

Sweet potato (*Ipomoea batatas* L.) as a drought tolerant and food security crop

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Sweet potato is an important 'indigenised' root crop in South Africa. It features prominently in smallholder cropping systems because of its versatility, drought tolerance and positive role in food security. It outranks most staple crops in vitamins, minerals, dietary fibre and protein content. Much information is available on sweet potato as a drought tolerant and food security crop, but critical reviews that link its drought tolerance with food security are lacking. We review sweet potato as a food security crop, focusing on mechanisms associated with drought. We conclude that the crop has great potential in the light of imminent challenges associated with drought as a negative effect of climate change.

Introduction

Globally, sweet potato (*Ipomoea batatas* L.) is considered an important, versatile and underutilised food security crop.^{1,2} It belongs to the second most important set of food crops in developing countries, namely root crops.¹ The crop is highly nutritive, and it outranks most carbohydrate foods in terms of vitamin, mineral, dietary fibre and protein content.^{2,3} A recent report from the Food and Agriculture Organization (FAO)⁴ indicated that 24.8% of the population in southern Africa remain undernourished and agricultural projects and crops that can deliver quick results were needed to meet the first 2015 millennium development goal. Sweet potato is one crop that has a wide ecological adaptation, drought tolerance and a short maturity period of 3 to 5 months.³ It can also be harvested sequentially, thus ensuring continuous food availability and access, an important dimension of food security.

Prior to 1986, sweet potato was regarded as a low value, low status and highly perishable commodity in southern Africa.⁵ It received little research attention until the Southern African Root Crops Research Networks (SARRNET) intervened by distributing germplasm and encouraging demand-led research. This initiative prompted the release of several new varieties within southern Africa.

Orange-fleshed and yellow-fleshed cultivars have been recognised as good sources of β -carotene, a precursor of vitamin A^{6,7} and are promoted across the developing world. According to Laurie⁸, vitamin A deficiency in South Africa is still a serious health problem. Studies by Labadarios⁹ reported that 64% of children between the ages of 1 and 9 years, and 27% of women of reproductive age, were vitamin A deficient in South Africa. The highest prevalence was concentrated in Limpopo (43.5%) and KwaZulu-Natal (38.9%). Poor education of mothers was highlighted as the main cause of vitamin A deficiency in rural communities.⁸ This deficiency suggests that nutrition education, not just literacy, needs to be part of participatory studies on food security in the rural areas affected by poverty and malnutrition.

In South Africa, sweet potato is grown throughout the tropical regions, including KwaZulu-Natal.⁸ Its consumption is steadily increasing despite relatively low production levels.¹⁰ Average yields are ten times lower for small-scale farmers compared with commercial growers. Laurie and Magoro¹¹ reported mean yields of 3.9–9.5 t/ha on communal gardens compared with 25.2 t/ha at experimental stations. These yields confirm the large yield gap that exists between poor and well-equipped environments. Because sweet potato is considered an important source of food, particularly in the dry season,¹² its importance for improving food security cannot be overemphasised. Despite the reported low yields among smallholder farmers, the crop has flexible planting and harvesting schedules, especially in frost-free areas.¹³

Sweet potato is a drought tolerant crop with the potential to enhance food and nutrition security, especially for subsistence and small-scale farmers in South Africa. For sweet potato, drought stress accounts for 25% total annual yield loss¹⁴ compared to more than 50% yield loss or complete failure in staple crops such as maize.¹⁵ Despite this advantage, its importance as a food security crop is still underestimated and fails to attract sufficient attention from agricultural researchers. The aim of this review was to illustrate, from an agronomic perspective, the importance of sweet potato as a traditional drought tolerant and potential food security crop.

