had mean protein content, >7%. The lowest and highest mean Fe contents were found in genotypes G4 and G8 at 1.62 and 2.55

**Table 3.** Combined analysis of variance of eight nutritional traits for 25 sweetpotato genotypes evaluated across six environments in Ethiopia during 2014 cropping season

| | | Traits and mean squares | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Source of variation | df | β-carotene | Protein | Iron | Zinc | Starch | Fructose | Glucose | Sucrose |
| Environment (E) | 5 | 23.07*** | 317.20*** | 12.18*** | 6.41*** | 371.08*** | 4.55*** | 22.46*** | 347.80*** |
| Replication (R) | 5 | 0.09ns | 0.3ns | 0.04ns | 0.01ns | 6.46* | 0.18ns | 0.12ns | 1.73ns |
| Block (B) | 9 | 0.46ns | 0.10ns | 0.16** | 0.04ns | 4.67ns | 0.11ns | 0.13ns | 0.99ns |
| Genotype (G) | 24 | 489.45*** | 5.90*** | 0.64** | 0.25** | 271.78*** | 6.08*** | 12.60*** | 108.98*** |
| G × E | 120 | 8.61*** | 4.10*** | 0.19** | 0.12** | 89.27** | 5.40*** | 11.70*** | 36.80*** |
| Error | 136 | 0.81 | 0.30 | 0.05 | 0.03 | 2.52 | 0.14 | 0.14 | 0.71 |

df = degrees of freedom; ns = not significant, G × E = genotype by environment interaction.
*,** and *** = significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ probability level, respectively

mg 100 g$^{-1}$, respectively. About half of the tested genotypes had Fe content > 2.0 mg 100 g$^{-1}$ (Table 4).

The lowest and the highest mean Zn content was 0.71 and 1.42 mg 100 g$^{-1}$ for genotypes G25 and G8, respectively (Table 4). Most genotypes had mean Zn content close to 1.0 mg 100 g$^{-1}$. The highest starch content was recorded for genotypes G16 and G23, with 68.0% and 67.4%, respectively. Conversely, the lowest starch values were recorded for genotypes G8 and G25 at 47.1% and 50.8%, respectively. Ten genotypes had a starch content that was >60.0%. Genotype G15 and G25 had the highest fructose content of 5.23% and 5.1%, respectively. Six genotypes, G8, G12, G13, G15, G17 and G25, had fructose content >4.0%. Nine genotypes had fructose content of <3.0% (Table 4).

The local check sweetpotato variety 'Tula', designated as G25, had the highest glucose content of 7.49%, while genotype G23 had <3.0%. About 60% of the genotypes had a glucose content of >4.0%. Six genotypes, namely G7, G8, G15, G21, G22 and G25, had a sucrose content exceeding 10%, with G8 producing 16.20% sucrose. The lowest sucrose content was recorded for G16 at 2.71%. Only five genotypes had sucrose content <5.0% (Table 4).

Generally, a newly developed genotype, designated G8, had the highest contents of β-carotene (20.01 mg 100 g$^{-1}$), protein (7.08%), iron (2.55 mg 100 g$^{-1}$), zinc (1.42 mg 100 g$^{-1}$), fructose (4.45%), glucose (5.34%) and sucrose (16.20%). Genotypes G15 and G19 also performed relatively well for the above nutritional traits. These genotypes (G8, G15 and G19) also had mean fresh root yield of 23.5,13.7 and 21.3 t ha$^{-1}$, respectively. They had root dry matter content of 26.99%, 25.23% and 33.09%, respectively (Table 4).

### *Relationship among nutritional traits in sweetpotato*

Correlation coefficients describing pair-wise association of the eight nutritional traits of 25 sweetpotato genotypes are presented in Table 5. β-carotene content had significantly high positive correlation with most of the traits except with protein content and starch. It had a non-significant correlation with protein content and negative correlation ($r = -0.43$) with starch content. Protein content had significantly positive correlations with the mineral contents Fe and Zn, with correlation coefficients of $r = 0.80$ and 0.79, respectively. On the other hand, it had high negative correlations with starch and sucrose contents, with $r = -0.16$ and $-0.27$, respectively. This trait had non-significant correlations with β-carotene, fructose and glucose. Fe content had a significantly high positive correlation of $r = 0.83$ with Zn content. Starch content had strong and significantly negative correlations with all the studied nutritional traits. Fructose and glucose showed the highest positive correlation of $r = 0.92$. Fructose, glucose and sucrose had strong positive relationships.

## Discussion

The results indicate the presence of genetic variation among the tested genotypes for the nutritional traits. The results also suggest that most sweetpotato nutritional traits are influenced by G×E interaction effects (Nasayao & Saladaga 1988; Manrique & Hermann 2001; Grüneberg et al. 2005; Osiru et al. 2009).

