RELATIONSHIP BETWEEN ENVIRONMENTAL TEMPERATURE AND RAINFALL ON BETA CAROTENE CONTENT AND YIELD IN SELECTED SWEETPOTATO (*Ipomoea batatas* (L.) Lam.) VARIETIES

SINGOGO BRIAN

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DECLARATION

I, Brian Singogo, hereby declare that the work presented in this dissertation was my own and has never been submitted for a degree at this or any other university

Signature_____

Date_____

APPROVAL

This dissertation of Mr. Brian Singogo was approved as fulfilling part of the requirements of the award of degree of Master of Science in Agronomy by the University of Zambia.

Examiner's Name and Signature **Date**

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ABSTRACT

Sweetpotato (*Ipomea batatas (L.) Lam*) is becoming one of the most important tuber crops in Zambia and ranks second in importance from cassava. Orange fleshed varieties are being introduced to reduce vitamin A deficiency. However, the expression of β-carotene content, dry matter content and tuber yield among these varieties under different environmental conditions is not known. This study was conducted to establish the relationship between environmental temperature and rainfall on β-carotene content and yield of four orange fleshed sweetpotato varieties namely; Orange Chingovwa, Olympia, Kokota and Zambezi. The study was conducted in the Eastern province of Zambia at three sites with different climatic conditions. Sites were categorised into high temperature site (HTS) (38.5 ^{o}C), moderate temperature site 1 (MTS1) (32.2 ^{o}C) and moderate temperature site 2 (MTS2) (31.2 ^{o}C). Average rainfall for the 3 sites was 341 mm, 647 mm and 520 mm, respectively during the 2013/2014 growing season. Results showed that environment significantly influenced β-carotene content. HTS showed lower β-carotene contents than the 2 MTS. HTS showed 7.23mg/100g whereas MTS recorded MTS1 (15.56mg/100g) and MTS2 (15.46mg/100g). Among varieties, Zambezi and Orange Chingovwa were best performers for β-carotene content across all sites at 21.21mg/100g followed and (18.85mg/100g), respectively. Kokota was least performing genotype (3.28mg/100g) followed by Olympia (7.65mg/100g). β-carotene differed within genotypes and across production environments. Results indicated that β-carotene increased with warm temperatures and declined with hot temperatures. HTS showed lower yields (0.97 t/ha) than the two moderate temperature sites. The two moderate temperature sites had similar root yield results of 11.96 and 9.41 t/ha. Genotype Olympia consistently produced highest root yield across sites 12.2 t/ha followed by Kokota (7.6 t/ha) while Zambezi and Orange Chingovwa had 3.6 and 6.4 t/ha. Vine Yield (VY) was highly significantly different for sites at $p < 0.001$. HTS showed highest VY (23.6 t/ha) while the two MTS had lowest VY of (8.7 and 12.9 t/ha). Leaf area (LA) was significantly different for sites, varieties and their interactions. Significant interactions were recorded under different environments for Orange Chingovwa and Olympia. Genotype Kokota and Zambezi had consistently high mean LA across all sites. HTS exhibited high leaf development, high LA, high VY with low tuber development, low β-carotene, and low root yield as compared to the other two MTS. However further research to further quantify these relations particularly under controlled temperature regimes are necessary and sweetpotato breeders should be breeding genotypes ideal for specific environments for enhanced yield and β-carotene content in sweetpotato roots

DEDICATION

To my dear wife Precious for the huge role she assumed in taking care of the family during my absence and encouragement she gave me during this study, my son Joseph and my daughter Thabo.

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CHAPTER 1

1. 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, 2007; Kokkinos *et al.*, 2006). It ranks as the third most important tuber crop (Kokkinos *et al.*, 2006). In Zambia, sweetpotato is the second most important root and tuber crop after cassava and has the potential to contribute significantly to food security as an important source of energy and vitamin A (Chiona *et al*., 2007). The crop is widely adapted to a wide range of growing conditions, and gives high returns for a little outlay. This crop does not only have a better yield compared to most cereal crops, but also has high nutritional value, in addition to the tubers, the leaves are used as relish as well as livestock feed (FoDis Information Series, 2009). According to the Ministry of Agriculture and Livestock and Central Statistics Office (CSO) 2010/2011 Crop Forecast, sweetpotato production declined by 42 percent to 146,614 metric tons in the 2010/2011 season from a peak of 252,867 metric tons in the 2009/2010 season. However, the current production of sweetpotatoes is forecast to increase by 95.96 percent for the 2015/2016 farming season rising from 118,330 metric tons in 2014/2015 to 231, 882 metric tons last season and this is generally an indication of an upward trend in sweetpotato production in the country in the last few decades (FAO, 2013).

The adaptation of sweetpotato to marginal environments, 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. The crop is also able to provide food in areas with short rain periods and prolonged drought where other crops cannot survive, since it only takes a short period with a minimum of 90 days after planting to reach maturity (Stanthers *et al*., 2005).

The Root and Tuber Research Team of Zambia Agricultural Research Institute (ZARI) has been developing and promoting orange fleshed sweetpotato varieties that are superior in terms of yield, organoleptic characteristics and also high beta carotene content. The last component (beta carotene) being critical as a remedy for vitamin A deficiency which afflicts a high number of people in Zambia (NFNC, 2002). Currently, there is a paucity of

information in Zambia that clearly indicates how environmental conditions viz a viz soil and air temperature as well as rainfall affects beta carotene accumulation and yield of orange fleshed sweetpotato varieties.

1.1 Objective

The main objective of this study was to determine the relationship of environmental temperature and rainfall during plant development on beta carotene accumulation and yield of orange fleshed sweetpotatoes.

1.1.1 Specific objective

Specifically, the study evaluated the effect of environment (medium temperature environment- Chipata, Kalichero (Region II), Lundazi (Region II) and high temperature site-Masumba (Region I) on four new orange fleshed sweetpotato genotypes namely Olympia, Orange Chingovwa, Kokota and Zambezi.

Findings from this study will contribute to improving production of sweetpotato by answering questions about the expression of β-carotene accumulation, dry matter content and root yield among these varieties under different environmental conditions.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Sweetpotato Taxonomy

Sweetpotato (*Ipomea batatas* (L). Lam) is a member of the family *Convolvulaceae*, Genus *Ipomoea*, section *Batatas* and the order *Polemonialess* (Oggema *et al*., 2007). This family comprises of 55 genera (Watson and Dallwitz, 2000; Nawiri, 2014). The genera is said to contain over 500 species. Sweetpotato has also been classified (Huaman, 1992) under the Tribe- *Ipomoeae*, Genus- *Ipomoea*, Sub-genus- *Quamoclit*. Among more than 100 species of the genus *Ipomea,* a group of wild plants ranging from diploid to hexapod's, called *I. trifida* complex (Kobayoshi, 1984; Mackay *et al.*, 1987) is thought to be ancestral plant for sweetpotato (Nishiyama, 1971, 1982; Shiotanni and Kawase, 1970, 1980; Shiotani, 1987; Mackay *et al.,* 1989).

2.2. Development phases of sweetpotato

The development cycle of sweetpotato from crop establishment to harvesting the storage roots comprises three phases within a time span of 90-150 days. All the phases are affected by variety and the environmental conditions (Stanthers *et al.,* 2013). The first phase (40 to 60 days) is characterized by slow vine growth and rapid development of adventitious roots, followed by the intermediate phase (45 to 120 days) in which there is the rapid growth of vines and an increase in leaf area as well as storage root initiation (CARDI, 2010). The final phase is the total development of the tubers and takes 45 to 90 days. The leaf area is at its maximum at about 100 Days After Planting (DAP), and any further increase in biomass is due to formation of storage roots. CARDI, (2010) further reported that the first 20 days of the initial phase are important as they determine the total number of storage roots formed.

2.3. Physiology of sweetpotato

Sweetpotato storage root formation and development is a complex process which is characterized by the cessation of root elongation, genesis of primary and secondary vascular cambium, anomalous and interstitial cambia, increase in radial growth by increased rate of cell division, cell proliferation and cell expansion concomitant with the massive deposition of starch and storage proteins such as sporamin which eventually result in enlargement of storage roots (Ravi *et al.,* 2009).

The storage root development is a function of increase in number of cells due to cell division and proliferation and its massive filling with starch. Sweetpotato storage root yield is determined by the duration and rate of storage root growth which varies widely among cultivars (Ravi et *al.,* 2009).

2.4 Environmental requirements and abiotic stress effects

Various environmental factors can affect plant growth and development as well as their nutrient accumulation levels. These factors may include soil, environmental temperature, water, light and nutrients (Mark *et al.,* 2005). However, it is suffice to mention that the actual response will also depend on genetic constitution of a given germplasm

2.4.1 Temperature

Air and soil temperature regulate competition between shoot and storage root development of sweetpotato (Nakatani, 1989; Ravi *et al*., 2009). Night air temperature seems to be the most critical factor for storage root growth presumably due to greater translocation of sugar from the shoot to roots during this time (Nakatani, 1989; Ravi *et al*., 2009). Lower night air temperature (11.3- 26.4 $^{\circ}$C) significantly increases the bulking rate of storage roots (Nakatani, 1989; Mukhopadhyay *et al*., 1991; Ravi *et al*., 2009). Ravi *et al*., (2009) further reported that night temperature between 15 - 25 $^{\circ}$C promotes storage root formation and growth.

Generally, the production of sweetpotatoes requires at least 120 frost free days for optimum growth and is of minimum commercial importance where mean summer temperatures are lower than 20 $^{\circ}$C (Becky, 2014). The crop can thrive in hot weather, but little or no growth occurs when soil or air temperatures are below 16 $^{\circ}$C (Tanaka and Sekioka, 1976). Sweetpotato is therefore considered a warm weather crop and exhibits high levels of sensitivity towards low temperatures (Onwueme, 1978; Belehu, 2003). Mark *et al.,* (2005) reported that significant air temperature variations both at low and high temperature extremes can limit plant development. This is not an exception for sweetpotato as the crop is adversely affected by both low and high temperature extremes. It has been confirmed by Harter and Whitnet (1962); Belehu (2003) who reported that the crop will not survive temperatures of less than 12 $^{\circ}$C, and will barely survive at 15 $^{\circ}$C with no growth activities exhibited. Other researchers showed that sweetpotato growth is at optimum when soil temperatures are near 20 $^{\circ}$C and air temperatures near 30 $^{\circ}$C (Tanaka and Sekioka, 1976).The growth of sweetpotato crop increased above 15 $^{\circ}$C up to 35 $^{\circ}$C and showed retardation at 38 $^{\circ}$C (Harter and Whitnet

1962; Belehu, 2003). The crop is also reported to grow best where average temperatures are around 24 °C. The thermal optimum is reported to be above 24 °C (Kay, 1973; Belehu, 2003). The paucity of information on sweetpotato storage root beta carotene accumulation responses to wide range of environmental temperature variations, led to conducting this current study.

Among the ever-changing components of the environment, the constantly rising ambient temperature, particularly with emergence of the problem of climate change, is considered one of the most detrimental stresses. The global air temperature is predicted to rise by 0.2 °C per decade, which will lead to temperatures 1.8 – 4.0 °C higher than the current level by 2100 (IPCC, 2007).

