*Full Length Research Paper*

# Total *β*-carotene content of orange sweetpotato cultivated under optimal conditions and at a rural village

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At community level, sweetpotato is often cultivated in marginal soils, with low agricultural inputs and is harvested when needed. Total *β*-carotene content of orange sweetpotato harvested four, five and six months after planting at optimal cultivation conditions and at a rural village was determined. Compared to those produced under optimal conditions, sweetpotato produced under rural village conditions were smaller, had higher *β*-carotene content and required a smaller serving size to provide 100% of the dietary vitamin A requirements. Harvesting at four, five and six months after planting at a rural village showed gradual increases in *β*-carotene content; no change was observed under optimal conditions. Differences in *β*-carotene content due to harvesting time and management level should be considered in food-based interventions addressing vitamin A deficiency.

**Key words:** Provitamin A content, orange sweet potato, cultivation conditions.

## INTRODUCTION

Orange sweetpotato, a biofortified crop naturally rich in *β*-carotene, has a large potential to significantly contribute towards eliminating vitamin A deficiency in developing countries. Both efficacy (Haskell et al., 2004; van Jaarsveld et al., 2005) and effectiveness (Low et al., 2007; Hotz et al., 2012) trials have demonstrated the potential of orange sweetpotato to positively impact dietary vitamin A intake and vitamin A status. In Africa, which has one of the highest prevalence's of vitamin A deficiency (44.4%; WHO, 2009), an estimated 50 million children under the age of six could benefit from replacing the current white-fleshed sweetpotato varieties with new orange-fleshed varieties (Low et al., 2001).

Strategies focusing on local production of orange sweetpotato are used to combat vitamin A deficiency in several Sub-Saharan African countries (Kapinga et al., 2007). In gardening projects in South Africa, orange sweetpotato is promoted in combination with other *β*-carotene-rich vegetables (Faber and Laurie, 2011). South Africa is being regarded as a water-stressed country (Bennie and Hensley, 2001), and a shortage of water for irrigation is amongst the challenges experienced with gardening projects (Faber and Laurie, 2011). In addition, sweetpotato is often cultivated in marginal soils under low agricultural input conditions. Although sweetpotato can give adequate yields under such conditions (Lebot, 2009), it is uncertain whether this will affect the *β*-carotene content. It has been reported that environmental factors, genetic factors and production management strategies can significantly influence the *β*-carotene content of crops (K'osambo et al., 1998; Kopsell and Kopsell, 2006). Drought stress is one of the most important yield-limiting factors, especially in areas where cultivation depends on rain-fed conditions

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(Anselmo et al., 1998). Although sweetpotato is regarded as a moderately drought tolerant crop, it is sensitive to water stress during root initiation and development (Indira and Kabeerathumma, 1988). Orange-fleshed types are generally less drought tolerant (Tumwegamire et al., 2004).

Sweetpotato storage roots are usually ready for harvesting at four months (warm climates) to six months (temperate climates) after planting (Niederwieser, 2004). In many traditional settings sweetpotato is harvested as needed (a practice called piece meal harvesting). When the roots are kept in the soil until needed, the carotenoid and $\beta$-carotene content of the roots may be influenced by sweetpotato variety and the age of the storage roots (K'osambo et al., 1998; Chattopadhyay et al., 2006).

The aim of this study was to determine the $\beta$-carotene content of orange sweetpotato at different time intervals during the harvesting period for sweetpotatoes planted under optimal cultivation conditions at the research institute and at a rural village.

## MATERIALS AND METHODS

### Plant material

Sweetpotato variety Resisto, with dark orange flesh colour, was used in the study. Resisto is rich in $\beta$-carotene, containing 11 987 to 20 525 µg $\beta$-carotene 100 g$^{-1}$ fresh roots over various locations (Laurie et al., 2012a) and the eating quality is acceptable to consumers (Laurie et al., 2013). The vine cuttings for the trial at the research institute were propagated in a field multiplication block at the Agricultural Research Council (ARC)-Roodeplaat Vegetable and Ornamental Plant Institute. A community-based sweetpotato nursery, which obtained its planting material from the ARC, supplied the vine cuttings for the community trial.

