Vol. 17(3), pp. 479-486, March, 2021
DOI: 10.5897/AJAR2020.14927
Article Number: E310E1266343
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Variation in beta carotene and yield in sweetpotato (*Ipomoea batatas* (L.) Lam.) associated with ambient temperature and genotype

Brian SINGOGO[1], Mebelo MATAA[2*], Kalaluka MUNYINDA[2], Davies LUNGU[2] and Emily MUELLER[3]

[1]Palabana Dairy Training Institute, P. O. Box 50199, Lusaka, Zambia.
[2]Department of Plant Sciences, School of Agricultural Sciences, University of Zambia, P. O. Box 32379, Lusaka, Zambia.
[3]Formally with International Potato Center, Integrating Orange-fleshed Sweetpotato Project Zambia, Msekera Research Station, Chipata, Zambia.

Received 23 April, 2020; Accepted 15 December, 2020

This study was conducted to determine the relationship between ambient temperature during growing season on tuber β-carotene content and yield of four orange-fleshed sweetpotato varieties; Orange Chingovwa, Olympia, Kokota and Zambezi. A split plot experiment design with the environment (main plot) and variety (subplots). The environments were: High-temperature site (HTS) (average temperature of 38.5°C) and moderate temperature site 1 (MTS 1) and moderate temperature site 2 (MTS 2) (average temperature 32.2 and 31.2°C, respectively). Results suggested that assimilate partitioning between below ground components (tubers) and above ground components (leaves and vines) were inversely related and influenced by ambient temperature during development. Low temperatures favoured tuber formation. The HTS had lower yield (0.97 ton ha^{-1}) compared to the two moderate temperature sites that had tuber yield between 11.96 and 9.41 ton ha^{-1}. The HTS at 7.23 mg/100 g had lower β-carotene contents compared to the MTS sites (≈15.5 mg/100 g). Zambezi and Orange Chingovwa had higher β-carotene content at 21.21 mg/100 g and (18.85 mg/100 g). Kokota had the least β-carotene (3.28 mg/100 g Vine Yield (VY) was significantly different for sites. HTS had the highest VY and leaf area (23.6 t/ha) while the two MTS had low VY of 8.7 and 12.9 t/ha.

Key words: Partitioning, tuber, leaf area, vine, yield.

INTRODUCTION

Sweetpotato (*Ipomea batatas* (L). Lam) is an important crop in the subtropical and tropical regions of the world and is ranked as the world's seventh most important food crop after wheat, rice, maize, potato, barley and cassava (FAOSTAT, 2020; Kokkinos et al., 2006). It ranks as the third most important tuber crop (Kokkinos et al., 2006). When contrasted with other major staple food crops, sweetpotato has a diverse range of positive attributes: High yield, nutritional value (e.g., vitamins, nutraceuticals, glycaemic index, and dietary fiber), production High

*Corresponding author. E-mail: mebelomataa@yahoo.com.

yield, nutritional value (e.g., vitamins, nutraceuticals, glycaemic index, and dietary fiber), production geography, length of production cycle, and resistance to production stresses (high temperature, water deficit, insect and disease pressure, low soil fertility) (Kays, 2005).

In Zambia, sweetpotato is the second most important root and tuber crop after cassava (*Manihot esculenta*) and has the potential to contribute significantly to food security as an important source of energy and vitamin A (Chiona et al., 2007; Tembo et al., 2017). In Zambia, sweetpotato are consumed as a snack or dessert but expanded production may see more processing and increased revenues to growers. Previously local landraces were the mainstay of production but this has changed with new improved varieties including orange-fleshed ones coming out of the root and tuber research activities. Orange fleshed varieties are high in beta carotene- a pro-vitamin that is converted to vitamin A in the human body. Vitamin A deficiency characterized by blindness or poor eye function is widespread especially among the low income brackets of the population (Hampwaye et al., 2016). High beta carotene crops such as orange-fleshed sweetpotatoes are a sustainable low-cost method of preventing vitamin A deficiency in humans. Carotenoids and anthocyanins are photosynthetic accessory pigments, critical for among other reasons, the prevention of photodynamic effect (lysis or breakdown of chlorophyll in the presence of light and oxygen) in addition to extending the light harvesting range (Larcher, 1995) and for widening the photosynthetically active radiation range between 400 and 700 nm (Folta and Carvalho, 2015).