Sweetpotato storage root initiation and subsequent growth are sensitive to temperature conditions. Reddy *et al*., (2013) reports that storage root number is significantly affected by temperature. However, there is no information on how environmental temperatures can affect the accumulation of beta carotene in storage roots. This study will therefore endeavour to focus more on the relationship between environmental temperature and beta carotene content and yield of orange fleshed sweetpotatoes. Heat stress affects life processes of organisms, acting directly or through the modification of surrounding environmental components. Plants, in particular, as sessile organisms, cannot move to more favourable environments; consequently, plant growth and developmental processes are substantially affected, often lethally, by high temperature stress (Lobell and Asner, 2003)

Research on carrots (*Daucas carota*) which accumulate large amounts of beta carotene indicates that when planted under 12 °C had larger and wider taproots and a higher dry matter content (20 %) than those grown at 25 °C (Nthabiseng *et al.,* 2011). Rosenfeld *et al*. (1998a) and Rosenfeld *et al*., (1998b) grew carrots at constant temperatures of 9, 12, 15, 18 and 21 °C and obtained the highest root dry mass at 12 and 15 °C. Olympics, (1973); Benjamin *et al*., (1997); Nthabiseng *et al.,* (2011) also found a decrease in root dry mass of 47 % at temperatures between 15 and 25 °C. The optimum temperature for growth, yield and quality ranged between 10 and 25 °C (Joubert *et al*., 1994; Rubatzky *et al*., 1999). Alam *et al.* (2004); Nthabiseng *et al.,* (2011) also indicated that the optimum day and night temperatures for plant growth are between 21 and 22 °C and 18 and 20 °C, respectively.

Mark *et al*., (2005) evaluated the effect of temperature on biomass and carotenoid pigment accumulation in Kale (*Brassica oleracea* L.) and spinach (*Spinacia oleracea* L.) and observed that the accumulation of lutein in the leaf tissues was influenced by air temperature. Leaf tissue lutein (Figure 1) increased linearly as air temperature increased from 15 to 30 $^{\circ}$C. Lutein which is classified as a dihydroxycarotenoid and lycopene (Figure 2) as a hydrocarbon carotenoid, are non-vitamin A active carotenoids with very high antioxidant properties. Lutein is the end product of the β,ε branch of carotenoid biosynthesis pathway (Figure 3.) (Howitt and Pogson, 2006). Lutein is the most abundant carotenoid in photosynthetic plant tissues where it plays important roles in light-harvesting complex-II structure and function. Lutein which is synthesized from the α- carotene in green plant tissues is very important in absorbing light in the 400 -500nm range and thereby effectively expanding the range of light that can be utilised for photosynthesis as plants expand to new and varied environments around the planet (Engelmann *et al.,* 2011). The accumulation of beta carotene in the leaf tissue was also influenced by changes in the air temperature. Leaf tissue beta carotene responded significantly to changes in air temperature for both crops. Increases in air temperatures from 15 to 30 $^{\circ}$C resulted in linear increase in leaf tissue β- carotene for kale (Mark *et al*., 2005).

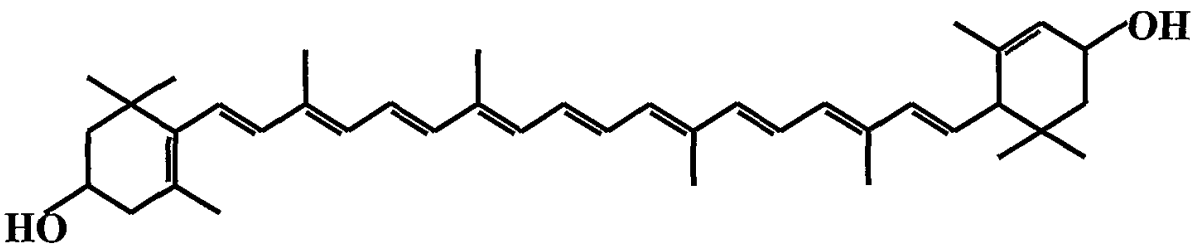


Figure 1. Structure of Lutein

Lutein ($C_{40}H_{56}O_2$) is an oxygenated carotenoid containing eleven conjugated double bonds

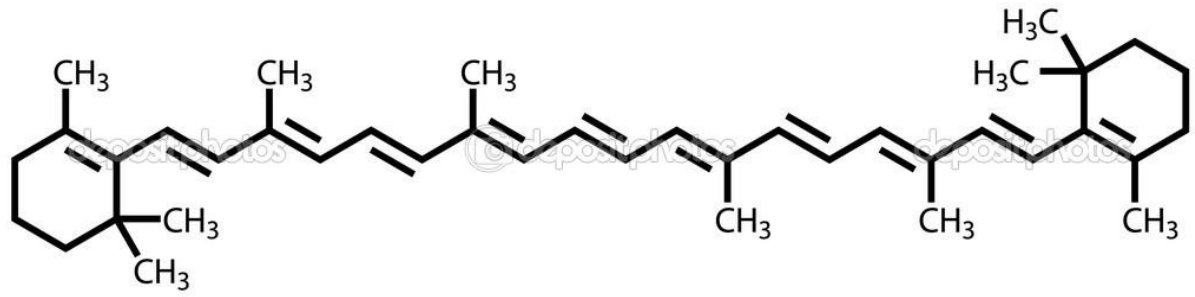


Figure 2. Structure of Lycopene

Lycopene ($C_{40}H_{56}$) is a hydrophobic, acyclic carotenoid containing eleven conjugated double bonds

Other studies conducted on carrots (Nthabiseng *et al.*, 2011) revealed that yield parameters and the external quality parameters such as root length, diameter and absence of defects were also influenced significantly by temperature. Carrot root length and diameter were significantly influenced by temperatures (15/5 °C) and absence of defects such as green shoulder and hairiness were significantly negatively influenced by higher temperatures (28/20 °C). Some of the internal quality parameters such as firmness, total soluble solids, carotene, β-pinene and caryophyllene were also significantly affected by temperature. Firmness, total soluble solids and carotene were significantly influenced by lower temperature (15/5 °C) whereas β-pinene and caryophyllene were significantly influenced by higher temperatures (28/20 °C). Ravi *et al.,* (2009) reports that at air temperatures greater than 30 °C increase in Indole-3-acetic acid (IAA) oxidase activity causes reduction in storage root formation and growth while increase in gibberellic acid promotes shoot growth. Tekalign & Hammes (2010) also reported that potatoes (*Solanum tuberosum*) grown under high temperatures are characterized by high levels of endogenous gibberellin that have a delaying or inhibitory effect on tuberisation. In addition, gibberellin acid accumulation in tuber tissue can specifically impede starch accumulation (Booth and Lovell, 1972; Paiva *et al*., 1983; Vreugdenhil and Sergeeva, 1999; Tekalign and Hammes, 2010), inhibit the accumulation of other tuber specific proteins.

Cool soil temperatures (20 °C) have been reported to cause lower sucrose content in the sweetpotatoes stems than levels at high temperatures of (30 °C) (Ravi *et al*., 2009). The study also revealed that while sucrose content in stems are lower at cool soil temperatures, the starch levels are favoured at the same temperatures, making the starch inverse that of sucrose. This suggests greater conversion of sucrose to starch in storage roots is favoured at cooler soil temperature. Similar to air temperature, soil temperatures between 20- 30 °C favour storage root formation and growth while soil temperature at 15 °C promotes fibrous root formation. Soil temperatures higher than 30 °C have been reported to promote shoot growth at the expense of storage root growth in sweetpotatoes (Hasegawa and Yahiro, 1957; Spence and Humphries, 1972; Ravi *et al*., 2009). Higher temperature more than 28 °C diverts photosynthetic partitioning toward fibrous roots than to storage roots (Eguchi *et al*., 2003; Ravi *et al*., 2009).

2.4.2 Light

Most sweetpotato varieties are sensitive to day length (Ngailo *et al.*, 2013). Chipungahelo *et al.,* (2007) reported that sweetpotato requires high levels of solar radiation for optimum growth and tuber yield. Chipungahelo *et al.,* (2010) also reported that some further research showed that moderate shading (55% light reduction) cause significant tuber reduction and at greater than 70% light reduction suppresses tuber formation while in deep shade, sweetpotato plant develop fewer but larger leaves and stem size increase. Bouwkamp, 1985; Mortley *et al.,* (1996) also reported that light duration is a very important factor affecting the growth and yield of sweetpotato crop. Kim (1957); Mortley *et al.,* (1996) observed a stimulation in storage root formation under long days and suggested that this effect resulted from greater net C fixation rather than being an effect of photoperiod. Sweetpotato is photosensitive with a photoperiod of 11.5 hour day length or less promoting flowering, while at 13.5hr day light, flowering ceases, but storage root yield is not affected (Tindall, 1983). Generally, short days with low light intensity promote root development. Higher storage root yields have also been reported when the crop was grown under 12- hour light periods than for the crop grown under shorter (8 - hour) or longer (18 - hour) light periods (McDavid and Alamu, 1980; Mortley *et al*., 1996). In a similar manner, other studies (Porter, 1979) confirmed the previous reports of higher yields when sweetpotato was grown under 14– hour light periods compared to 8-hour light periods (Porter, 1979; Mortley *et al.,* 1996)

Light has a direct influence on the temperature. Sunlight is responsible for warming the earth, oceans and atmosphere through infrared radiation. Both water and land reflect back some of that radiation to warm the atmosphere or other objects in contact with the surface (Roussy, 2006). Therefore, the higher the intensity of sunlight the higher the air temperature. Solar radiation absorbed by the atmosphere and the heat emitted by the earth increase the air temperature (FAO, 2013). The sensible heat of the surrounding air transfers energy to the crop and exerts controlling influence on the rate of evapotranspiration.

2.4.3 Water

Faced with increasing scarcity of water resources, drought has become the single most critical threat to world food security. Because the world's water supply is finite, future food demand for rapidly increasing population pressures is likely to further aggravate the effects of drought (Somerville and Briscoe, 2001; Farooq *et al.,*2009). Laurie *et al.,* (2009) reported that

although sweetpotato can survive severe moisture stress conditions, marketable root yield is adversely reduced. Severe moisture stress affects the crops' shoot development, leaf area index, marketable yield and stomatal conductance. It is known that severe water stress results in closure of stoma and dramatic decline in photosynthesis and respiration rate (Laurie *et al.,* 2009). Wilson *et al.,* (1976) also reported crop's failure to produce best quality and yields under severe moisture stress despite the crop being drought tolerant.

Sweetpotato requires about 500 mm water for 16- 20 weeks growth period (King, 1985; Kays, 1985; Onyekwere and Nwinyi, 1989; Chukwu, 1995; Ravi *et al*. 2009). Other authors report that the crop requires between 360 and 800mm of rainfall over its entire growing season (Belehu, 2003) while Tanaka and Sekioka (1976) reported that the crop can tolerate ranges of 500-1300 mm of rainfall per growth cycle. However, storage root yields are also said to be affected by the amount, timing and distribution of water and when the available soil moisture falls below 20 %, under water deficit stress conditions, there is usually a noticeable decrease in storage root yield of the crop (Hernandez and Hernandez, 1967; Chowdhury and Ravi, 1987, 1988; Indira and Kabeerathumma, 1988; Nair *et al*., 1996; Ravi *et al*., 2009). Excessive moisture early in the season delays storage root development and enlargement whereas late in the season induces cracking and rotting of roots. Cases of flooded or dry soil conditions may also cause specific roots to lignify, irreversibly limiting their potential to become storage roots (Togari, 1950; Ravi & Indira, 1996; Lewthwaite, 2004). This lignification and reduction in storage root yield is greater in cultivars with weak sink capacity than those with higher sink capacity (Ravi and Indira, 1996; Ravi *et al*. 2009).

Oswald *et al*., (2009) reports that average root yields are relatively low ranging between 3 to 6 t/ha if water supply is a limiting factor or up to 10 to 12 t/ha where natural soil fertility and rainfall are adequate. The potential yield of sweetpotato can be up to 40 to 50 t/ha, or possibly a bit less for high dry matter indigenous landraces.