Eight out of the 25 genotypes had no β-carotene. These genotypes had cream to white flesh. The remaining 17 genotypes had varying levels of β-carotene content, most of which would provide the recommended daily allowance (RDA) of vitamin A. A 100 g OFSP per day in a meal can provide more than the RDA required to prevent vitamin A deficiency (Hagenimana et al. 2001; Christina 2007; Tanumihardjo et al. 2010). Therefore, depending on the color intensity of the OFSP variety used, and taking into account losses of β-carotene during cooking (approximately 20% loss through boiling), a quarter to one cup of boiled and mashed sweetpotato meets the RDA of vitamin A of a young child (Prakash 1994; van Jaarsveld et al. 2006;

**Table 4.** Mean performance of sweetpotato genotypes for eight nutritional traits evaluated across six environments in Ethiopia during 2014 cropping season.

| | | Traits | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotypes ID | Pedigree/Name | Fresh root yield (t ha$^{-1}$) | Root dry matter (%) | β-carotene (mg 100 g$^{-1}$) | Protein (%) | Iron (mg 100 g$^{-1}$) | Zinc (mg 100 g$^{-1}$) | Starch (%) | Fructose (%) | Glucose (%) | Sucrose (%) |
| G1 | Ukrewe × Ejumula-10 | 25.09 | 31.82 | 12.48 | 7.43 | 2.27 | 1.04 | 59.23 | 2.70 | 3.70 | 6.54 |
| G2 | Ukrewe × Ejumula-13 | 21.99 | 32.47 | 6.91 | 6.27 | 1.96 | 0.94 | 58.19 | 3.15 | 3.88 | 8.67 |
| G3 | Ukrewe × PIPI-1 | 21.11 | 37.15 | 0.00 | 5.51 | 1.59 | 0.76 | 64.50 | 3.83 | 4.81 | 3.95 |
| G4 | Ukrewe × NASPOT-1 | 13.94 | 34.84 | 0.00 | 5.52 | 1.62 | 0.86 | 63.19 | 3.36 | 4.23 | 6.54 |
| G5 | Ukrewe × Ogansagan-5 | 19.88 | 33.03 | 13.16 | 7.28 | 2.09 | 1.06 | 62.61 | 2.47 | 3.03 | 5.42 |
| G6 | Resisto × Ejumula-7 | 26.92 | 32.60 | 14.27 | 6.99 | 2.05 | 1.01 | 59.31 | 3.08 | 4.12 | 5.99 |
| G7 | Resisto × PIPI-1 | 22.01 | 29.84 | 13.53 | 6.24 | 1.85 | 0.84 | 57.78 | 3.74 | 4.58 | 12.42 |
| G8 | Resisto × PIPI-2 | 23.45 | 26.99 | 20.01 | 7.08 | 2.55 | 1.42 | 47.07 | 4.45 | 5.34 | 16.20 |
| G9 | Resisto × PIPI-4 | 18.29 | 32.59 | 0.00 | 6.84 | 1.84 | 1.01 | 59.03 | 3.70 | 4.16 | 8.81 |
| G10 | Resisto × PIPI-14 | 12.96 | 29.36 | 0.00 | 6.58 | 1.83 | 1.04 | 62.58 | 3.37 | 4.25 | 5.09 |
| G11 | Resisto × Temesgen-10 | 13.68 | 40.19 | 0.00 | 6.13 | 1.72 | 0.92 | 65.40 | 2.96 | 4.19 | 4.16 |
| G12 | Resisto × Temesgen-12 | 21.69 | 30.84 | 10.89 | 5.06 | 1.79 | 0.74 | 57.89 | 4.23 | 4.80 | 9.80 |
| G13 | Resisto × Temesgen-14 | 20.46 | 30.55 | 9.46 | 6.69 | 2.08 | 1.08 | 55.65 | 4.40 | 5.80 | 5.61 |
| G14 | Resisto × Temesgen-17 | 12.71 | 31.59 | 10.32 | 7.48 | 2.07 | 1.09 | 59.32 | 3.49 | 4.88 | 7.08 |
| G15 | Resisto × Temesgen-23 | 13.70 | 25.23 | 16.59 | 5.48 | 1.90 | 0.97 | 53.16 | 5.23 | 6.42 | 10.07 |
| G16 | Resisto × Ogansagen-5 | 24.19 | 38.23 | 0.00 | 6.44 | 1.81 | 1.00 | 67.95 | 2.04 | 2.62 | 2.71 |
| G17 | Resisto × Ogansagen-16 | 23.10 | 29.45 | 5.26 | 6.44 | 2.16 | 1.14 | 52.14 | 4.67 | 5.79 | 9.87 |
| G18 | Resisto × Ogansagen-20 | 20.67 | 36.23 | 0.00 | 7.83 | 2.10 | 1.06 | 64.32 | 2.79 | 3.19 | 4.37 |
| G19 | Resisto × Ogansagen-23 | 21.30 | 33.09 | 16.30 | 7.81 | 2.20 | 1.07 | 58.66 | 2.97 | 3.71 | 6.55 |
| G20 | Ejumula × PIPI-10 | 25.46 | 30.06 | 13.99 | 6.39 | 2.09 | 1.01 | 60.32 | 2.92 | 3.54 | 8.98 |
| G21 | Ejumula × PIPI-18 | 9.64 | 25.35 | 14.26 | 6.10 | 2.18 | 0.93 | 55.87 | 3.32 | 3.75 | 11.38 |
| G22 | Ejumula × PIPI-19 | 20.95 | 26.75 | 14.26 | 6.46 | 2.12 | 1.05 | 55.15 | 3.75 | 4.65 | 10.60 |
| G23 | Ejumula × Temesgen-15 | 23.80 | 32.91 | 0.00 | 5.73 | 1.64 | 0.87 | 67.37 | 2.58 | 2.74 | 4.67 |
| G24 | Ejumula × Ogansagen-17 | 21.60 | 30.48 | 11.37 | 6.64 | 2.06 | 1.07 | 60.32 | 2.94 | 3.63 | 5.94 |
| G25 | Tula | 7.55 | 24.30 | 9.51 | 5.49 | 1.74 | 0.71 | 50.76 | 5.14 | 7.49 | 13.44 |
| Mean | | 19.45 | 31.44 | 8.47 | 6.48 | 1.97 | 0.99 | 59.11 | 3.49 | 4.37 | 7.79 |
| LSD (0.05) | | 3.24 | 2.32 | 0.73 | 0.47 | 0.17 | 0.14 | 1.28 | 0.30 | 0.30 | 0.68 |
| CV (%) | | 25.64 | 15.4 | 5.50 | 8.90 | 10.97 | 17.27 | 2.69 | 10.78 | 8.59 | 10.81 |
| $R^2$ (%) | | 73.2 | 83.4 | 99.20 | 98.03 | 94.06 | 93.14 | 98.33 | 97.82 | 98.99 | 98.98 |