The adaptation of sweetpotato to marginal environments and its contribution to household food security and flexibility in mixed farming systems makes it an important component of strategies to help the rural poor improve their livelihoods, largely as a source of income and energy (Far, 2007; FoDis, 2009; Stanthers et al., 2005). This crop does not only have a better yield and harvest index compared to most cereal crops, but also has high nutritional value. In addition to the tubers, the leaves are used as a vegetable as well as livestock feed (FoDis Information Series, 2009). There has been an increase production of sweetpotato in Zambia and it is forecast to double from 118,330 metric tons in 2015 to 231, 882 metric tons in 2016 (FAO, 2013). However, total world sweetpotato production has been in decline from 150 Mt in 1998 to about 91 Mt in 2018 (FAOSTAT, 2020). The decline is partly due to bulky propagation materials and relatively high production costs when compared to seed propagated crops (Kays, 2005).

In Zambia, a number of improved varieties and heirlooms are grown in different parts of the country but little is known about their nutritional characteristics such as the levels of bioactive compounds like beta carotene when grown in different environments (Mataa et al., 2018). In the current study, beta carotene and yield were the traits of primary interest. The environment is generally considered as the physical and biological factors along with their chemical interactions that ultimately affect the performance or survival of an organism (Anon, 2013; Allard and Bradshaw, 1964). It also refers to the surrounding of a physical system that may interact with the system by exchanging mass, energy, or other properties. There is general agreement that interactions between genotype and environment have an important bearing on plant development and productivity especially of better varieties (Sokal and Rolfe, 1981; Mataa and Sichilima, 2019).

Sweetpotatoes are grown throughout Zambia but there are no detailed studies on optimum environmental conditions or recommended areas for production in Zambia. This study, therefore, sought to determine the relationship of ambient temperature during plant development on beta carotene accumulation and yield among newly released orange-fleshed sweetpotato cultivars. Findings from this study will contribute to understanding the expression of β-carotene accumulation and root yield under different environmental conditions. Ultimately this information can assist in developing varieties that are more stable and illustrate environments best suited for particular sweetpotato varieties.

MATERIALS AND METHODS

Experimental sites

Zambia has varied climatic and soil characteristics and is divided into three agro- ecological regions based on rainfall and temperature. This work was conducted in Agro ecological regions I and II. The Agro-ecological zone I climate is characterised by mean minimum temperatures of 20 to 25°C and maximum of 38°C; annual rainfall not exceeding 800 mm. Agro ecological zone II is characterised by annual rainfall between 800 and 1000 mm, with mean minimum of 10°C and maximum of 32°C (Bunyolo et al., 1995). .

The study was conducted in three districts of the Eastern Zambia during the 2013/2014 growing season. The sites were selected on the basis of their unique and pronounced differences in temperature and rainfall. Three sites were used- one in region I (Mambwe) and two sites in Agro- ecological region II- namely Lundazi and Chipata. In Lundazi district, the study was conducted in the Central camp (S 12° 16.788’ E 033° 11.611’) with a high elevation of 1340 m above sea level- thus slightly cool zone, while for Chipata site, Kalichero Agricultural Camp (S 13° 29.648’ E 032° 26.352’) with an elevation of 960 m above sea level typically representing a moderately warm temperature site was used. Mambwe site (S 13° 13.306’ E 031° 55.811’) with an elevation of 501 m above sea level was characterised by high ambient temperatures. The soil and other environmental characteristics of the study sites are presented in Table 1. Mambwe was the hot-temperature site with low rainfall, while Kalichero and Lundazi were moderate rainfall and temperature sites. Lundazi being at a higher elevation had a slightly cooler temperature regime.

Experimental design and layout

A split plot experiment design with four replications was used, with the environment being the main plot and varieties as subplots

Table 1. Summary of soil analysis results for the three test sites where the sweetpotato (*Ipomea batatas*) study was conducted.