2.4.4 Nutrients

In order to realize good yields and quality storage roots, adequate levels of soil potassium, nitrogen and phosphorus are necessary (Lewthwaite, 2004). According to Latha *et al.,* (2004) the optimum pH range for sweetpotato production is 5.6 to 6.6. Nitrogen, phosphorous and potassium at a 75:50:75 and liming at 2 t/ha have been described as ideal for the crop (Nair and Mohankumar, 1984; Latha *et al.*, 2004). However, it is also reported that supra optimal

levels of nitrogen encourages vegetative growth at the expense of tuber development. The root to shoot ratio was decreased at higher levels of nitrogen (Asokan *et al*., 1984; Latha *et al*. 2004). In most cases, excess nitrogen stimulates vegetative growth at the expense of storage root development (O' Sullivan *et al*. 1997; Lewthwaite, 2004). Applications which are made above optimal levels may result in excessive foliage growth at the expense of root growth, nutrient leaching into aquifers, and an undesirable accumulation of salts in the soil root zone (Tanaka and Sekioka, 1976). Sweetpotato is a crop that requires not only nitrogen and phosphorus but especially adequate potassium for optimum root growth (Tanaka and Sekioka, 1976). Potassium deficiency has a greater effect on storage root yield than on the plant canopy (Bourke 1985; Lewthwaite 2004). The addition of potassium can offset excessive nitrogen effects such as disproportionate canopy growth and reduced yields (Bouwkamp 1985b; Lewthwaite 2004). Root yield responses to sequential application of potassium are frequently linear, with approximately 1.2 t/ha per 28kg/ha of applied potassium (Jones *et al.*, 1979; Lewthwaite 2004).

2.4.5 Soil Types

Sweetpotatoes have a narrow range of soils for optimum production. Preferred soils are sandy loams, on level or only slightly sloping land, that is moderately fertile and well drained (Tanaka and Sekioka, 1976). Poorly drained, heavy soils will result in irregularly sized and shaped fleshy roots. Soils high in organic matter may result in rough, cracked, jumbo-sized roots (Tanaka and Sekioka, 1976). The crop may also be grown in rotation with other crops as a measure to replenish nutrients and discontinue pests' life cycles. Normally, three-year rotations are recommended to reduce damage from scurf and Fusarium wilt (Tanaka and Sekioka, 1976).

Although sweetpotato is considered low pH tolerant, it cannot withstand salinity and alkalinity. Salinity significantly reduces growth of stems and roots and results in lateral rolling of leaf lobules, reduction in leaf size and necrosis of older leaves (Villafane, 1997; Latha *et al*., 2004)

2.5 Chemical constituents

2.5.1 Carbohydrates

Approximately 80 - 90% of the sweetpotato dry matter (24- 27% fresh weight) is made up of carbohydrates, which consists mainly of starch and sugars, with lesser amounts of pectins, hemicelluloses and cellulose (Woolfe, 1992). However, the relative composition of carbohydrates in sweetpotato roots varies not only with cultivars and maturity of the roots, but also with storage time and cooking or processing (Woolfe, 1992). According to the United States Department of Agriculture (USDA) Nutrient Database, uncooked sweetpotato tubers can contain up to 20.12g per 100g tuber, while leaves have been reported to contain up to 8.64g per 100g tuber of carbohydrates. Further reports (Corleone, 2013) indicate that a 100 g serving of the white potato contains 21 g of carbohydrates and 2.2 g of fibre, and the sweet potato has 21 g of carbohydrates and 3.3 g of fibre.

2.5.2 Proteins

Sweetpotato offers an averagely acceptable protein nutritive value with a chemical score of 82 and despite having the sulphur amino-acids as the major limiting factors (FAO, 2015) Amino acid analysis of sweetpotato roots and vines indicates them to be of good nutritional quality but deficient in total sulfur amino acids and lysine in terms of ideal protein (Fuller and Chamberlain, 1982; FAO, 2015).

The average total protein content of sweetpotato is generally reported to be as low as 1.5 % (fresh weight basis) and 5 % (dry weight basis), however it is superior to other roots and tubers such as cassava, plantains, and taro and inferior to potato, yams and cereals (Woolfe, 1992; Ingabire and Vasanthakaalam, 2011). The protein content of these tubers varied from 1.0% to 2.5 % (about 5% dry weight basis) (Salunke and Kadam, 1998; Montreka and Benjamin, 2003; Ingabire and Vasanthakaalam, 2011).

2.5.3 Vitamins

Contrary to the belief of many consumers that sweetpotato roots are solely an energy source, they have been proven to contain substantial sources of ascorbic acid (Vitamin C) and moderate amounts of thiamin (B_1), riboflavin (B_2) and niacin as well as pyridoxine and its derivatives (B_6), pantothenic acid (B_5) and folic acid (Woolfe, 2003).They are also reported to contain some appreciable levels of tocopherols (vitamin E) (Woolfe, 1992). Sweetpotato

has been reported to contain 23.5 and 33.3mg/100g of fresh weight of vitamin C in some varieties (Hollinger, 1945). The crop also produces variable and sometimes large quantities of carotenoids which act as a precursors for vitamin A (Woolfe, 1992).

2.5.4 Fibre

Different types of plants vary in their amount and kind of fiber. Fiber includes pectin, gum, mucilage, cellulose, hemicellulose and lignin (Ingabire and Vasanthakaalam, 2011). Sweetpotato is a good source of dietary fibre. Fibre is important in reducing constipation which happens when food moves too slowly through the large intestines, often resulting in hard stool that is difficult to pass. Fibre-rich foods helps move the contents of the large intestine along more quickly. Further, fibre also absorbs water, softening stools so that they pass more easily. Ingabire and Vasanthakaalam, (2011) reported the fibre content of some sweetpotatoes varieties to have ranged from 0.11 to 0.14 %.

The total pectin content of four North American cultivars tested ranged from 0.73% to 1.3% (fresh weight basis) (Reddy and Sistrunk, 1980; Woolfe, 1992). However, other finding from Filipino cultivars found a total pectin content of 2.6% (fresh weight basis) (Kawabata *et al*., 1984; Woolfe, 2003) and 3 – 5% (fresh weight basis) found in eight North American cultivars at harvest (Ahmed and Scott, 1958; Woolfe, 1992). Further reports by Woolfe (1992) on dietary fibre components of raw sweetpotato roots from Tonga indicates Hemicellulose 3.8% and 1.2% dry weight basis and fresh weight basis respectively. Whereas cellulose indicated 1.9% (dry weight basis) and 0.6% (fresh weight basis) and Lignin with 1.4 and 0.4% for dry and fresh weight basis, respectively.

2.5.5 Dry Matter

Starch is the main component constituting 70% of the dry weight of sweetpotato (Woolfe, 1992). Slafer and Savin (1994); Mwanga *et al*., (2007) and Placide *et al*., (2013) reported high dry matter content as an important characteristic of a good sweetpotato variety. Storage roots with high starch and low hexoses contents are important characteristics preferred by the sweetpotato industry (Slafer and Savin, 1994). High starch and low soluble sugar contents decrease the cost of sweetpotato processing due to the absence of oxidation reactions (McKibbin *et al*., 2006; Placide *et al*., 2013). Oxidation reaction is mainly favoured by high content of hexoses such as glucose and fructose. This reaction leads to the development of

brown and dark colours and bitter taste after drying or frying (Dale and Bradshaw, 2003; Placide *et al*., 2013).

Sweetpotato is said to be among crops with highest dry matter productivity rates (Scott *et al.,* 2000; Ravi *et al.,* 2009). The crop whose high productivity is due to the high sink potential of the storage root (Hozyo *et al.,* 1971; Hozyo, 1977; Hahn, 1977; Ravi *et al.,* 2009) and the photosynthetic efficiency of leaves (Keutgen *et al.,* 2002; Ravi *et al*., 2009), produces 152 MJ/ ha/ day calories (Ravi *et al*., 2009). Varieties with high dry matter content above 35% of the flesh weight have been used as a raw material for the biofuel and processing industries (Gruneberg *et al*., 2009; Placide *et al*., 2013).

2.5.6 Sweetpotato as a source of β-carotene

The sweetpotato has been reported to contain a total carotenoid content ranging from 0 to more than 20mg/100g of fresh weight, which can be equivalent to 0 to 60 mg/100g of dry weight (Stanthers *et al*., 2005; Takahata, 1995; Takahata *et al.,* 1993; Mbwaga *et al*., 2007). From plant storage parts different crops have different levels of Vitamin-A and sweetpotato mainly orange fleshed are among the few crops that provide higher amount of ß-carotene content.

2.5.7 Beta carotene biosynthesis

In plants, carotenoids play a protective role in photosynthesis by dissipating excess light energy absorbed by the photosynthetic mechanism (Adams *et al.,* 2004). Carotenoids also extend the range of photosynthetically active radiation spectrum that the plant can use (Larcher, 1995).They also serve as precursors for the synthesis of other biologically important compounds (Millborrow 2001; Bouvier *et al*., 2003; Fester *et al*., 2002; Guo *et al*., 2012). Carotenes are a class of hydrocarbons which belongs to the carotenoid family. There are over 600 carotenoids found in nature and they are generally colourful orange, red, and yellow pigments synthesized by photosynthetic plants, bacteria and fungi. Carotenoids are hydrocarbon compounds that can be chemically subdivided into *xanthophylls* (oxygenated molecules) and carotenes (hydrocarbons lacking oxygen). These tetraterpenes usually consist of 8 isoprene units derived from isopentenyl diphosphate, the same precursor required for cholesterol synthesis in animals. However, in plants, carotenoids are synthesized in plastids via the 1-deoxy-D-xylulose-5-phosphate pathway rather than the mevalonic acid pathway of cholesterol biosynthesis (Bramley, 2002; Engelmann *et al*., 2011). As isoprenoids, carotenoid

compounds originate in the plastid-localized 2-C-methyl-D-erythritol 4-phosphate (MEP) pathway that starts with the reaction between pyruvate and glyceraldehyde-3-phosphate. The first steps in the MEP pathway are regulated by 1-deoxy-D-xylulose-5-phostaphate synthase (DXS) and 1-deoxy-D-xylulose 5-phosphate reductoisomerase (DXR) (Figure 3). The isopentenyl diphosphate then condenses with dimethylallyl diphosphate to yield geranylgeranyl diphosphate (GGPP), a C_{20} molecule, which subsequently condenses with another GGPP via Phytoene synthase to give the basic carotenoid phytoene (Bramley, 2002; Engelmann *et al*., 2011). The enzyme phytoene synthase (PSY) is a major catalyst in the reaction leading to the formation of the colourless carotenoid phytoene which does not usually accumulate in tissues (Armstrong, 1994; Howitt and Pogson, 2006).

In plants, four desaturation reactions then catalyse the colourless phytoene into the red coloured compound called lycopene by introducing two symmetrical double bonds. These desaturation reactions are catalysed by two enzymes, the phytoene desaturase synthase (PDS) and (zeta-carotene) ζ-carotene desaturase (ZDS). The production of all-trans-lycopene which is the preferred substrate for the cyclases also requires the carotenoid isomerase (CRTISO) (Isaacson *et al*., 2002; Park *et al*., 2002; Howitt and Pogson, 2006).

Cyclization of lycopene is a branch point in the pathway, where the *β,β* branch leads to *β*-carotene and its derivatives and *β,ε* branch leads to α-carotenes and its derivatives. Lycopene *β*-cyclase catalyses the formation of *β*-carotenes by introducing *β* rings at either end of lycopene (Figure 3).