Sweet potato as a traditional crop

Sweet potato is amongst the oldest crops in the world, especially in the wet tropics, and was among the first staple crops before the introduction of cereals. Today it is counted among root crops (cassava, sweet potato, yams and aroids) that represent the second most important set of staple foods in developing countries, closely following cereal crops.^{1,2} According to Battisti¹⁶, sweet potato is a misunderstood vegetable, often confused with yams. Portuguese explorers are believed to have introduced sweet potato to Africa in the 16th century.^{1,17} From there it was taken to the eastern and western parts of the world in the form of storage roots by Spanish explorers. When it failed to yield in European countries because of low temperatures, it was brought back to Africa and was planted in the warm coastal regions where it spread rapidly.^{1,18}

According to Laurie⁸, sweet potato was introduced to South Africa in 1652 around the time when the Dutch, under the leadership of Jan van Riebeeck colonised the Cape. It is now referred to as one of the traditional crops¹⁹ and a plant of the past¹ because of the time it arrived in Southern Africa. Sweet potato has been indigenised^{13,19} and classified as a neglected and underutilised crop species. About 12 cultivars were released by the Agricultural Research Council between 1959 and 1989: 7 new (cream-fleshed) varieties and 1 locally bred orange-fleshed variety (Serolane) were released (in South Africa) for local production during the 2003/2004 season.^{11,20} According

to Laurie⁸, nine of the released varieties to date are orange-fleshed sweet potato (OFSP) varieties. Production of these varieties has also spread throughout the tropical and warm regions of the country, the main producing regions being the Western Cape, northeast Limpopo, Free State, Eastern Cape, Gauteng, Mpumalanga lowveld, and northern KwaZulu-Natal Provinces.

KwaZulu-Natal environment for sweet potato production

KwaZulu-Natal is a subtropical region situated on the east coast of South Africa with diverse climate, soils and topography, virtually making it a 'world-in-one'.²¹ It is a summer rainfall area (600–2000 mm/annum) with weather that ranges from extremely hot along the coast in summer to heavy snow in the mountainous midlands in winter.^{21,22} KwaZulu-Natal has three climate zones of which 1% is tropical, 44% subtropical and 55% temperate.²² The environment in the tropical and subtropical parts of the province are regarded as suitable for sweet potato production throughout the year. Depending on whether farmers produce the white or OFSP varieties, the high prevalence of vitamin A deficiency^{7,9} in the province could be controlled through the consumption of this vegetable (Figure 1).

Variations in the climatic zones of KZN are bound to bring about several abiotic and biotic stress conditions, which have direct and indirect effects on the crop.²³ Sweet potatoes are very sensitive to frost and require hot days and warm nights. The suitable conditions prevailing in the bioresource group areas along the coast, in parts of the midlands and the northern areas of Zululand,^{21,22} are dominated by smallholder farmers. The crop has a cropping season of 4–5 months so smallholder farmers can plant sweet potatoes from August to March, thus spreading the cropping season. Underutilised crops such as sweet potato tend to possess characteristics adaptable to abiotic stress conditions. These conditions are predicted to become even more prevalent in the coming decades as a result of the effects of climate change.²⁴ The current and predicted challenges call for an agricultural system that is able to provide food crops that are capable of meeting current and future food demands and nutrition security. It is necessary to investigate whether the province that has a high population of rural poor people, namely KwaZulu-Natal, can be used as the major production areas for drought tolerant cultivars of sweet potatoes for food security and commercialisation in the near future.

Importance and utilisation

Sweet potato is regarded as the most important root crop of the tropics because of its flexibility in a number of production aspects.¹³ It can be planted and harvested at any time of the year, especially in frost free areas. It has a short cropping season, uses non-edible parts as planting material, and has a non-trellising growth habit as well as low requirement

for soil nutrients.^{1,5,10} Bovell-Benjamin² reported that it produces more edible energy than any other major food crop. It is more productive within short periods on marginal lands and plays an important role in the economy of poor households.¹² The most important edible sweet potato parts are the roots and immature leaves, which are used for human consumption, animal feed and to some extent, for industrial purposes.^{2,25}

It has been reported that in some African countries, starchy crops such as sweet potato are the staple food while other countries use it as an additional or as a food security crop.^{14,26} The use of sweet potato for food security concurs with earlier reports that sweet potato storage roots were often kept in the ground and harvested when needed.²⁶ Keeping the roots in the field not harvested is an indication that sweet potato can provide a continuous food supply during the off season with no requirement for expensive storage infrastructure. It becomes important in the diet seasonally, typically in the month or two before the major grain harvest or when the grain stock from the previous year has been exhausted. Sweet potato also provides a food reserve when the major grain crop fails because of drought¹⁵ and pest infestation.