Trial site	Annual mean temperature (°C)		pH	N (g kg^{-1})	P (mg kg^{-1})	K (cmol/kg)	CEC (cmol/kg)	Soil texture (USDA)	Elevation (masl)	Rainfall (mm/annum)
	Soil	Air								
High temp site (HTS) (Masumba)	32.4	38.5	6.29	0.11	5.08	1.7	13.5	Loamy sand	501	341
Medium temp site (MTS 1) (Lundazi)	25.5	32.2	6.4	0.07	25.33	0.54	4.5	Sandy loam	1340	647
Medium temp site (MTS 2) (Kalichero)	25.8	31.2	5.92	0.11	31.24	1.17	9.75	Loamy sand	960	520

Table 2. Key characteristics of the sweetpotato (*Ipomea batatas*) varieties used in the study.

Variety	Pedigree	Year of release	Beta carotene content	Maturity classification	Recommended production environment
Olympia	V15 x OP (OP progeny from a polycross population)	2014	4.92 mg/100 g fresh weight basis.	5 months	Widely adapted
Orange Chingovwa	LUS 114 x OP	2014	11.03 mg/100 g fresh weight basis	5 months	Widely adapted
Kokota	LUS 140 x OP	2014	4.92 mg/100 g fresh weight basis	5 months	Widely adapted
Zambezi	TIS2537 x OP	1993	10.9 mg/100 g fresh weight basis	5 months	Widely adapted, except in drought prone areas

Source: Kapinga et al. (2010).

(Sokal and Rolfe, 1981). Plots each measuring 30 m^2 with two guard rows were planted to each of the four varieties. Planting was on ridges and each ridge was 6 m long with a total of 20 planting stations at an intra-spacing of 30 cm. Each variety was replicated four times at each site and each site consisted of 16 plots of 5 m × 6 m rows marked as experimental units. The standard height for the ridges was about 45 cm across all the sites.

Plant materials

Four orange-fleshed sweetpotato varieties; Zambezi, Olympia, Kokota, and Orange Chingovwa used in the study were obtained from The Zambia Agriculture Research Institute (ZARI) Roots and Tuber crops Improvements at Msekera station in Chipata district of Zambia. The general varietal characteristics are given in Table 2. All planting materials were raised in insect- proof- screen houses to minimize disease and pest contamination. At planting 100 kg ha^{-1} of a 10- 20- 10 N: P: K analysis fertilizer was applied to the crop in order to meet the minimum nutritional requirements in accordance with Valenzuela et al. (1994) were 22.5- 50 kg ha^{-1} of N, 50- 270 kg ha^{-1} P_2O_5 and 50- 75 kg K_2O kg ha^{-1}. The crop was planted in the rainy season and therefore, no supplemental irrigation was done.

Soil temperature was determined periodically during the growing season using a copper-plated soil thermometers mounted in the ground at each site at a depth of 20 cm. The maximum and minimum daily ambient temperatures were also measured using the max and min thermometers. Rainfall was measured by using a manual rain gauge system.

Data collection

Data was collected on, vegetative parameters; vine weight (t/ha) and leaf area (cm^2) and β-carotene content, root yield. Briefly, at maturity (150 days after planting), the foliage weight per net plot and total root yield were recorded after grading them into different sizes based on their diameters. Leaf area (LA) was determined to estimate light capture and photosynthetic efficiency. This was done manually where leaf area = 0.56 x P x 6.20; where P = length x breadth of sweetpotato leaves, 0.56 and 6.20 are constants which account for the irregularity of sweetpotato leaves (Asiegbu, 1991; Stanley, 2010).

Beta carotene determination

The β-carotene content was determined using high-performance liquid chromatography (HPLC) analysis as described by Rodriguez-Amaya and Kimura (2004). Briefly, four replicate samples 1000 g root portion were selected from each plot and put in A3 brown paper bags. The samples were washed with deionized water and quickly wrapped in aluminium foils and transported under

Table 3. Summary of analysis of variance for some parameters measured on sweetpotato (*Ipomoea batatas*) varieties across the three sites.

Sources of variation	Root yield (t/ha)	β - carotene (mg/100 g)	Leaf area (cm^2)	Vine weight (ton ha^{-1})
Site	**	**	**	**
Variety	**	**	**	ns
Site x Variety	*	**	**	ns

^{Ns}, Not significant at 5% probability, **highly significant at P<0.001.

cool conditions to the laboratory. Samples were washed, peeled, and cut longitudinally from end to end into four quarters. In the laboratory, opposite parts of the cut roots were then combined and chopped into small cubes which were packed into polythene bags and stored frozen at -20°C.