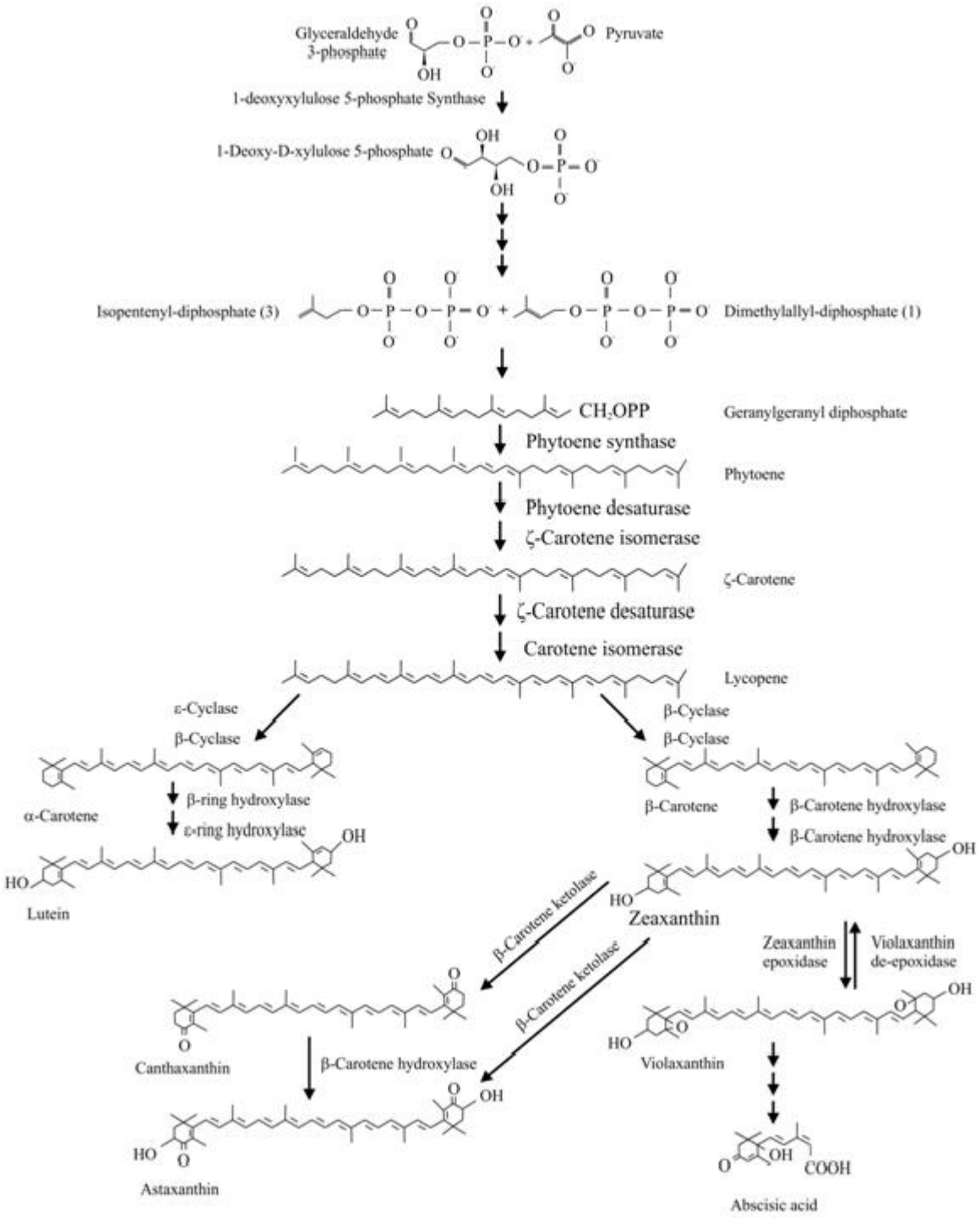


Figure 3. Carotenoid biosynthesis pathway found in plants [reproduced from Hannoufa and Hossain (2011) and Howitt and Pogson (2006)]

2.6 Sweetpotato production

2.6.1 World production

This commodity ranks among the world's seven most important food crops (along with wheat, rice, maize, potato, barley, and cassava) and is cultivated in over 100 developing countries (FAOSTAT, 2013; Aziz , 2013). World production of sweetpotato has been consistent at just over 100 million metric tons during the years 2007-2011 (FAOSTAT, 2013; Aziz , 2013). In 2011, world production of sweet potato was 105 Million metric tons with the top producer, China, accounting for 72% of the total production (FAOSTAT, 2013; Aziz , 2013). In the Americas, the main producers were USA (1.2 million metric tons), followed by Argentina, 390,000 metric tons and Cuba 312,000 metric tons (Aziz , 2013). The total production of sweetpotato in the USA grew by 49% in 2011, when compared to 2001 with a total of 1.22 million metric tons quantity produced (Aziz, 2013). For the years 2013 and 2014, the average world production of sweetpotato increased from 103 million tons in 2013 to 104.5 million tons in 2014 (Faostat, 2015).

2.6.2 National production

In Zambia, sweetpotato production has also been static from 1961 to 2009. Notable increments in the total production was in 2010 to 2013 (Faostat, 2015). From the year 2011 to 2013, the production has increased steadily to over 100,000 metric tons per annum and according to Food and agriculture organization (Faostat, 2015), the years 2011, 2012 and 2013 recorded incremental production of 146, 600 metric tons, 163,000 metric tons and 188,000 metric tons, respectively. In the year 2015/2016 farming season, the production of sweetpotato increased by 95.96 % to 231,882 metric tons from 118,330 metric tons in the 2014/2015 farming season (CSO, 2016).

2.7 Biotic constraints and sweetpotato production

2.7.1 Diseases

There are several biotic stresses that affect the production of sweetpotatoes. The notable biotic constraints to sweetpotato production include a wide range of sweetpotato diseases, viruses, weevils and white flies. Sweetpotato viruses have the potential to cause yield reductions of up to 98% (Mukasa *et al*., 2003). Sweetpotato Feathery Mottle Virus (SPFMV), Sweetpotato Mild Mottle viruses (SPMMV), Sweetpotato Chlorotic Fleck Virus (SPCFV) are

some of the important viruses that can severely cause plant degeneration and yield losses (Tairo, 2006) However, the use of disease free planting materials is an effective way to control sweetpotato viruses and weevil (FoDis Information Series, 2009).

Bacterial diseases such as bacterial stem (*Erwinia chrysanthemi*) and root rot (*Dickeya dadantii*) can be economically damaging worldwide (Ames *et al.,* 1996; Traynor, 2005). Other detrimental bacterial diseases include bacterial wilt (*Pseudomonas solanacearum*), important in southern China and soil rot (*Streptomyces ipomoea*), is important in parts of USA and Japan.

Plants may also be infected by other pathogens such as mycoplasma (little leaf disease). This disease is characterized by infected plants having small pale yellow stunted leaves and stems (Traynor, 2005). The infection is spread by leafhoppers and if plants are infected while young, yields are greatly reduced (Traynor, 2005)

2.7.1 Pests

Worldwide there are at least 270 species of insects and 17 species of mites that feed on sweetpotatoes (QDPM/FAO protocol 2009; Ames *et al.,* 1996). Insect pests are categorized into defoliators, virus transmitters, stem borers and root feeders. The major and most notorious pest of sweetpotato is largely the sweetpotato weevil (*Class spp*) (Traynor, 2005). Worldwide there are three main economically important sweetpotato weevils: *Cylas formicarius* occurs globally, while *C. puncticollis* and *C. brunneus* are the main species in Africa (QDPM/FAO protocol 2009; Ames *et al*., 1996). The West Indian sweetpotato weevil, *Euscsepes postfasciatus* occurs in Central and South America, the Caribbean, and the Pacific Islands (QDPM/FAO protocol 2009; Ames *et al.,* 1996.

The larvae burrow into the roots making them un-marketable and they can pupate in the stems and be transferred in planting material (QDPM/FAO protocol 2009; Ames *et al.,* 1996). The most damaging stage of weevils is the larval stage. The larvae mainly attack stems and underground parts, although they may also feed on leaves. Adult weevils oviposit in the bases of vines and in exposed roots, while the larvae tunnel through storage roots causing major economic losses (QDPM /FAO 2009; Jansson and Raman 1991). The damage caused by larvae and adults also stimulates the production of terpene phytoalexins, which make the storage roots unhealthy for human consumption (QDPM/FAO protocol 2009; Ames *et al.,*

1996). Weevil population and damage is most prevalent during dry seasons, probably because drought increases soil cracking, which leads to exposure of roots to weevils. Once established in a crop this pest is difficult to control. Destroying all crop residue after harvest and crop rotations are the best ways to keep weevil numbers down (Traynor, 2005).

Root-knot nematodes (*Meloidogyne species*) are important pests in sweetpotatoes that occur worldwide. Nematode attack in sweetpotato causes stunting, yellow foliage, abnormal flower production, round to spindle-shaped swellings (galls), necrotic root system, and low yields (QDPM/FAO protocol 2009; Ames *et al.,* 1996).

3 Crop Improvement/ breeding

Several organizations have been involved in the breeding and improvement of sweetpotatoes. One of the major focus of sweetpotato improvement particularly in Zambia has been development of orange fleshed varieties to combat vitamin A deficiency. A number of orange fleshed varieties have been released, and are being grown by farmers, while a few others are advanced promising lines (Kapinga *et al*., 2010). A good number of the lines are important parents in regional and national breeding programs to improve levels of β-carotene and root dry matter in sweetpotato in the region. Some of the materials are landraces from African countries while others are introduced germplasm from the USA, South America, and Asia, and have been found to be adapted to particular environments in Sub Saharan Africa.

Research programmes in Zambia are ongoing under the Research Department of the Ministry of Agriculture. Trials under the Root and Tuber Improvement Programme (RTIP) are aimed at developing new varieties and improving on some existing varieties to come up with improved varieties.

4 Future of crop use and production

Compared to maize, sweetpotato has the potential to produce more than 30% starch a factor that makes the crop draw more interest in bioethanol production (Biofuels Centre of North Carolina, 2011). The crop also continues to find its use as an important raw material to manufacture different products such as noodles, vermicelli, jelly, amylophosphate, soluble and refined starch, and alcohol drinks (Loebenstein and Thottappilly, 2009; Woolfe, 1992). The accumulation of anthocyanins in sweetpotatoes which imparts purple colour in some cultivars is seemingly becoming an important factor in the food coloration industry. The outlook of future for sweetpotato use points to it being used more in the pharmaceutical and

cosmetic industries (Fan *et al*., 2008; Nedunchezhiyan *et al.*, 2012) apart from the usual juice, alcoholic beverages, bread, jams, confectionaries and noodle industries (Montilla *et al.,* 2011; Nedunchezhiyan *et al.,* 2012).

The recent findings of the radical scavenging, antimutagenicity and efficacy against liver disease of sweetpotato anthocyanins (Nedunchezhiyan *et al.,* 2012) are a proof of how important the crop will be in the near future.

In most countries of the world, sweetpotato has been used solely for human consumption purposes but recently some countries like China one of the world's biggest producers have adopted the use of sweetpotato foliage and tubers for livestock feed (Huang *et al.,* 2003; Fuglie, 2007).

CHAPTER 3

3. Materials and Methods

3.1. Experimental Sites

The study was conducted in three districts of Eastern province of Zambia during the 2013/2014 growing season. These sites were selected on the basis of their unique characteristics for temperature and rainfall. They included; Lundazi (Region II), Chipata (Region II) and Masumba (Region I). In Lundazi district, the study was conducted in the Central camp (S 12^{o} 16.788' E 033^{o} 11.611') at an elevation of 1340 m above sea level; the Chipata district site was at Kalichero Agricultural Camp (S 13^{o} 29.648' E 032^{o} 26.352') at an elevation of 960 m above sea level while in Mambwe district (S 13^{o} 13.306' E 031^{o} 55.811') at an elevation of 501 m above sea level. The soil and other environmental characteristics of the study sites are presented in Tables 1 and 2, while rainfall and temperature for the sites are presented in figures 4 and 5, respectively. Mambwe was the high temperature site, while Kalichero and Lundazi were moderate temperature sites (Table 1).