Storage roots can be boiled, baked or roasted with some people preferring to eat them raw. The leaves can also be consumed as a green leafy vegetable.^{10,25} Sweet potato leaves may possibly have some medicinal properties as the polyphenol-rich green extracts are reported to play a role in reducing prostate cancer.^{25,27,28} Reports from China, the leading global sweet potato producer, indicate that they also use sweet potato for starch production and as a raw material for biofuel production.^{1,29} The plant sap (juice) of red sweet potato has been reported to play a vital role in producing dye for cloth in South America. The attractive foliage adds aesthetic value³⁰ and is another non-nutritive use of sweet potato.

Flavonoid compounds of fruit and vegetables are considered therapeutic agents because they have health benefits such as their supposed protection against certain cancers, cardiovascular diseases and aging.^{27,28} It is necessary to investigate if and how drought affects these properties because phenols and flavonoids may be responsive to stress.

Nutritional value

The sweet potato root provides almost a balanced diet for the human body. The crop contains significant amounts of carbohydrates when compared to other starchy crops such as rice, maize and sorghum porridge, although the protein content is slightly lower than in potatoes and other grain crops (Table 1).¹ It contains almost all the macro- and micro-nutrients, substantial quantities of vitamin C, moderate amounts of vitamin B complex (vitamins B1, B2, B5 and B6) and folic acid, as well as satisfactory amounts of vitamin E.^{2,31}

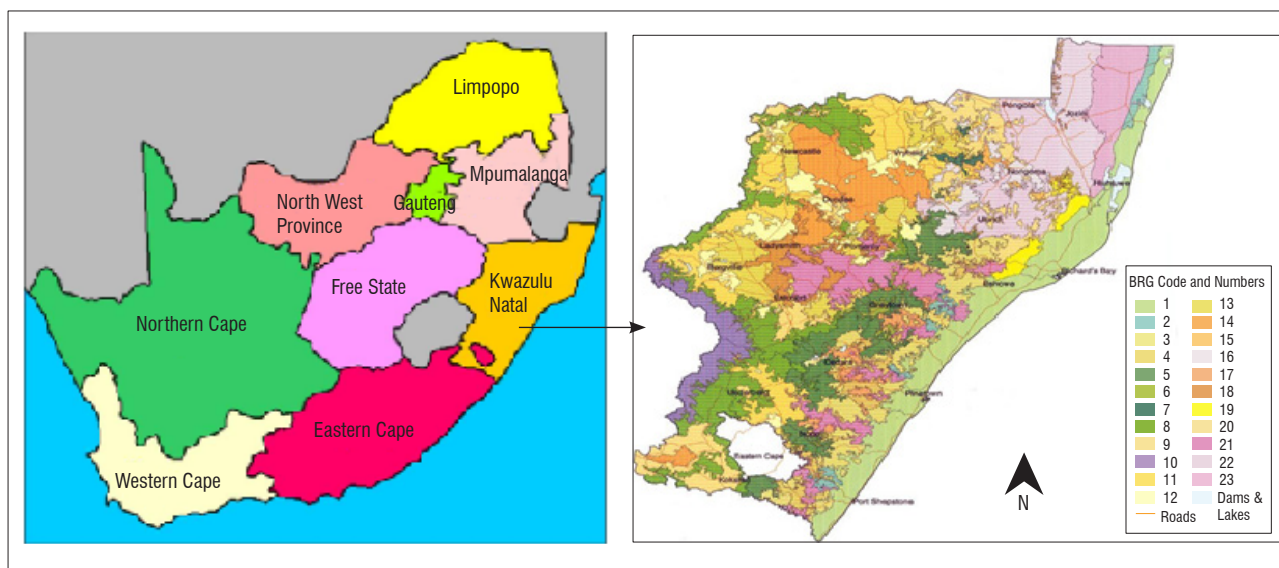


Figure 1: Map of KwaZulu-Natal and the different agro-ecological zones.