Data analysis

Data were analyzed using GenStat 16 Software (VSN International 2015). Data were subjected to analysis of variance and where significant treatment effects (p ≤ 0.05) were discerned, means were separated using the least significant difference (LSD).

RESULTS

Climatic parameters

Mean soil and air temperatures were 32.4 and 38.5°C for Mambwe (high temperature site- HTS); 25.5 and 32.2°C for Lundazi (moderate temperature site MTS 1) and 25.8 and 31.2°C for Kalichero (moderate temperature site- MTS 2) respectively. Mean annual rainfall for the season was 341, 647 and 520 mm for the HTS, MTS 1 and MTS 2 respectively. Overall, location (site) had a highly significant effect on root yield, root beta carotene, leaf area and vine weight whereas genotype affected root yield, beta carotene content and leaf area but not vine weight (Table 3). Significant site by variety interactions were observed for root yield, beta carotene and leaf area but not with vine weight.

Beta carotene content

Beta carotene content was highly significantly different (P < 0.001) across sites and among genotypes (Table 4). The high-temperature site showed lower contents than the two moderate temperature sites. There were no differences between the two moderate warm temperature sites 1(Lundazi) and 2 (Kalichero). High-temperature site (Masumba) recorded 7.23 mg/100 g while moderate temperature sites 1 and 2 had 15.55 and 15.46 mg/100 g beta carotene content, respectively. Zambezi had the highest (21.21 g/100 g) β-carotene contents followed by Orange Chingovwa (18.85 g/100 g) and Olympia (7.65 mg/100 g). Kokota variety was lowest (3.28 g/100 g) in the highest β-carotene contents (Table 5). The interaction between environments and genotypes was significant (P < 0.001). Zambezi was the best performer at both Masumba the high-temperature site (HTS) and at Kalichero moderate temperature site (MTS-2), whereas Orange Chingovwa was the best performer at Lundazi moderate temperature site (MTS 1).

Yield

Yield of sweetpotato tubers varied among genotypes and environments (P <0 .001). The high- temperature site showed lower root yields (0.97 t/ha) than the two moderate temperature sites. The two moderate sites had similar root yield values of 11.96 ton ha^{-1} for Lundazi and 9.41 ton ha^{-1} for Kalichero sites. Zambezi had the lowest root yield (3.61 ton ha^{-1}) across all sites followed by Orange Chingovwa (6.40 t/ha) and Kokota (7.62 ton ha^{-1}). Olympia was the best performer in root yield and gave the highest yield (12.17 t/ha) across all sites (Table 5). Orange Chingovwa and Zambezi showed values lower than the overall mean obtained across sites. In high-temperature environment Zambezi had the lowest (0.14 ton ha^{-1}) followed by Orange Chingovwa (0.21 ton ha^{-1}) and Kokota (0.26 ton ha^{-1}). The moderate temperature sites 1 and 2 on the other hand recorded similar higher values across all cultivars with yield differences obtaining within cultivars. The analyses of yield across sites and variety and their interactions showed significant differences (Table 5).

Vine weight

The study revealed significant differences in mass of vines (P < 0.001) across environments for. The high-temperature site showed significantly highest vine weight (23.64 ton ha^{-1}) than the two moderate temperature sites. The two moderate temperature sites 1 and 2 had vine weights of 12.90 and 8.74 ton ha^{-1}, respectively. There was no significant difference observed in vine weights among varieties within the sites (Table 6).

Leaf area analysis

Across site analysis (Table 4) indicated highly significant differences (p < 0.001) in leaf area among sites, varieties, and sites x variety interactions. High-temperature site had

Table 4. Beta carotene content of the four sweetpotato (*Ipomea batatas*) varieties grown across the three different temperature regime sites in Eastern province of Zambia in the 2013- 2014 season.

Variety	Beta carotene content (mg/100g)			
	High temperature site		Moderate temperature sites	
	Mambwe	Lundazi	Kalichero	Overall mean
Kokota	0.41 (3.26)	3.81(14.16)	5.61(20.46)	3.28
O. Chingovwa	10.65 (84.8)	26.9 (100)	19 (69.32)	18.85
Olympia	5.32 (42.35)	7.81 (29.03)	9.82 (35.83)	7.65
Zambezi	12.56 (100)	23.67(87.99)	27.41 (100)	21.21
Mean	**7.23**	**15.55**	**15.46**	**12.75**

[z] Overall means for all varieties across sites. [y] Figure in parenthesis is yield expressed as a percentage of the highest cultivar beta carotene content within the column (across sites).