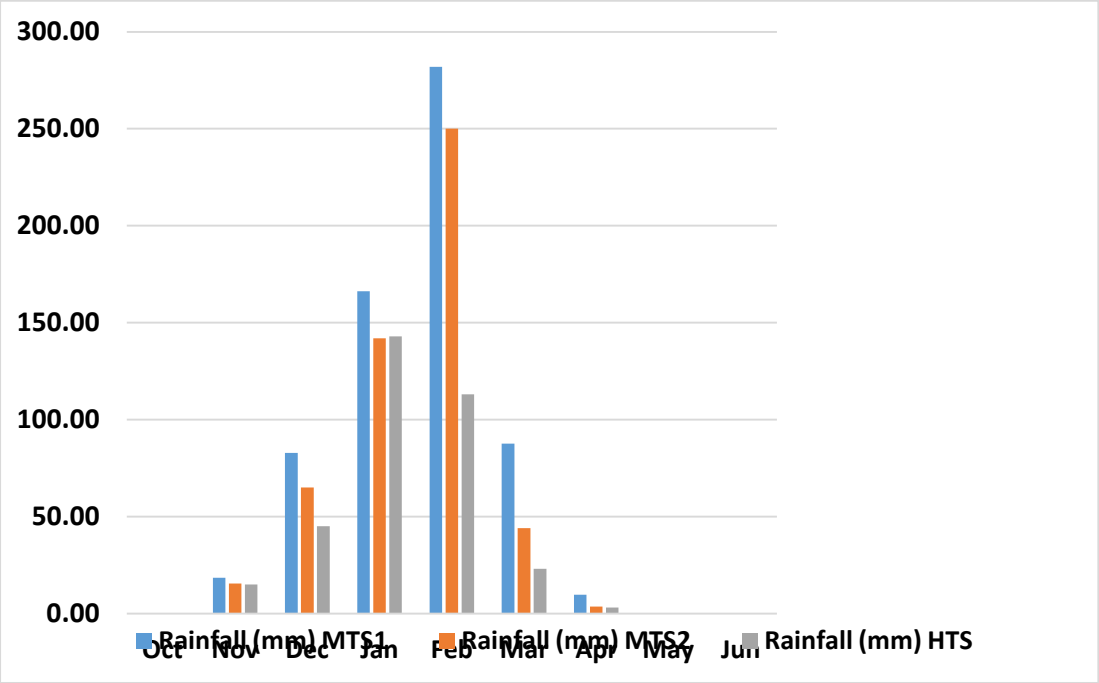
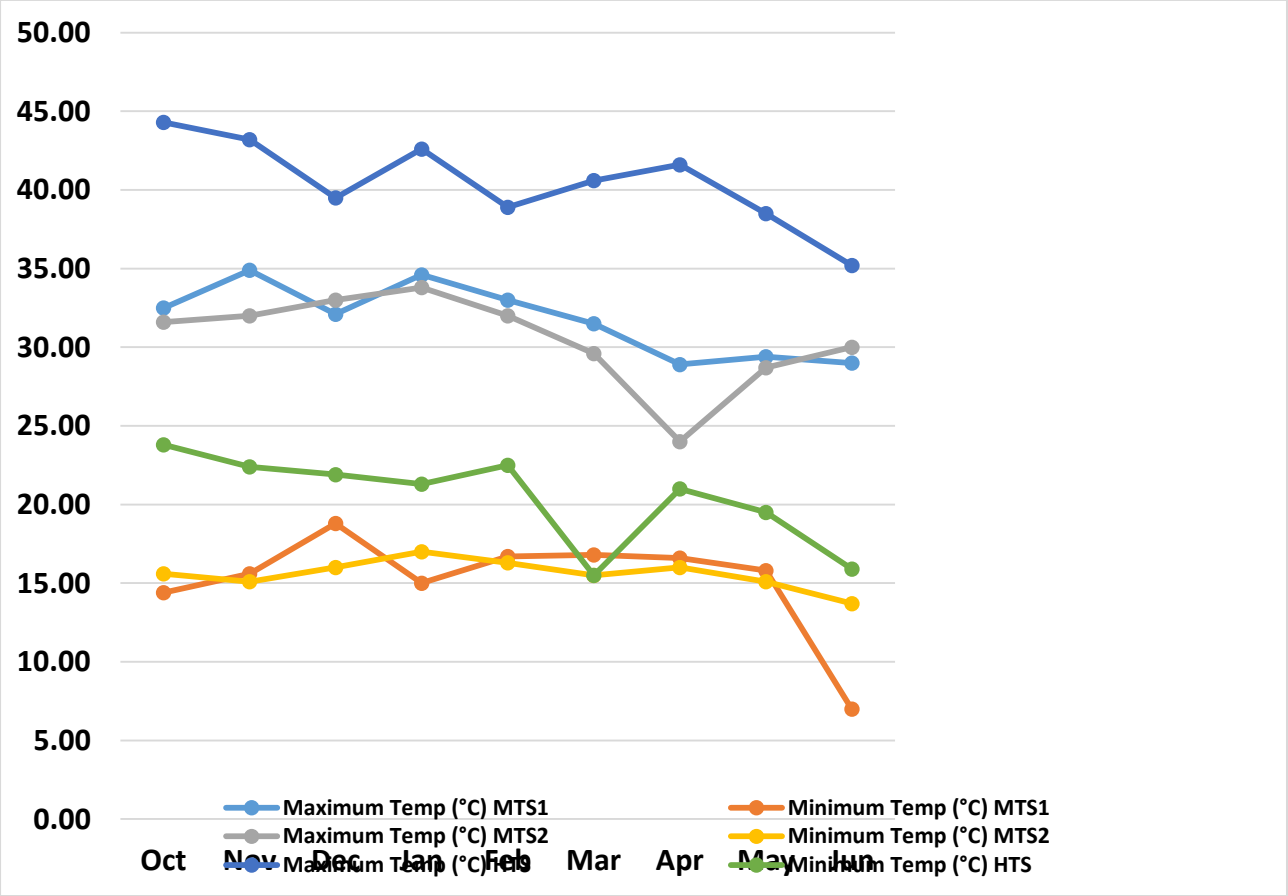


Figure 4. Rainfall for the three sites in the 2013/2014 season



KEY: MTS1 – Moderate temperature site 1 (Lundazi), MTS2- Moderate temperature site 2 (Kalichero) and HTS – High temperature site (Masumba)

Figure 5. Temperature data for the three study sites for 2013/2014 season

3.2. Plant materials

Four orange fleshed sweetpotato varieties Zambezi, Olympia, Kokota and Orange Chingovwa were used in the study. They were selected on the basis of their maturity period and intensity of the orange colour. The materials were obtained from Zambia Agriculture Research Institute Roots and Tuber crops Improvements section at Msekera station in Chipata district of Zambia. All varieties used in this study have a minimum of 4 months maturity period. Key parameters of the varieties used in the study are given in Table 3.

3.3. Chemical analysis

Prior to cultivation of the land in November, 2013, soil samples were collected from a depth range of 0-20cm soil depth. Major nutrients (Nitrogen, phosphorous, potassium), Cation exchange capacity (CEC), organic carbon, pH and soil conductance were determined in the laboratory at the University of Zambia Soil Science Department laboratory. Nitrogen was determined by the Macro Kjeldahl method (1960) as described by (Songolo and Pauwelyn, 2001) , phosphorus was determined using Bray 1 method and potassium was determined using Ammonium Acetate method buffered at pH 7, while organic carbon was determined using Walkley and Black method as described by Songolo and Pauwelyn, 2001. Cation exchange capacity was determined by Leaching method using ammonium acetate buffered at pH 7 and pH was determined using 0.01M calcium chloride (Songolo and Pauwelyn, 2001)

3.4. Land preparations and planting

Land preparation was done in December after rains had established and sufficient vegetation had grown to plough under. Land preparation was done using hand hoes. Standard ridges of 45cm high were prepared at 1m inter row spacing. Disease free planting materials obtained from the screen house were planted at the 30cm intra row spacing. During planting, 3 vine nodes were buried into soil leaving two nodes outside to establish as root and shoot systems respectively.

Table 1: Description of sites: Soils, temperatures (°C) and elevation in meters above sea level (masl)

Trial site	**Locality**	**Mean temperature °C**		**Soil type**	**Elevation (masl)**	**Average Rainfall (mm/annum)**
		Soil	**Air**			
High Temperature (Masumba)	S 12° 16' E 033° 11'	32.4	38.5	Loamy sand Well drainage soils	501	341
Moderate Temp Site 1 (Lundazi)	S 13° 29' E 032° 26	25.5	32.2	Sandy soils Well drainage soils	1340	647
Moderate Temp Site 2 (Kalichero)	S 13° 13' E 031° 55'	25.8	31.2	Loamy sand Well drainage soils	960	520

Table 2. Summary of soil analysis results for the three test sites where the sweetpotato (*Ipomea batatas*) study was conducted

Trial site	**pH**	**N%**	**P (mg/kg)**	**K (cmol/kg)**	**CEC(cmol/kg)**	**Soil texture (USDA)**
High Temperature (Masumba)	6.29	0.11	5.08	1.7	13.5	Loamy sand
Moderate Temp Site 1 (Lundazi)	6.4	0.07	25.33	0.54	4.5	Sandy loam
Moderate Temp Site 2 (Kalichero)	5.92	0.11	31.24	1.17	9.75	Loamy sand

3.5. General Crop Management

Normal agronomic practices were followed. Basal fertilizer (D compound) was also applied at the rate recommended by Latha *et al*., (2004) and Valenzuela, 1994. At planting a total of 100kg/ha D compound fertilizer was supplied to the crop in order to meet the minimum nutritional requirements of 22.5- 50 kg of N, 50- 270 kg P_2O_5 and 50- 75 kg K_2O (Valenzuela, 1994)

Weeding was done as weeds emerged. Before the crop was fully established, weeding was by hand hoe and later by hand to avoid damage to developing roots and tubers. At least more than two weeding were done using a hoe while a third one was done by hand pulling.

3.6. Temperature and rainfall measurement

Soil temperature was measured by copper plated soil thermometers mounted in the ground at each site at a depth of 20cm. 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.

3.7. Experimental design

A Split plot experiment design was used in this study, with environment being the main plot and varieties as sub plots. The plots each measuring 30 square meters with two guard rows was planted to each of the four varieties. Each ridge of 6 meters long carried 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 of 45cm across all the sites.

Table 3. 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/100g fresh weight basis	5 months	Widely adapted
Orange Chingovwa	LUS 114 x OP	2014	11.03 mg/100g fresh weight basis	5 months	Widely adapted
Kokota	LUS 140 x OP	2014	4.92 mg/100g fresh weight basis	5 months	Widely adapted
Zambezi	TIS2537 x OP	1993	10.9 mg/100g fresh weight basis	5 months	Does well in most areas except drought prone ones

Source: Chiona, M and Kapinga *et al.*, 2010

3.8. Data collection and Analysis

Data was collected on; Beta carotene content, Root yield, Marketable and Non-marketable weights, Harvest index, Vine mass at maturity, Dry matter content and Vitamin C content. Yield data was obtained by harvesting plants from four rows of each plot excluding the guard rows. The total tuber yield obtained from each net plot was then converted to mean tuber yield per hectare (t/ha). At maturity, the foliage weight per net plot, and weight of marketable and non-marketable roots and total root yield was recorded after grading them into different sizes based on their diameters. The grading was done per net plot of each treatment. The determination of marketable and non-marketable weights was conducted per net plot for each treatment and mean weight per hectare were then calculated.

The marketable tubers were those tubers exceeding 4.5 cm diameter and medium roots were 2.5 to 4.5 cm diameter while non-marketable roots consisted of small roots of less than 2.5 cm diameter (Osiru *et al.*, 2009). Leaf area was determined 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). Harvesting was done at 150 days after planting when the crop had matured.

3.8.1. Dry matter

Carefully harvested sweetpotato tubers, without visible damage were randomly selected from each net plot for determination of dry matter. From each plot four samples were collected, put in big A1 size polyethylene bags and immediately placed in cool conditions under a shade to avoid loss of moisture prior to analysis. Within two days after harvesting and sample preparation process, all samples were taken to University of Zambia, Food science and Technology laboratory for analysis. Dry matter determination was done after weighing 300 g samples of sliced roots and oven- drying to a constant weight at 70 $^{\circ}$C. Dry matter content of storage roots was expressed as the average percentage of dry weight of fresh weight (Mwanga *et al.*, 2007).

