Scientia Horticulturae 142 (2012) 180–184

Contents lists available at SciVerse ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

β-Carotene yield and productivity of orange-fleshed sweet potato (*Ipomoea batatas* L. Lam.) as influenced by irrigation and fertilizer application treatments

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ARTICLE INFO

Article history:
Received 9 December 2011
Received in revised form 3 May 2012
Accepted 22 May 2012

Keywords:
Drought stress
Fertilizer regimes
Retinol activity equivalents
Sweet potato
Water regimes
Water productivity

ABSTRACT

β-Carotene rich orange-fleshed sweet potatoes are increasingly used in community-based interventions aimed at addressing vitamin A deficiency, but are often cultivated in marginal soils and with sub-optimal agricultural inputs. The aim of the study was to determine (i) β-carotene content, β-carotene yield and water productivity at increments of water application, and, (ii) β-carotene content and β-carotene yield at increments of chemical fertilizer application for orange-fleshed sweet potato in separate field trials. β-Carotene content at the low irrigation treatment was between 15 and 34% higher than at optimal irrigation treatment. Increased water application brought about a two-fold increase in β-carotene yield per unit area. The best combination of β-carotene yield and water productivity (g β-carotene ha^{-1} mm^{-1} water applied) was achieved at the intermediate (60%) irrigation treatment. Calculations showed that 1 ha of orange-fleshed sweet potato produced at the intermediate water application at yield level of 24.6–28.4 t ha^{-1}, can potentially provide 452–730 households (of six persons) with an adequate amount of vitamin A over a period of 180 days. β-Carotene content was 14% higher for both intermediate (50%) and high (100%) fertilizer treatments, compared to the 0% fertilizer treatment. β-Carotene yield increased two-fold at the intermediate and four-fold at the high fertilization treatment. This paper provides novel information on the effect of irrigation on β-carotene yield, as well as β-carotene water productivity in orange-fleshed sweet potato. Follow-up research on a range of varieties is suggested toward obtaining recommendations for broad application in vitamin A crop-based interventions to optimize the β-carotene yield in orange-fleshed sweet potato.

1. Introduction

Orange-fleshed sweet potato is a rich, natural source of β-carotene. Consumption of orange-fleshed sweet potato has been shown to improve vitamin A status in children (van Jaarsveld et al., 2005). Vitamin A deficiency is a public health problem in the developing world. Globally 33.3% or 190 million children younger than five years are vitamin A deficient (WHO, 2009). Vitamin A deficiency impairs the immune system and the affected children have a lower resistance against common childhood infections, such as respiratory and diarrhoeal diseases, measles and malaria (Rice et al., 2004). In 2004, 6% (0.6 million) of under-five year old deaths were attributed to vitamin A deficiency (Black et al., 2008).

Estimates showed that in Africa, which has one of the highest prevalences of vitamin A deficiency (44.4%) (WHO, 2009), 50 million children under the age of six could benefit from replacing the current white-fleshed sweet potato varieties with new orange-fleshed varieties (Low et al., 2007). Orange-fleshed sweet potato is already being promoted to combat vitamin A deficiency in several sub-Saharan African countries (Kapinga et al., 2007), including South Africa (Faber et al., 2002; Laurie and Faber, 2008) through community-based interventions.

At the community level, sweet potato is often cultivated in marginal soils under low agricultural input conditions, and with limited water available for irrigation. Drought stress is one of the most important yield limiting factors in sweet potato production under rain-fed conditions (Anselmo et al., 1998; van Heerden and Laurie, 2008). Orange-fleshed sweet potato varieties are generally less drought tolerant than the white-fleshed varieties (Tumwegamire et al., 2004). There is lack of information on the

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0304-4238/$ – see front matter © 2012 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.scienta.2012.05.017

influence of water application level on the β-carotene content of orange-fleshed sweet potato. Concerning soil fertilization, George et al. (2002) showed that increasing potassium application levels by increments of 150 kg ha^{-1} from 0 to 600, resulted into increased carotene content for treatments up to the 300 kg ha^{-1}, although the extent of the increase was variety dependent. Abd El-Baky et al. (2010) found increases in carotene content with potassium application, as well as with zinc application.

The present study determined (i) the β-carotene content, β-carotene yield and water productivity at increments of water application, and, (ii) β-carotene content and β-carotene yield at increments of chemical fertilizer application for orange-fleshed sweet potato.

2. Materials and methods

2.1. Plant material

The orange-fleshed sweet potato varieties Resisto and W-119 (USA releases) were used in the study based on results obtained from multi-location varietal trials in South Africa (Laurie et al., 2002, 2009). Particularly Resisto, recommended for household production and is a rich source of β-carotene [13,200–19,400 μg 100 g^{-1} β-carotene in medium-sized fresh roots (van Jaarsveld et al., 2006)] with a pleasant taste. Vine cuttings of virus-indexed origin were used in three field trials.

2.2. Field trials

2.2.1. Irrigation treatments

Trials over two seasons (2006/7 and 2007/8 growing seasons) were conducted in rain out shelters at Roodeplaat, Pretoria area (25.604°S, 28.345°E; 1189 m altitude). The trials had a split-plot design with three replicates, and contained varieties Resisto (both seasons) and W-119 (second season). Three irrigation treatments, namely 100% (optimal), 60% (intermediate) and 30% (low) were imposed 7 days after planting as described by van Heerden and Laurie (2008). Amounts of irrigation applied are provided in Table 1.