Table 5. Yield of the four sweetpotato (*Ipomea batatas*) varieties grown across the three different temperature regime sites in Eastern province of Zambia in the 2013- 2014 season.

Variety	Yield of tubers (ton ha^{-1})			
	High temperature site		Moderate temperature sites	
	Mambwe	Lundazi	Kalichero	Overall mean
Kokota	0.21 (6.40)	13.08 (75)	9.56(60.5)	7.62
O. Chingovwa	0.26 (7.92)	9.74 (55.8)	9.19(58.2)	6.40
Olympia	3.28 (100)	17.44(100)	15.79(100)	12.17
Zambezi	0.14(4.26)	7.58(43.4)	3.11(19.69)	3.61
[z] Mean	0.97	11.96	9.41	7.45

[z]Overall means for all varieties across sites. [y] Figure in parenthesis is yield expressed as a percentage of the highest yielding cultivar within the column (across sites).

Table 6. Mass of vines of the four sweetpotato (*Ipomea batatas*) varieties grown across the three different temperature regime sites in Eastern province of Zambia in the 2013- 2014 season.

Variety	Mass of tubers (ton ha^{-1})			
	High temperature site		Moderate temperature sites	
	Mambwe	Lundazi	Kalichero	Overall mean
Kokota	25.878(100)	10.238(66.7)	10.42(100)	15.514
O. Chingovwa	22.508(86.9)	12.333(80.3)	8.738(83.9)	14.526
Olympia	22.792(88.0)	13.688(89.1)	8.725(83.7)	15.067
Zambezi	23.392(90.3)	15.36(100)	7.067(67.8)	15.27
[z] Mean	**23.641**	**12.905**	**8.739**	

[z]Overall means for all varieties across sites. [y] Figure in parenthesis is mass of vines expressed as a percentage of the highest yielding cultivar within the column (across sites).

significantly higher leaf area than the two moderate temperature sites. No differences in leaf area were observed between the two moderate sites. There were no statistical differences observed in leaf areas among varieties within sites. However, performance varied among sites with the highest leaf areas recorded in the high-temperature site in all genotypes used in the study (Table 7). Kokota indicated the highest leaf area (413.4 cm^2), which was followed by Zambezi (300.5 cm^2), Orange Chingovwa (287.1 cm^2), and Olympia (249.8 cm^2).

DISCUSSION

The study showed that beta carotene content in sweetpotato tubers was influenced by both genotype and environment. Environmental effects contributed more to the variability in beta carotene contents compared to the genotype. The highest beta carotene was observed at the

Table 7. Leaf area of the four sweetpotato (*Ipomea batatas*) varieties grown across the three different temperature regime sites in Eastern province of Zambia in the 2013- 2014 season.

Variety	Leaf area (cm^2)			
	High temperature site		Moderate temperature sites	
	Mambwe	Lundazi	Kalichero	Overall mean
Kokota	560.1(100)	356.2(100)	323.9(100)	413.4
O. Chingovwa	421.8(75.3)	159(44.6)	280.5(86.6)	287.1
Olympia	315.1(56.3)	242.5(68.1)	191.9(59.2)	249.8
Zambezi	347.2(61.9)	293.9(82.5)	260.5(80.4)	300.5
[z] Mean	**411.1**	**262.9**	**264.2**	**312.7**

[z] Overall means for all varieties across sites. [y] Figure in parenthesis is mass of vines expressed as a percentage of the highest yielding cultivar within the column (across sites).