3.8.2. Beta carotene analysis

From the initial batch of harvested roots, 1000g portion was selected and put in A3 brown envelopes and after washing with deionized water the samples were wrapped in aluminium

foils prior to transportation to Lusaka for HPLC analysis at Zambia Agriculture Research Institute - Mt. Makulu Research Microbiology laboratory. Care was taken to ensure that the roots were under cool conditions and away from light prior and during analysis. The samples were then 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 in a fridge at -20 $^{\circ}$C. The procedure used in the determination of beta carotene content was as described by Rodriguez-Amaya and Kimura (2004)

3.8.3. Harvest Index

Harvest Index was estimated as a ratio of the total storage root yield of a plant to the total plant biomass at harvest (Harrison *et al*., 1981; Sharifi *et al*., 2009; Yeng *et al*., 2012). It expresses the percentage of storage root yield (considered as economic yield) to total biological yield.

3.8.4. Vitamin C determination

Vitamin C was determined using the iodometric titration method as described by Kanafe (2009)

CHAPTER 4

3 RESULTS

4.1 Effects of environment on beta carotene content of the four sweetpotato varieties.

Table 4 shows that locations were highly significantly different ($P < 0.001$) for beta carotene content for the four sweetpotato varieties used in the study. Means for total beta carotene content (mg/100g) across the three environments with different temperature regimes are presented in (Figure 8). The high temperature site showed lower contents than the two moderate temperature sites. There were no differences between the two moderate temperature sites 1 and 2. High temperature site recorded 7.23 mg/100g while moderate temperature sites 1 and 2 had 15.55 and 15.46 mg/100g, respectively.

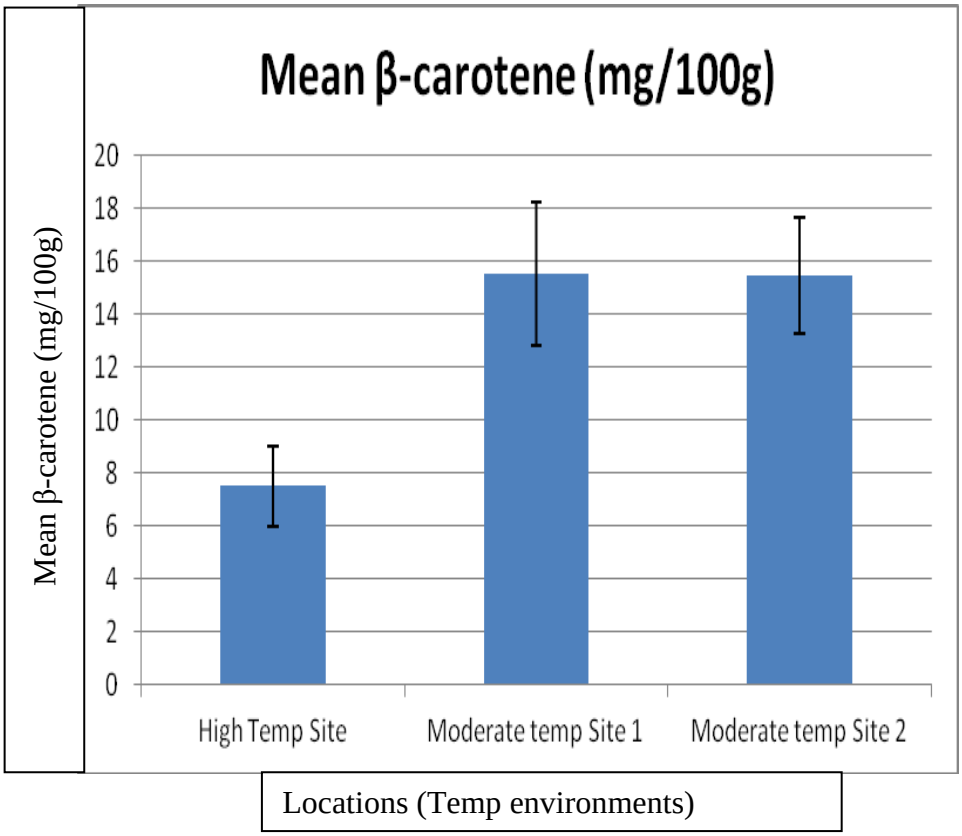


Figure 6: Response of β-carotene content (mg/100g) in all genotypes across the three different temperature environmental sites in in Eastern province of Zambia in the 2013- 2014 season

Observations

High temperature and moisture stressed site showed lower beta carotene contents than the 2 moderate temp sites; no difference between the two moderate sites.

4.2 Beta Carotene content

Table 5 shows that sites, varieties and their interactions were significantly different for beta carotene concentration at $P < .001$. The performance of the four varieties used in this study indicated beta carotene variation within and across the three sites. The two moderate temperature sites showed a higher performance of cultivar beta carotene than the high temperature site. Across all sites, Zambezi variety maintained the highest beta carotene content. For high temperature site Zambezi had the highest beta carotene content (12.56 mg/100g) followed by O. Chingovwa with 10.65 mg/100g. The lowest value was recorded by Kokota variety (0.41mg/100g) while Olympia had 5.32 mg/100g (Table 5). On the other hand, moderate temperature sites showed similar trends in beta carotene content. Kokota gave lowest beta carotene contents in all the three sites while Zambezi was the highest in all the sites. Orange Chingovwa and Olympia gave the second and third beta carotene yield values across all sites. Site by variety interaction were significant for beta carotene content. The average contents obtained in moderate site 1 (Lundazi), are similar to those obtained in moderate site 2 (Kalichero) with 15.55 and 15.46mg/100g respectively. Zambezi variety showed the highest beta carotene yield (23.67mg/100g) followed by O. Chingovwa (26.9mg/100g) and Olympia (7.81mg/100g). Kokota had the least beta carotene content in moderate temp site 1 and 2 of (3.81mg/100g) and 5.61mg/100g, respectively.

Moderate temperature site 2 showed a higher beta carotene content for Zambezi 27.41mg/100g followed by O. Chingovwa (19mg/100g) while varieties Olympia and Kokota entered lowest contents of 9.82mg/100g and 5.61mg/100g respectively. The general trend observed across three sites was that Zambezi was outstanding in beta carotene concentrations, followed by O. Chingovwa, Olympia and lastly Kokota. However, mean site beta carotene concentration was high in the moderate Temperature sites.

Table 4: Summary of analysis of variance for some parameters measured on sweetpotato (*Ipomoea batatas*) across the three sites

Sources of Variation	df	Root Yield(t/ha)	β - Carotene (mg/100g)	Marketable Roots (t/ha)	Non Marketable Roots (t/ha)	Leaf Area (cm^2)	Vine Weight (t/ha)	Dry Matter (%)	HI (%)	Vitamin C
Replication	3	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site	2	**	**	**	**	**	**	ns	**	ns
Variety	3	**	**	**	ns	**	ns	**	**	ns
Site. Variety	6	*	**	*	ns	**	ns	ns	**	ns
Residual	29									
CV (%)		8.4	7.7	11.1	7.1	2.5	14.4	4.2	10	1.5

[ns]not significant at 5% probability, **highly significant at P<0.001

Variety	High Temp Site Masumba	Moderate Temp Site 1 Lundazi	Moderate Temp Site 2 Kalichero	Across Site Means
		Beta carotene (mg/100g)([y])		
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[z]	**7.23**	**15.55**	**15.46**	**12.75**
Site. LSD	2.168			
Var. LSD	2.452			
Var.x Site LSD	4.032			
Rep. CV %	7.7			

[z]Overall means for all varieties across sites
[y]Expressed as a percentage of the highest cultivar beta carotene content.

Observations

High temperature site showed lower contents than the 2 moderate temperature sites; no difference between the 2 moderate sites. Kokota had lowest beta carotene across all sites followed by Olympia. Orange Chingovwa and Zambezi had similar values. In high temperature environment Kokota had 0.41mg/100g while the moderate temperature sites 1 and 2 it recorded beta carotene content 3.81mg/100g and 5.61mg/100g respectively. O. Chingovwa, Olympia and Zambezi also showed lower beta carotene in high temperature site and higher in moderately warm temperature sites. O. Chingovwa and Zambezi had similar values in moderate temp sites.

4.3 Yield Evaluation

4.3.1 Root Yield

The analyses of variance for yield across sites and variety and their interactions showed significant differences (P <0 .001). At high temperature site (Masumba) Olympia had the highest total tuber yield (3.28 t/ha) with lowest tuber yield shown by Zambezi (0.14 t/ha), while O. Chingovwa and Kokota had 0.26 t/ha and 0.21 t/ha, respectively. For moderate temperature site 1, Olympia performed well compared to other varieties with (17.44 t/ha) followed by Kokota (13.08 t/ha) and O. Chingovwa (9.74 t/ha) while Zambezi was the least with (7.58 t/ha). Moderate temperature site 2 (Kalichero) followed the trend exhibited in the other two sites for total yield. At this site, Olympia had highest root yield (15.79 t/ha) followed by Kokota with (9.56 t/ha) while O. Chingovwa and Zambezi recorded (9.19 t/ha) and (3.11 t/ha), respectively. With reference to sites, it was shown that high temperature site had lower root yield compared to the other two moderate temperature sites. The two moderate temperatures sites had similar values for root yield. The response of these varieties to the three environments were different across and within sites but showed yield similarities within a high temperature site with an exception of Olympia. Across all sites Olympia gave a highest root yield of (12.17 t/ha) followed by Kokota (7.62 t/ha) and O. Chingovwa (6.40 t/ha) with Zambezi being the lowest (3.61 t/ha) (Table 6).

Table 5: Mean root yield (t/ha) of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	High Temp Site	**Moderate Temp Site 1**	**Moderate Temp Site 2**	**Across Site**
	Masumba	**Lundazi**	**Kalichero**	
Variety		**Root yield (t/ha)([y])**		**Means**
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**
Mean[z]	**0.97**	**11.96**	**9.41**	**7.45**
Site. LSD	1.664			
Var. LSD	1.921			
Var.x Site LSD	3.328			
Rep. CV%	8.4			

[z]Overall means for all varieties across sites
[y]Expressed as a percentage of the highest cultivar root yield.

Observations

High temperature site showed lower root yields (t/ha) than the two moderate temperature sites. The two moderate sites had similar root yield values. Zambezi had lowest root yield across all sites followed by O. Chingovwa and Kokota. Olympia on the other hand showed highest yield across all sites with similar values obtained in the moderate temperature sites. Orange Chingovwa and Zambezi showed values lower than the overall mean obtained across sites. In high temperature environment Zambezi had lowest (0.14t/ha) followed by O. Chingovwa (0.21t/ha) and Kokota (0.26t/ha). The moderate temperature sites 1 and 2 on the other hand recorded similar higher values across all cultivars with yield differences obtaining within cultivars. Olympia showed a highest yield followed by Kokota, O. Chingovwa and Zambezi with 12.17t/ha, 7.62t/ha, 6.40t/ha and 3.61t/ha respectively.

4.3.2 Marketable yield (t/ha)

The moderate temperature site Lundazi gave the highest marketable root yield of (8.95 t/ha) followed by the other moderate temperature site Kalichero (7.5 t/ha) while the high temperature site had (0.587 t/ha) of marketable root yield. Olympia showed a consistently highest marketable root weight across all sites with (3.250 t/ha) for high temperature site, (13.875 t/ha) for moderate temperature site Lundazi and (13.788 t/ha) for other moderate temperature site, Kalichero. Individual sites also showed wider margins for marketable yield. High temperature site recorded lowest results for marketable roots with completely no roots at all in most cases. Except for Olympia, all other three varieties (Kokota, Orange Chingovwa and Zambezi) gave no yield (0 t/ha).

In the moderate temperature site, Lundazi Olympia gave the highest weight (13.875 t/ha) followed by Kokota (10.250 t/ha) and Orange Chingovwa (6.812 t/ha) while Zambezi was the lowest (4.888 t/ha). For moderate temperature site 2 (Kalichero site), Kokota was second highest marketable weight (7.950 t/ha) after Olympia (13.788 t/ha). This was followed by Orange Chingovwa (7.062 t/ha) and Zambezi (1.237 t/ha). Table 7 shows that across sites Olympia gave a highest mean weight (10.304 t/ha) followed by Kokota (5.976 t/ha), Orange Chingovwa (4.525 t/ha) and Zambezi (1.942 t/ha).