ID = identification.

**Table 5.** Correlation coefficients describing pair-wise association among seven nutritional traits of sweetpotato genotypes evaluated across six environments in Ethiopia during 2014 cropping season.

| Traits | Protein | Iron | Zinc | Starch | Fructose | Glucose | Sucrose |
|---|---|---|---|---|---|---|---|
| β-carotene | 0.10ns | 0.27*** | 0.14* | −0.43*** | 0.12* | 0.12* | 0.36*** |
| Protein | | 0.80*** | 0.79*** | −0.16** | −0.11ns | −0.10ns | −0.27*** |
| Iron | | | 0.83*** | −0.45*** | 0.10ns | 0.11ns | −0.06ns |
| Zinc | | | | −0.29*** | −0.01ns | 0.01ns | −0.22** |
| Starch | | | | | −0.70*** | −0.72*** | −0.66*** |
| Fructose | | | | | | 0.92*** | 0.41*** |
| Glucose | | | | | | | 0.38*** |

ns = not significant.
*,** and *** = denote significant correlations at 0.05, 0.01 and 0.001 probability levels, respectively,

Fleshman et al. 2011). Faber et al (2013) reported that with the assumption of 75% retention of vitamin A after cooking, 100 g sweetpotato under optimal conditions will provide 178%–185% of the vitamin A requirements for seven to 12 month old infants, 222%–232% for four to eight years old children, and 127%–132% for adult females. Under rural village conditions, a 100 g sweetpotato will provide 207%–260% of the vitamin A requirements for seven to 12 month old infants, 259%–325% for four to eight years old children, and 148%–185% for adult females. Among the tested genotypes, G8 had the highest β-carotene content (20.01 mg 100 $g^{-1}$) of the genotypes included in the study and therefore can be recommended as a good source of pro-vitamin A.

The protein content of the clones ranged between 5.06% and 7.83%. Similar results were reported by Tumwegamire et al. (2011) in 90 sweetpotato accessions evaluated in Uganda with protein content ranging between 5.3% and 8.4%. In the current study, genotypes G18 and G19 had the highest protein content of 7.83% and 7.81%, respectively. About 50% of the studied genotypes had Fe content > 2.0 mg 100 $g^{-1}$. Genotype, G8, had the highest Fe content of 2.55 mg 100 $g^{-1}$ and Zn content of 1.42 mg 100 $g^{-1}$. This genotype also had the highest β-carotene content as described above. Therefore, G8 is the best genotype that can be recommended as a breeding parent for the improvement of sweetpotato for micronutrient contents. However, its starch content was exceptionally low and needs improvement.