two moderate temperature sites (Lundazi and Kalichero) while the high temperature site (Masumba) produced the lowest content. Masumba site was located at low altitude characterized by very hot ambient conditions and low rainfall. Lundazi was at high altitude and characterized by moderate ambient temperatures and rainfall which appeared to be optimum for sweetpotato production. Kalichero is at medium altitude and is characterised by moderately warm temperatures and adequate rainfall. The variations within genotypes would be a result of the genetic make-up of the cultivars in the synthesis of carotenoids (Rodriguez-Amaya and Kimura, 2004; Kathabwalika et al., 2016). The results obtained in this study are also similar to those reported by Serenje and Mwala (2010) and Mbwaga et al. (2007). Lester (2006) suggested that lower leaf temperatures are favorable for β-carotene synthesis and that there is a gradual decline in beta carotene synthesis as temperatures increase. Carotenes are synthesised in the Chromoplasts. The primary role of carotenoids is thought to be prevention of photodynamic effect (lysis or breakdown of chlorophyll in the presence of light and oxygen) in addition to extending the light harvesting range (Larcher, 1995). Both sub-optimal and supra optimal temperature conditions coupled with moisture deficit affect the integrity of the thylakoid membrane, and thus affect the stability of the carotenoid compound (Maevskaya et al., 2004; Rokka et al., 2000; Mark and Dean, 2005).

In this study although no differences were discerned among the two moderate temperature sites, there were clear differences between the high temperature and low temperature sites. Rainfall was significantly lower in the high temperature sites. All these conditions contributed to differences in yield and between carotene contents. High temperatures may have caused damage to the photosynthetic apparatus and the thylakoid membrane and the collapse of full function of cells thereby reducing the electron transfer capacity of the plant and hence reduced β-carotene accumulation.

The results from this study on yield of tubers showed that it is significantly affected by the environment (ambient temperature) and genotype. Variations in total root yields obtained in this study are attributable to the variations in the environmental conditions under which each trial was conducted. Yield of different varieties varied across sites. High ambient temperature reduced yield and beta carotene content. The high yielding varieties were identified as Olympia and Kokota which yielded above the average yield obtained across all the varieties. The mean yields obtained from this study for varieties of Olympia, Kokota are similar to those reported by International Potato Centre, CIP (2011). Ngailo et al. (2013) reported that the environment has a great effect on the yield of sweetpotato genotypes and normally cold and very hot environments reduce tuber yield while moderate or optimal climatic environmental conditions promoted tuber yield. The variations in yield among sites are attributable to variations in environmental climatic conditions largely temperature and rainfall. Osiru et al. (2009) reported the importance of weather and climatic factors as major contributing factors in the variation of sweetpotato yields.

The results indicated that assimilate partitioning between below ground components (tubers) and above ground components (leaves and vines) was inversely related and influenced by ambient conditions during development. High ambient temperatures caused the plants to produce more leaves and vines and less tubers. It can be postulated that under the moderate ambient temperatures, genotypes partitioned most of their photosynthetic products or carbohydrates and stored them in tubers below the ground. Under high ambient conditions the opposite occurred. The increase in tuber yield at the expense of vine growth was also reported by Parwada et al. (2011). Kareem (2013) and Kathabwalika et al. (2013) also reported that sweetpotato tuber yield was highest in cultivars that had recorded low vine lengths than those with high vine length. This entails that the effect of the environment is cardinal in determining cultivars' ability to produce more shoot than storage roots on any varieties of sweetpotatoes. Cultivars with high tuber yields are likely to produce low vine yield as well as a low vine growth rate (Kathabwalika et al., 2013). The reason for this variation yield is unclear but it has been noted in Irish potato (*Solanum tuberosum*) that the stimulus for tuberization is exposure to low ambient temperatures (Vos, 1999). Although these are two different species it appears the sweetpotato varieties tested are also sensitive to high temperatures.

As noted, carotenoids play a vital role in the preventing the photodynamic effect where chlorophyll irreversibly damaged by light (Hipkins, 1984). Typically beta carotene occurs in the leaves as accessory pigments to the photosynthetic apparatus. Although we did not determine the content in the leaves it could have been expected that the amount of beta carotene content under high temperatures where the genotypes produced leafier or vegetative tissues, the amount would be high, however, this did not happen. Instead, a decline of yield was observed.

Conclusion

The study revealed significant variations on beta carotene accumulation and yield of orange-fleshed sweetpotato varieties under different environmental conditions. Beta carotene content and yield of sweetpotato differed within genotypes and across production environments. Additional work would be helpful to further understand and determine critical temperature thresholds particularly in light of the generally accepted roles of carotenoids in photosynthesis, light stress, and plant development.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors are grateful to the International Potato Centre (CIP) Integrating Orange Zambia project for financial support towards this research and the Zambia Agriculture Research Institute (ZARI) for support. This work was part of the MSc. Agronomy study of the principal author at the University of Zambia.

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