Table 6: Weight of marketable roots (t/ha) of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	High Temp Site	**Moderate Temp Site 1**	**Moderate Temp Site 2**	**Across Site**
	Masumba	**Lundazi**	**Kalichero**	
Variety		**Weight of marketable roots (t/ha)([y])**		**Means**
Kokota	0 (0)	10.25(73.8)	7.95(57.6)	**5.976**
O. Chingovwa	0 (0)	6.812(49.0)	7.062(51.2)	**4.525**
Olympia	3.25 (100)	13.875(100)	13.788(100)	**10.304**
Zambezi	0 (0)	4.888(35.2)	1.237(8.9)	**1.942**
Mean[z]	**0.587**	**8.956**	**7.509**	**5.684**
Site. LSD	1.388			
Var. LSD	1.603			
Var.x Site LSD	2.8			
Rep. CV	11.2			

[z]Overall means for all varieties across sites
[y]Expressed as a percentage of the highest cultivar weight marketable root.

Observations

Moderate temperature sites had significantly higher marketable yield than high temperature site. No difference between the two moderate temperature sites. In high temperature site there was no marketable yield in Kokota, Orange Chingovwa and Zambezi. Across all sites performance showed that Olympia had highest weight of marketable roots with 10.3 t/ha, followed by Kokota (5.97 t/ha) and Orange Chingovwa (4.52 t/ha).Zambezi was the lowest with 1.94 t/ha

4.3.3 Non Marketable yield (t/ha)

Means for non-marketable yield are presented (Table 8). Analysis of variance for non-marketable yield showed that the values were significantly different among sites (P <0 .001). Moderate temperature site 1 (Lundazi) had the highest non marketable root weight (3.0 t/ha) followed by moderate temperature site 2 (Kalichero) (1.9 t/ha) and high temperature site (1.628 t/ha). Means for each variety across the sites indicate that Olympia had the highest mean for non-marketable root weight (2.138 t/ha). This was followed by O. Chingovwa (2.0 t/ha), Kokota (1.66 t/ha) and Zambezi (1.605 t/ha). For high temperature, Olympia showed highest weight (0.854 t/ha) with Zambezi being lowest with (0.252 t/ha). Kokota and O. Chingovwa had (0.534 t/ha) and (0.378 t/ha), respectively. In the moderate temperature site (Lundazi), Olympia had the highest non marketable root weight (3.562 t/ha) compared to other varieties. The lowest value was recorded by Zambezi with (2.688 t/ha).

Table 7: Weight of non-marketable roots (t/ha) of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	High Temp Site	**Moderate Temp Site 1**	**Moderate Temp Site 2**	**Across Site**
	Masumba	**Lundazi**	**Kalichero**	
Variety		**Weight of Non Marketable Tubers (t/ha) ([y])**		**Means**
Kokota	0.534(62.5)	2.833(79.5)	1.613(75.9)	**1.66**
O. Chingovwa	0.379(44.4)	2.925(82.1)	2.125(100)	**2.0**
Olympia	0.854(100)	3.562(100)	2.0(94.1)	**2.138**
Zambezi	0.252(29.5)	2.688(75.5)	1.875(88.2)	**1.605**
Mean[z]	**0.505**	**3.002**	**1.903**	**1.803**
Site. LSD	0.602			
Var. LSD	0.695			
Var.x Site LSD	1.2			
Rep. CV %	7.1			

[z]Overall means for all varieties across sites

[y]Expressed as a percentage of the highest cultivar weight of non-marketable root.

Observations

Moderate temperature sites had significantly higher non marketable weight than high temperature site. There were no difference between the two moderate temperature sites. Olympia recorded high weight across all sites

4.3.4 Vine Weight

Table 9 shows that there was a significant difference ($P< 0.001$) across site for vine weight. It was found that at high temperature site Kokota yielded highest vine weight compared to other varieties. Comparing vine yield within this site, higher vine weight was produced by Kokota (25.9 t/ha) followed by Zambezi (23.4 t/ha) while Olympia and Orange Chingovwa were the lowest with (22.7 t/ha) and (22.5 t/ha), respectively. Moderate temperature site had similar results. Moderate temperature site 1 showed high vine weights for Zambezi variety (15.4 t/ha). Lowest vine weight was recorded by Kokota (10.2 t/ha) while Olympia and O. Chingovwa vine weights were (13.7 t/ha) and (12.3 t/ha), respectively. Moderate temperature site 2 (Kalichero) recorded lower vine weight values in comparison to other sites. Kokota gave a highest vine weight (10.4 t/ha) while Zambezi was the lowest with (7.0 t/ha) (Table 9). However no significant differences were observed for site and variety interaction in vine weight.

Table 8: Weight of vines (t/ha) of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	High Temp Site	**Moderate Temp Site 1**	**Moderate Temp Site 2**	**Across Site**
	Masumba	**Lundazi**	**Kalichero**	
Variety		**Vine Weight (t/ha)([y])**		**Means**
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**
Mean[z]	**23.641**	**12.905**	**8.739**	**15.095**
Site. LSD	2.4			
Var. LSD	2.9			
Var.x Site LSD	5.0			
Rep. CV	14.4			

[z]Overall means for all varieties across sites
[y]Expressed as a percentage of the highest cultivar vine weight.

Observations

High temperature site showed significantly high vine weight (23.641 t/ha) than the two moderate temperature sites. The two moderate sites had vine weights of 12.905 t/ha and 8.739 t/ha for moderate temperature sites 1 and 2 respectively. There were no statistical differences observed in vine weights among varieties within the sites. However, performance varied from one site to another with the highest weights recorded in high temperature site in all cultivars used in the study. There was no significant site by variety interaction for vine weight.

4.3.5 Dry Matter Content %

Analysis of variance for dry matter (DM) content in Table 10 shows that there were high significant differences among varieties ($p < 0.001$). The highest root dry matter content percentage were obtained from Zambezi variety (34.54%), followed by Kokota (33.28%), O. Chingovwa (32.16%) and the lowest value record was Olympia (28.98%). However, there were no statistical differences obtained for mean dry matter performance across the three sites. All sites had similar values for dry matter content. Moderate Temperature site 2 (Kalichero) had (33.98%), high temperature site (Masumba) (31.57%) while high temperature site 1 (Lundazi) had (31.14%) (Table 10).

Table 9: Dry matter % of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	High Temp Site	**Moderate Temp Site 1**	**Moderate Temp Site 2**	Across
	Masumba	**Lundazi**	**Kalichero**	Site
Variety		**% DM**		Means
Kokota	34.48	33.78	31.60	**33.28**
O. Chingovwa	28.18	32.27	36.03	**32.16**
Olympia	29.08	26.19	31.53	**28.98**
Zambezi	34.56	32.33	36.74	**34.54**
Mean[z]	**31.57**	**31.14**	**33.98**	**32.23**
Site. LSD	2.238			
Var. LSD	2.575			
Var.x Site LSD	4.476			
Rep. CV %	4.2			

[z]Overall means for all varieties across sites

Observations

No difference was observed among three sites in terms of dry matter content. There was no significant site by variety interaction for dry matter content. However, varieties were significantly different for dry matter. Zambezi showed the highest dry matter content across all sites with lowest being Olympia with 34.54% and 28.98% respectively.

4.4 Vitamin C content

Table 4 shows that site, variety and site x variety interaction were not significantly different for vine vitamin C content.

4.5 Leaf Area (cm^2)

Across site analysis (Table 11) indicated high significant difference ($P< 0.001$) in leaf area among sites, varieties and sites x variety interactions. Kokota indicated the highest leaf area (413.4cm^2), which was followed by Zambezi (300.5 cm^2) Orange Chingovwa (287.1cm^2) and Olympia (249.8cm^2).

Table 10:Table of means for Leaf area of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	High Temp Site	**Moderate Temp Site 1**	**Moderate Temp Site 2**	Across
	Masumba	**Lundazi**	**Kalichero**	Site
Variety		Leaf Area (cm^2)([y])		Means
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**
Mean[z]	**411.1**	**262.9**	**264.2**	**312.7**
Site. LSD	16.30			
Var. LSD	39.40			
Var.x Site LSD	60.43			
Rep. CV %	2.5			

[z]Overall means for all varieties across sites

[y]Expressed as a percentage of the highest cultivar leaf area.

Observations

High temperature site showed significantly high leaf area than the two moderate temperature sites. The two moderate sites had similar values for leaf area. There were no statistical differences observed in leaf areas among varieties within sites. However, performance varied from one site to another with the highest leaf areas recorded in high temperature site in all cultivars used in the study.

4.6 Harvest Index (HI %)

Site, variety and site x variety interactions were all highly significant for Harvest Index ($P<0.001$) (Table 12). Olympia performed exceptionally well for harvest Index percentage (41.7%), followed by Orange Chingovwa (26.6%) and Kokota (22.7%) while Zambezi recorded the lowest percentage (17.8%). Olympia was observed to be statistically different from Zambezi and Kokota varieties across all the three sites. However, no statistical differences were observed between Olympia and Orange Chingovwa (Table 12).

Table 11: Means for Harvest Index of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	High Temp Site	Moderate Temp Site 1	Moderate Temp Site 2	Across Site
	Masumba	Lundazi	Kalichero	
Variety		Harvest Index (%)		Means
Kokota	4.1	25.4	38.4	**22.7**
O. Chingovwa	5.5	28.2	46.1	**26.6**
Olympia	50.2	31.3	55.8	**41.7**
Zambezi	4.5	22.5	26.5	**17.8**
Mean[z]	**16.1**	**26.9**	**41.7**	**28.2**
Site. LSD	6.7			
Var. LSD	7.74			
Var.x Site LSD	13.40			
Rep. CV %	10.0			

[z]Overall means for all varieties across sites

Observations

Moderate temperature sites had higher HI than higher temperature sites**.** Moderate temperature site 2 had higher harvest index of 41.7% followed by moderate temperature site 1 with 26.9%, while the high temperature site showed the lowest harvest index of 16.1%. Olympia had the highest harvest index percentage across all sites (41.7%). Kokota and Orange Chingovwa had similar values for HI across all sites

4.7 Relationship between dry matter, yield, temperature, rainfall and Beta carotene content of sweetpotato roots

A simple correlation analysis was conducted to determine the relationship between temperature, rainfall, dry matter content and yield on beta carotene accumulation in orange fleshed sweetpotatoes in the four varieties. Results obtained from the simple linear correlation of beta carotene with temperature and rainfall showed negative correlations of (r = -0.434), (r = -0.438) and (r = +0.401) for air temperature, soil temperature and rainfall, respectively. Yield had a negative correlation with beta carotene (r = -0.438) implying that increasing yield may lead to decrease of beta carotene concentrations in storage roots. These results are in agreement with the findings by Mbwanga (2007). However, beta carotene content showed a positive correlation (r = +0.364) with dry matter content of storage roots (Table 13).

Table 12: Correlation of Beta carotene content against Temperature, Rainfall, Dry matter and yield of four sweetpotato (*Ipomea batatas*) varieties grown across the three different ambient temperature sites in Eastern Zambia districts

	r	**Relationship**
Dry Matter %	+0.364	positively correlated
Air Temperature.	-0.434	negatively correlated
Soil Temperature.	-0.438	negatively correlated
Rainfall	+0.401	positively correlated
Root Yield	-0.433	negatively correlated

CHAPTER 5

5 DISCUSSION

The results from this study on root yield indicated significant differences for environment and genotype main effects. Environmental factors seemed to contribute more to the variability of total storage root yield than does the genotypes. 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 performance of individual varieties across sites was variable, indicating the possibility of genotype and environmental influences. The high yielding varieties were identified as Olympia and Kokota which yielded above the average yield obtained across all the varieties.