Individual plots consisted of three 1.8 m long ridges, 0.8 m apart and a 0.3 m within-row planting distance (18 plants per plot) with double border rows. Plastic canvas was placed between the different irrigation treatments to prevent water movement between treatments.

The soil type was sandy-loam (15% clay in upper 600 mm) and fertilizer was applied based on a soil analysis. During season one, pre-plant fertilizer consisted of 500 kg ha^{-1} chemical fertilizer mix N:P:K 2:3:4 (6.7% N, 10% P, 13.3% K) and topdressings of 125 kg ha^{-1} limestone ammonium nitrate (28% N) applied at 14 and 21 days after planting, and 125 kg ha^{-1} potassium nitrate (13% N, 38% K) at 42 and 48 days after planting. The total fertilizer application for season one was 137, 50 and 160 kg ha^{-1} N, P and K, respectively. During season two, 500 kg ha^{-1} chemical fertilizer mix N:P:K 1:0:1 (18.5% N, 0% P, 18.5% K) was applied at planting, followed by 150 kg ha^{-1} ammonium sulphate (21% N) at 15 and 30 days after planting, and 200 kg ha^{-1} potassium sulphate (40% K) at 21 and 42 days after planting. The total fertilizer application for season two was 156, 50 and 252 kg ha^{-1} N, P and K, respectively. At five months after planting, the sweet potatoes were harvested and data recorded for marketable (good quality roots between 100 and 1200 g) and total storage root weights. Medium-sized storage roots of Resisto (two seasons) and W-119 (one season) were sampled randomly over the replicates of each treatment for determination of β-carotene content.

2.2.2. Fertilizer treatments

The trial was conducted during 2008 at a rural production site with nutrient-poor sandy soil in a farmer's field in the Hazyview area, Mpumalanga Province (25.049°S, 31.144°E; 484 m altitude). This is a subtropical area and production occurred during the cool weather season. The trial layout was a completely randomized block design with three replicates of Resisto. Individual plots comprised three 3.9 m long rows with spacing of 1.3 m between rows and a 0.3 m within-row planting distance (39 plants per plot, 15.2 m^2).

The soil nutrient status before planting was 1 mg kg^{-1} P, 27 mg kg^{-1} K, 229 mg kg^{-1} Ca and 49 mg kg^{-1} Mg with 6% clay content. Chemical fertilizers were applied at 0%, 50% (intermediate) and 100% (high) of the recommended fertilization based on the soil analysis. The aimed application at 50% was 75, 15 and 95 kg ha^{-1} N, P and K, respectively, and for the 100% treatment 150, 30 and 190 kg ha^{-1} N, P and K, respectively. The fertilizers were applied to the soil shortly before planting at 250 kg ha^{-1} potassium nitrate (13% N, 38% K) and 150 kg ha^{-1} superphosphate (10.5% P) at the 50%, and double these amounts at the 100% treatment. Two equal top dressings of 150 kg ha^{-1} and 300 kg ha^{-1} limestone ammonium nitrate (28% N), respectively, at the 50% and 100% fertilizer treatments, were applied at 28 and 56 days after planting.

Some supplementary irrigation was done, though the trial was mostly dependant on rain (136.5 mm precipitation recorded). The sweet potatoes were harvested after a six month growth period (optimal for cool season growing period). The total storage root yield was determined and storage roots of Resisto were sampled randomly over the replicates of each treatment for analysis of β-carotene content.

2.2.3. Determination of total *β*-carotene content

For each treatment sample, five intact fresh storage roots were peeled, washed and the two opposite longitudinally sectioned quarters were combined, homogenized, aliquots weighed and stored at −20 °C until analysis. The β-carotene content in approximately 2 g aliquots of the fresh homogenized sweet potato samples was analyzed in duplicate by high-performance liquid chromatography (HPLC) as previously described by Rautenbach et al. (2010) and van Jaarsveld et al. (2006).

2.2.4. Data processing and analysis

Mean total β-carotene content of the duplicate samples was calculated. An analysis of variance was performed to determine the variance in the root yield data using the statistical program GenStat® 10th edition (Payne et al., 2007). The Fisher's protected least significant difference (LSD) test was used to test the differences between means of total root yield. The water productivity (WP_{IRF}) (Lenka and Singh, 2011) for root yield based on irrigation in field conditions was calculated as kg of root yield per ha per mm of water. The vitamin A value was expressed in μg RAEs (retinol activity equivalents) based on Trumbo et al. (2001) (12 μg *trans*-β-carotene = 1 μg retinol = 1 μg RAE). The β-carotene yield was calculated as kg β-carotene produced per unit area (ha). The water productivity for β-carotene production was expressed as g β-carotene produced per unit area (ha) per mm water applied. The potential contribution of 1 ha of orange-fleshed sweet potato to vitamin A requirements for a households of six (one adult male, 900 μg RAE/day; one adult female, 700 μg RAE/day; two 1–3 year old children, two times 300 μg RAE/day; two 4–8 year old children, two times 400 μg RAE/day) was calculated assuming a 30% loss of β-carotene during cooking (van Jaarsveld et al., 2006) and based on the recommended dietary allowance (RDA) (Trumbo et al., 2001).