Sweetpotato was cultivated with high agricultural input (optimal conditions; according to Niederwieser (2004) at the ARC and with low agricultural input (real-life situation as experienced in food-based intervention projects) in a rural village in the Valley of a Thousand Hills, KwaZulu-Natal Province, South Africa. Representative soil samples were collected from the two sites and soil analysis was conducted at the ARC-Institute for Soil Climate and Water accredited laboratory using Inductively Coupled Plasma-atomic Emission Spectroscopy (ICP-AES) (USEPA Method 6010).

For sweetpotato planted under optimal conditions, pre-plant fertilizer and three topdressings were applied supplying 149, 0 and 115 kg ha$^{-1}$ nitrogen (N), phosphorous (P) and potassium (K), respectively, based on the soil analysis. Soil preparation was done mechanically. Three blocks were established, each consisting of 60 plants. Overhead irrigation was applied when 40% of the plant available water (PAW) in the soil was depleted. A total of 480 mm water was applied to supplement the 150 mm of rainfall which occurred during the growing season. Chemical weed control was applied before planting, and thereafter weeds were controlled by hand hoeing. Insect pest control was done by Deltametrin (60 mL/100 L$^{-1}$) and Chlorpyrifos (60 Ml/200 L$^{-1}$) applications at four and eight weeks after planting. Folicur 250 ew (150 mL/100 L$^{-1}$) was applied to control Alternaria stem-and-leaf blight.

For the sweetpotato planted at the rural village, vine cuttings were established in blocks with the same layout as at the ARC. Soil preparation was done by hand and compost produced by the community was applied to the soil before planting. Water was applied daily by watering with buckets. No chemical weed, pest and disease control was used at the village site.

Sample batches were harvested at four, five and six months after planting at both the research institute and rural village cultivation sites. During each harvesting day a block of 60 plants were uprooted and 25 medium-sized roots sampled randomly. Each batch of 25 storage roots of Resisto sampled per harvesting period in each of the two sites were washed and, from these, a laboratory sample was obtained by randomly selecting eight storage roots (approximately 3 kg) to determine total $\beta$-carotene content. The intact fresh storage roots were transported directly after harvesting to the Nutritional Intervention Research Unit, Medical Research Council for analytical sample preparation.

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

From each batch of eight storage roots, the five storage roots in the best condition were peeled, washed and the two opposite quarters from longitudinally quartered roots were combined, homogenized, aliquots weighed and stored at -20°C until analysis. The $\beta$-carotene content in approximately 2 g aliquots of the fresh homogenised sweetpotato samples was analysed in duplicate by high pressure liquid chromatography (HPLC) as previously described (Low and van Jaarsveld, 2008).

## RESULTS AND DISCUSSION

The soil nutrient status at stipulated optimal conditions and before and after applying compost at community conditions is presented in Table 1. At the stipulated optimal conditions, the soil nutrient status was optimal except for the Ca:Mg ratio which was low. According to the chemical analysis of the compost (mean of three samples) applied at rural village conditions, little nitrogen (N) release could have been expected since the total carbon (C) content was far below 30%. The C:N ratio was low (<18%) indicating that fairly old compost was used. Even after compost was applied, the P status of the soil was fairly low, Ca and Mg relatively high, whereas the soil-pH and Ca:Mg ratio were acceptable.

The average root weight and total $\beta$-carotene content in fresh Resisto storage roots as determined for community-level production and under optimal conditions are given in Table 2. The average root weight was smaller for storage roots produced under rural village conditions compared to storage roots produced under optimal conditions (83 to 124 versus 293 to 318 g, respectively). The overall mean $\beta$-carotene content (18507 µg/100 g$^{-1}$) calculated from the four, five and six month harvesting periods was 30% higher at rural village level than the overall mean $\beta$-carotene content (14511 µg/100 g$^{-1}$) under optimal conditions.