Most of the white/cream-fleshed sweetpotatoes had high starch content, the highest being recorded for G16 and G23 with 67.95% and 67.37%, respectively. Conversely, the OFSPs had lower starch content. Accordingly, the lowest starch content was recorded for the OFSP genotype G8 (47.07%) which had the highest β-carotene content. This shows the presence of an inverse relationship between β-carotene and starch content in sweetpotato. Most of the OFSPs had high fructose content. Among these, two genotypes, G15 and G25 had the highest fructose content of 5.23% and 5.14%, respectively. In addition, four genotypes, namely G8, G12, G13 and G17, had a fructose content > 4.0%.

Genotype G25 (Tula), a locally grown check variety, had the highest glucose content of 7.49%. This variety also had the second highest fructose and sucrose content. Sucrose content of the genotypes ranged between 3.95% and 16.20%, which is similar to the range reported by Tumwegamire et al. (2011). The authors reported sucrose content ranging between 2.5% and 15.7% for 90 sweetpotato accessions evaluated in Uganda. In the present study, the genotype G8 expressed the highest sucrose content of 16.20%. Similarly, six OFSP genotypes, namely G7, G8, G15, G21, G22 and G25, had a high sucrose content,>10%.

Generally, the OFSPs had higher levels of nutritional characters than the white/cream-fleshed sweetpotato clones included in the study. A similar result was reported by Aywa et al. (2013) from their study on the nutrient content of colored sweetpotato varieties. They reported that OFSPs contained high levels of Fe, Cu, K, vitamin A and vitamin C, confirming the value of this crop as a rich source of organic and mineral dietary nutrients. Amagloh et al. (2013) compared sweetpotato- and maize-based complementary foods and reported that the former, on average, had significantly higher maltose, sucrose, free glucose and fructose, and total dietary fiber. The authors concluded that sweetpotato-based formulations have significant advantages as complementary foods.

Usually sweetpotato cultivars with high levels of sugars and low starch content tending to reduce the viscosity, increase the solubility and convey desirable sensory characteristics. Hence, it potentially avoids the loss of excessive energy and nutrients (Amagloh et al. 2013). A study by Truong et al. (1995) on texture of sweetpotato puree indicated that OFSPs are more suited for making this product since they have a moist texture after cooking, producing purees that are viscous, but flowable, and can be handled in various processing operations. Therefore, OFSP can be recommended as a source of pro-vitamin A and as a source of other important micronutrients (Woolfe 1992; Courtney et al. 2008; Grüneberg et al. 2009a; Waized et al. 2015).

Correlation analysis showed that β-carotene content had a positive association with most traits studied except protein and starch content. B-carotene content has a strong positive association with the levels of Fe and Zn. The presence of positive correlations between β-carotene content and mineral content has also been reported by other authors, suggesting the possibility of an indirect improvement of mineral content through selection for higher β-carotene content (Grüneberg et al. 2009b; Tumwegamire et al. 2011). However, β-carotene content had a negative correlation with starch content suggesting that OFSPs have less starch than white-fleshed sweetpotatoes, as reported by Truong et al. (1995) and Tumwegamire et al. (2011). Fe content had a high positive correlation of $r = 0.83$ with Zn content, implying the possibility of concurrent improvement of the two quality traits. Starch content had a strong negative correlation with all the other nutritional traits studied. As expected, a high starch content is not a characteristic of OFSPs. Higher starch content was recorded for cream-fleshed sweetpotatoes. According to Woolfe (1992), white- and cream-fleshed sweetpotatoes usually have high starch content with 50%–80% of dry matter, and sugar levels ranging from 5% to 15% of dry matter. The OFSPs have a lower starch content, with approximately 45%–55% of dry matter and a higher sugar content of 10%–20% of dry matter. Tumwegamire et al. (2011) also reported that a number of white-fleshed farmer varieties had higher dry matter, higher starch, and lower sucrose content than the OFSP variety used as a control.

Generally, sweetpotato is a potential source of many of the macro and micronutrients that are required by the human body. In the current study, among the tested genotypes, G8 had the highest nutritional levels except for starch. The genotypes G15 and G19 were also among the promising genotypes for the nutritional traits.

β-carotene content had a positive association with most of the traits studied, suggesting the potential to develop OFSP varieties enriched with important micronutrients that are essential for human health. The tested OFSPs are good sources of minerals such as Fe and Zn, and other nutritional traits such as protein, sucrose, glucose and fructose.

Genotypes G8, G15 and G19 generally performed well for the studied nutritional traits. The three genotypes had reasonable fresh root yield and root dry matter content and therefore can be recommended for large-scale production, food processing or further sweetpotato improvement to alleviate nutrient deficiencies in Ethiopia or similar environments in sub-Saharan Africa.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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