The total mean yields obtained from this study for varieties Olympia, Kokota are similar to those reported by CIP (2011). The differences in yield among these varieties are attributable to variety and also the environment. Ngailo *et al*., (2013) reported that 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 promotes tuber yield. Low root yield recorded in higher temperature are in agreement with the reported results by Kathabwalika *et al.,* (2013) and Ngailo *et al*., (2013). On the contrary, moderate temperature sites gave higher root yields.

The variety Zambezi has runners which can extend on the ground over long distances from the main plant. This spreading growth habit could contribute to partitioning more assimilates in the foliage at the expense of root bulking. The spreading growth habits also makes the variety lose energy on transferring the photo assimilates from sink to sources which may be distant from the active source, hence reduced bulking of roots.

The evaluation of yield results also indicated that high temperature sites generally gave very poor root yield across all genotypes compared to the two moderate temperature results. The variations in yield among sites are attributable to variations in environmental and climatic conditions largely temperature, rainfall and soil type. Osiru *et al.,* (2009) reported the importance of weather and climatic factors as major contributing factors in variation of sweetpotato yields.

The two moderate temperature sites had lower foliage and total vine weights compared to the high temperature site. On the contrary, the two sites had the highest root yield and large storage root sizes compared to high temperature site. Results also indicated that all genotypes behaved same in each location with differences observed from one environment to another as a result of differences in the environmental factors. Genotypes converted most of its photosynthetic products into carbohydrates stored in tubers below the ground. In moderate temperature sites, most of the carbohydrates accumulated by the cultivar was being translocated to the roots and not the top parts of vine growth as was the case with the high temperature site. 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 low vine growth rate (Kathabwalika *et al.,* 2013).

Weight of marketable roots was highly significantly different across sites and varieties ($P< 0.001$). High differences were obtained between a high temperature site and the other two moderate sites. The low marketable root yields and high non marketable yields obtained in the high temperature site can be attributed to the supra optimal temperature conditions predisposed to the crop during its growth period. These results are in conformity with Mbwaga *et al.,* (2007) who reported that high yielding varieties invest more assimilates in roots than in leaves. Higher temperatures experienced during plant growth in the high temperature site had a greater influence in diverting photosynthate partitioning toward fibrous roots than to storage roots and promoted shoot growth at the expense of storage root growth. However, no statistical difference could be found among varieties for non-marketable yield while marketable yield among varieties were statistically different.

The vine yield results obtained in this study are in conformity with reports by other researchers that higher environmental temperatures influences sweetpotato growth by promoting the vegetative growth at the expense of root growth. There were highly significant differences in

yield of foliage across sites. In all sites, varieties were not statistically different. The results on obtained on vine yield ties with the results obtained for total yields in the three sites as high temperature site with high foliage yield had generally poor root yields and moderate temperature sites with lower foliage had high root yield.

In terms of beta carotene accumulation, the study revealed that beta carotene content of sweetpotato roots was influenced by both genotype and environment as well as their interaction (Table 4). The results from this study indicated significant differences for environment and genotype main effects for beta carotene. Environmental effects had a huge contribution to the variability in beta carotene contents obtained in this study than does the genotypes. High temperature site showed lower beta carotene contents than the two moderate temperature sites. The two moderate temperature sites showed no differences in beta carotene content.

The beta carotene trend shown in this study could be attributed to prevailing environmental conditions in the study sites. A high temperature environment recorded poor beta carotene content yields across all genotypes, whereas the two moderate temperature sites gave high beta carotene content across all genotypes of sweetpotato used in the study. The high temperature site (Masumba) is located at low altitude and is characterized by hot environmental temperatures and low rainfall. The moderate sites on the other hand are located at high altitudes and are characterized by warm temperatures and high rainfall. These results compare well with the findings of Kathabwalika *et al.*, (2016).

A cross site analysis of cultivars for beta carotene expressed cultivars; Zambezi, orange Chingovwa to have high beta carotene content compared to other cultivars tested. Kokota was the lowest performing variety among all varieties across all sites. The variations within genotypes would be a result of genetic make-up of the cultivars in the synthesis of carotenoids (Rodriguez-Amaya and Kimura, 2004; Kathabwalika *et al.,* 2016). Some genotypes produce more beta-carotene than others due to the differences in their genetic makeup. The results obtained in this study are also similar to those reported by Serenje and Mwala (2010) who found up to 9.23mg/100g, Ndirigwe *et al*., 2005; Manrique and Hermann, 2001 who found beta carotene to range from 0.00 µg/g to 116.9µg/g and Kathabwalika *et al.*, (2016) reported beta carotene contents ranging from 3.5- 6.7mg/100g in orange fleshed sweetpotato genotypes. In

addition, high beta carotene contents obtained in the two moderately warm temperatures sites are in agreement with results obtained by Kathabwalika *et al*., (2016) who reported an increasing trend in beta carotene contents in sites with warm temperatures. However, the very hot environmental temperatures seem to affect beta carotene accumulation negatively in sweetpotatoes. The accumulation of beta carotene in the sweetpotato root tissues was influenced by changes in the environmental temperatures and rainfall during the crop growing period. Light intensity and light quality are extremely important in regulating the plant leaf temperature and its metabolic activities. Lester (2006) reported that light intensity is important in determining plant leaf temperature and that reducing light intensity reduces leaf temperature, which is favourable for beta carotene synthesis. This report by Lester (2006) hold true for the results obtained in this study, in that more beta carotene content was obtained in cultivars under moderate temperature environments than hot temperature environments (Figure 1). Both sub optimal and supra optimal temperature conditions affect the integrity of thylakoid membrane, and thus affect the synthesis and stability of carotenoid compound (Maevskaya *et al*., 2003; Rokka *et al*., 2000; Mark *et al.,* 2005). High temperatures (and low soil moisture) can reduce photosystem II (PSII) activity, antioxidant enzyme activity and increased Reactive oxygen species (ROS) content and thylakoid membrane damage as well as reduced yields. Beta carotenes are essential components of the photosynthetic machinery, and play a critical role in preventing photo oxidative damage.

CHAPTER 6

6 CONCLUSIONS AND RECOMMENDATIONS

This study sought to determine the relationship of environmental temperature and rainfall to some extent during plant development on beta carotene accumulation and yield of orange fleshed sweetpotatoes.

The study revealed substantial variations on beta carotene accumulation and yield of orange fleshed sweetpotato varieties under different environmental conditions. Beta carotene content and yield of sweetpotatoes differed within genotypes and across production environments. This study has shown that environmental temperatures seemed to have conferred pronounced effects on concentration of beta carotene in sweetpotato roots as well as on storage root yield. Beta carotene accumulation in storage roots increased in moderately warm temperature environments (agro ecological region II) while on the other hand, extremely hot temperature environment accompanied by low rainfall negatively affected the concentration of beta carotene and the yield of sweetpotato genotypes. This site indicated poorest results of beta carotenes and yield of sweetpotato genotypes used.

The results showed that despite environment showing a major effect on the beta carotene content and yield of orange sweetpotato varieties, genotypes also contributed to variations in the various traits. Genotypes Zambezi and Orange Chingovwa consistently produced highest amounts of beta carotene across sites. The environment affected the four sweetpotato genotypes differently with the moderately warm environmental site being highly favoured for production of beta carotenes and yield across all genotypes. All genotypes showed low total root yield, beta carotene and high vine yield in the extreme hot environmental climate (agro ecological Region I). The study on the other hand also showed that moderately warm temperature sites (agro ecological Region II) were suitable sites for production of sweetpotato genotypes for optimal yields and beta carotene accumulation.

Since this study was carried out in two different agro ecological regions with different environmental temperatures, it is recommended that sweetpotato breeders should be breeding

genotypes ideal for specific environments. In addition, it is recommended that further research be conducted under temperature and moisture controlled environments

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APPENDICES

Appendix A: Analysis of variance for beta carotene across the three sites

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Source of variation	d.f	s.s.	m.s	v.r.	F pr.
REP stratum	3	34.504	11.501	1.44	
REP.*Units* stratum					
Site	2	729.395	364.697	45.66	<.001
Variety	3	2694.525	898.175	112.45	<.001
Site.Variety	6	372.506	62.084	7.77	<.001
Residual	29	231.643	7.988		
Total	43	3798.047			

Appendix B: Analysis of variance for root yield across the three sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	13.960	4.653	0.87	
REP.*Units* stratum					
Site	2	1057.957	528.979	98.84	<.001
Variety	3	457.980	152.660	28.52	<.001
Site.variety	6	113.803	18.967	3.54	0.008
Residual	33	176.610	5.352		
Total	47	1820.310			

Appendix C: Analysis of variance for weight of marketable tubers (Kg/ha) across the three sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.445E+07	4.818E+06	1.31	
REP.*Units* stratum					
Site	2	6.402E+08	3.201E+08	86.81	<.001
Variety	3	4.413E+08	1.471E+08	39.89	<.001
Site.Variety	6	1.012E+08	1.686E+07	4.57	0.002
Residual	29	1.069E+08	3.687E+06		
Total	43	1.138E+09			

Appendix D: Analysis of variance for weight of Non Marketable roots (Kg/ha) across the three sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	589540	196513	0.28	
REP.*Units* stratum					
Site	2	50137303	25068651.	36.33	<.001
Variety	3	2068794	689598.	1.00	0.408
Site. Variety	6	1104931.	184155.	0.27	0.948
Residual	27	18633003.	690111.		
Total	41	60924234.			

Appendix E: Analysis of variance for vine weight across the three sites.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.705E+08	5.684E+07	4.68	
REP.*Units* stratum					
Site	2	1.892E+09	9.459E+08	77.94	<.001
Variety	3	6.363E+06	2.121E+06	0.17	0.913
Site.Variety	6	1.008E+08	1.680E+07	1.38	0.254
Residual	29	3.520E+08	1.214E+07		
Total	43	1.920E+09			

Appendix F: Analysis of variance for number of marketable roots harvested/ha for the four varieties across the three sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
REP stratum	3	6.008E+07	2.003E+07	1.03		
REP.*Units* stratum						
Site	2	2.757E+09	1.378E+09	70.98	<.001	
Variety	3	1.070E+09	3.568E+08	18.37	<.001	
Site.Variety	6	1.797E+08	2.995E+07	1.54		0.200
Residual	29	5.631E+08	1.942E+07			
Total	43	4.051E+09				

Appendix G: Analysis of variance for Dry Matter (DM) Content percentage for the four varieties across the three sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
REP stratum	3		65.083	21.694	2.26	
REP.*Units* stratum						
Site	2		74.621	37.311	3.89	0.032
Variety	3		208.027	69.342	7.24	<.001
Site.Variety	6		162.891	27.149	2.83	0.027
Residual	29		277.817	9.580		
Total	43		750.324			

Appendix H: Analysis of variance for Vitamin C content for four varieties across sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	63.6	21.2	0.07	
REP.*Units* stratum					
Site	2	1110.0	555.0	1.72	0.200
Variety	3	2699.7	899.9	2.79	0.062
Site.Variety	6	3584.2	597.4	1.85	0.130
Residual	25	8073.6	322.9		
Total	39	14158.7			

Appendix I: Analysis of variance for Leaf Area (LA) for the four varieties across the three sites

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
REP stratum	3	2159.	720.	0.38	
REP.*Units* stratum					
Site	2	232116.	116058.	61.87	<.001
Variety	3	178811.	59604.	31.78	<.001
Site. Variety	6	83536.	13923.	7.42	<.001
Residual	33	61901.	1876.		
Total	47	558522.			

Appendix J: Analysis of variance for Harvest Index (%) across the three sites

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	287.96	95.99	1.12	
REP.*Units* stratum					
Site	2	5268.35	2634.17	30.79	<.001
Variety	3	5371.16	1790.39	20.92	<.001
Site.Variety	6	2811.04	468.51	5.48	<.001
Residual	29	2395.80	85.56		
Total	43	13572.83			

Appendix K: Summary of Analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	13	2696.5	207.42	7.89	<.001
Residual	21	552.2	26.29		
Total	34	3248.7	95.55		