Storage roots produced at the rural village were smaller than those produced at the research institute. To investigate whether the difference in root size could explain the difference in $\beta$-carotene content of the roots between the two production sites, we measured the total $\beta$-carotene content of small (86 ± 17 g; n=5) and medium size (303 ± 51 g; n=5) roots produced at the research institute and harvested 4.2 months after planting. The

**Table 1.** Soil type and nutrient composition of soil samples collected from the trial sites at the ARC (optimal conditions) and the rural village (community conditions).

| Parameter | P-Bray 1 (mg kg$^{-1}$) | K (mg kg$^{-1}$) | Ca (mg kg$^{-1}$) | Mg (mg kg$^{-1}$) | Na (mg kg$^{-1}$) | Ca:Mg ratio | Cation balance | | | pH water | Clay (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Ca | Mg | K | | |
| ARC-Roodeplaat VOPI (prior to fertilization) | 92 | 147 | 1413 | 548 | 62 | 2.5:1 | 57 | 37.0 | 3.0 | 6.90 | 28 |
| Rural village, before compost | 11 | 132 | 1704 | 393 | 9 | 4.3:1 | 70 | 26.9 | 2.8 | 6.23 | 34 |
| Rural village, after compost | 12 | 357 | 1955 | 379 | 25 | 5.2:1 | 70 | 22.5 | 6.6 | 6.60 | 34 |
| **Indicators (Buys, 1988)** | | | | | | | | | | | |
| low values | <15 | <40 | <200 | <50 | <50 | | | | | <5.5 | |
| high values | >60 | >250 | >3000 | >300 | >250 | | | | | >7.3 | |
| optimum value for vegetables | 40-90 | 120-240 | 400-2500[a] | 100-400[a] | na[b] | 4:1 | 60-70 | 25-30 | 6-15 | 5-7 | <35 |

[a]Less critical. [b]Not available.

$\beta$-carotene content for small-sized roots (11 377 ± 149 µg 100 g$^{-1}$) was slightly lower than that of the medium-sized roots (13 399 ± 289 µg 100 g$^{-1}$); and was 31% lower than the $\beta$-carotene content of small roots produced under rural village conditions and harvested after four months. It therefore seems unlikely that the difference in root size resulted in the difference found in $\beta$-carotene content between the two production sites.

Climatic data obtained from the database of the ARC-Institute for Soil Climate and Water showed that the rural village had higher humidity, more moderate temperatures, lower radiation and higher rainfall as compared to the conditions at the research institute. Differences in climatic conditions could therefore have contributed towards the difference in $\beta$-carotene content between optimal and rural village level production. Rodriguez-Amaya (1997) indicated for example that a tropical climate enhances biosynthesis of fruit carotenoids, increasing their concentrations during ripening/maturing. In addition, the scheduling of water application at the rural village was probably not as regular as at the research institute and this could have lead to drought stress at some stages during plant growth. Sub-optimal

water application may lead to a reduction in root size as well as higher $\beta$-carotene content in sweetpotato (Laurie et al., 2012b). Irregular water applications at the rural village could therefore have contributed towards the smaller roots and higher total $\beta$-carotene content in sweetpotato, compared to those produced under optimal conditions.

The $\beta$-carotene content generally increases with crop age. However, there were no apparent differences in the total $\beta$-carotene content between storage roots harvested at the research institute after four, five and six months of planting (Table 2), and it appears that physiological maturity was reached at four months. However, total $\beta$-carotene content increased progressively in the storage roots from four to six months after planting at the rural village (16575 to 20779 µg 100 g$^{-1}$). K'osambo et al. (1998) found for sweetpotato roots of two orange varieties harvested at three, four, five and six months after planting, that the maximum total carotenoid content was attained at 5 months. They also showed that a significant interaction exists between variety and root age which affects carotenoid content. Chattopadhyay et al. (2006)

generally found a significant increase in $\beta$-carotene content from 3 to 3.5 months, and a decrease from 3.5 to 4 months, although there were differences among the varieties. Liu et al. (2009) found that the total carotenoid content of an orange sweetpotato varied, depending on the time of year when it was harvested. Collectively these findings and the results of the present study reiterates the importance of determination of the resultant $\beta$-carotene content for specific varieties at specific management conditions when promoted in food-based approaches.

Assuming 75% retention after cooking, 100 g sweetpotato under optimal conditions will provide 178 to 185% of the vitamin A requirements for seven to 12 month old infants, 222 to 232% for four to eight years old children, and 127 to 132% for adult females; and 100 g sweetpotato under rural village conditions will provide 207 to 260% of the vitamin A requirements for seven to 12 month old infants, 259 to 325% for four to eight years old children, and 148 to 185% for adult females. As compared to roots produced under optimal conditions, roots produced at the community level were smaller, but had higher $\beta$-carotene content and a smaller serving is thus needed to provide

**Table 2.** The total $\beta$-carotene content of fresh sweetpotato storage roots of the variety Resisto cultivated at optimal conditions and at community level during the growth season, vitamin A value, percentage contribution towards vitamin A requirements and serving size needed to provide 100% of the vitamin requirements.

| Months after planting | Root weight [c] (g) | Total $\beta$-Carotene [d] ($\mu$g 100 g$^{-1}$) | Vitamin A value [e] ($\mu$g RAE 100 g$^{-1}$) | %RDA provided by 100 g [f] | | | Amount [j] needed to provide 100% RDA | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 7-12 months [g] (%) | 4-8 years [h] (%) | Adult female [i] (%) | 7-12 months [g] (g) | 4-8 years [h] (g) | Adult female [i] (g) |
| **Optimal conditions [a]** | | | | | | | | | |
| 4 months | 307  (55) | 14 210 | 1 184 | 178 | 222 | 127 | 56 | 45 | 79 |
| 5 months | 293  (54) | 14 841 | 1 236 | 185 | 232 | 132 | 54 | 43 | 76 |
| 6 months | 318  (60) | 14 481 | 1 206 | 181 | 226 | 129 | 55 | 44 | 77 |
| **Rural village [b]** | | | | | | | | | |
| 4 months | 83 (15) | 16 575 | 1 381 | 207 | 259 | 148 | 48 | 39 | 68 |
| 5 months | 128  (48) | 18 168 | 1 514 | 227 | 284 | 162 | 44 | 35 | 62 |
| 6 months | 124  (27) | 20 779 | 1 731 | 260 | 325 | 185 | 39 | 31 | 54 |

[a]Planted at the research institute. [b]Planted at a rural village. [c]Values are given as mean (standard deviation) for five roots used for sample preparation and analysis. [d]Values are given as the mean of duplicate determinations; amount of *trans*-$\beta$-carotene is 98% of total $\beta$-carotene. [e]Vitamin A value in $\mu$g RAE (Retinol Activity Equivalents) was calculated by dividing the total $\beta$-carotene ($\mu$g) content by 12, assuming 12 $\mu$g *trans*-$\beta$-carotene = 1 $\mu$g Retinol = 1 $\mu$g RAE (Trumbo et al., 2001). [f]Based on 70% - 80% retention of $\beta$-carotene in sweetpotato of different sizes from the same harvest batch after cooking (van Jaarsveld et al., 2006), a retention factor of 75% was used to calculate the contribution from 100g orange sweetpotato to vitamin A requirements, which was expressed as a percentage of the Recommended Dietary Allowance (RDA), [g]RDA for a 7-12 month old baby is 500 $\mu$g RAE (Trumbo et al., 2001). [h]RDA for a 4-8 year old child is 400 $\mu$g RAE (Trumbo et al., 2001). [i]RDA for a non-pregnant, non-breastfeeding female 19 years and older is 700 $\mu$g RAE (Trumbo et al., 2001). [j]Raw weight.

an equivalent amount of $\beta$-carotene. This is beneficial particularly for young children as they consume relatively small amounts. A higher $\beta$-carotene content is also important in countries where orange sweetpotato is eaten as a vegetable (and thus consumed in smaller quantities), rather than a staple (and thus consumed in larger quantities). For commercial farming, there is no doubt that root size and yield are critical factors. In the case of local production for home consumption, the root size may not be as important, particularly for crops that are being planted to address a specific deficiency within the diet, such as orange sweetpotato for vitamin A.

The mineral content of edible plant parts are known to be influenced by soil mineral content, the interaction of elements in the soil and application of nutrients (Moraghan and Mascagni, 1991). Vitamin C content increases with high light intensity, less frequent irrigation; and decrease with high nitrogen application (Lee and Kader, 2000).

In conclusion, the study highlighted factors which should be taken into account in food-based programs aimed at addressing vitamin A deficiency. Sweet potatoes cultivated under rural village conditions were smaller but had higher $\beta$-carotene than those planted under optimal conditions. Total $\beta$-carotene content of sweetpotato increased progressively from four to six months after planting at community level, but not under optimal conditions.

## ACKNOWLEDGEMENTS

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