Table 1: Macro-nutrient content per 100 g boiled portion of sweet potato compared to other crops

Food	Moisture content (%)	Energy		Dietary fibre	Total carbohydrates	Fat	Protein
		kcal	KJ				
Sweet potato	71	114	477	2.4	26.3	0.4	1.7
Rice	68	135	565	0.8	28.0	0.3	2.3
Maize porridge	81	76	318	–	15.6	0.8	1.8
Sorghum porridge	80	85	356	–	17.0	0.5	2.7
Pasta	66	132	552	–	26.7	0.7	4.1
Potato	78	80	335	2.1	18.5	0.1	2.1

Source: Adopted from Woolfe¹

Orange-fleshed sweet potato has been reported by several authors to contain high amounts of vitamin A and is currently being promoted by the FAO and other in-country programmes as a supplementary food to combat vitamin deficiencies in children.^{2,3,7,20} According to Laurie²⁰, South Africa is also using orange-fleshed sweet potato varieties in food diversification programmes to alleviate vitamin A deficiencies. Such programmes include school and community garden projects within the integrated nutrition programme.^{32,33}

Sweet potato leaves are also nutritious (Table 2). They are a good source of protein and vitamins A, C and B₂ (riboflavin).¹ According to Bovell-Benjamin², sweet potato leaf protein content is twice as much as that from the storage roots. Leaves are also an excellent source of lutein.^{34,35} Lutein is responsible for central vision in the human eye and helps to keep eyes safe from oxidative stress and high-energy photons of blue light. Sweet potato is also popular in low fat diets and is recommended as a low glycaemic index (GI) food.^{2,13} Given the ailing nutritional status of many South African communities,¹¹ plus the fact that many food sources which typically provide these nutrients are not as drought tolerant, the sweet potato, with its high nutritional content, is a very important food source.¹⁰

General food security aspects

The world is reported to produce enough food to feed the human population, yet approximately 30% of sub-Saharan Africa's population (218 million people) suffers from chronic hunger and malnutrition.⁴ According to the World Health Organization³⁶, food security is built upon three pillars: availability, access and use (utilisation and stability). In trying to address the food availability pillar of food security, South Africa has identified small-scale agriculture as an important sector. This sector

still needs to be investigated as little effort has been made in channelling investment towards it. Rising food prices, particularly of maize and wheat, which are the staple diet for the poor in South Africa, poses serious problems for urban and rural poor people.³⁷

From the perspective of food security, sweet potato is an excellent crop as it often survives where staple crops fail.^{1-3,13} It contributes to food availability by providing high output per unit of land (yields about 3.9–9.5 t/ha under communal agriculture compared to less than 1–3 t/ha reported for maize under similar management) and can produce on marginal soils.^{1,11} The fact that it has higher energy (Table 1) than maize, also adds more strength to its potential role as a food security crop. Moreover, the fact that new OFSP varieties also contribute significantly towards vitamin A supplementation in rural households, where vitamin A deficiency is more prevalent, makes it a crop of choice. Good health is considered an outcome indicator for food utilisation in food security measurement,⁴ and the high nutritional status of sweet potato qualifies the crop as a food security alternative. Improved early maturing varieties are often ready for harvest in 3–5 months and can be harvested as needed over several months.^{26,38} The benefit of harvesting early and consuming over several months implies that there is a quick turnover and a lasting source of food, hence, improved food access, availability and stability. The food security benefits of sweet potato mentioned above could also lead to the crop being removed from the 'underutilised' category.

Accessibility to sweet potato is also simple because the vines and roots can be easily stored or multiplied. In drought prone areas, roots can be sprouted to produce vines so that communities have access to planting material. According to Lebot³⁹, sweet potato has often been a lifesaver, for example, it saved the Japanese nation when typhoons destroyed all their rice fields just before World War I. During the early 1960s, China was

Table 2: Nutrient composition of sweet potato leaves compared to other common vegetables

Crop	Total protein	β -carotene	Calcium	Iron	Riboflavin	Ascorbic acid
	(g/100 g)	(μ g/100 g)	(mg/100 g)			
Sweet potato leaves	29	2700	75–183	1.8–3.9	0.35	32–136
Amaranth	28	6545	176	2.8	0.22	23
Cabbage	1.9	–	44	0.4	–	–
Carrot	0.7	–	48	0.6	–	–
Spinach	3.2	–	93	3.1	–	–
Tomato	0.9	–	13	0.4	–	–
Lettuce	1.0	1000	23	0.9	0.08	15

Source: Adopted from Woolfe¹

plagued by famine and the availability of sweet potatoes saved millions of the population from starvation. The OFSP varieties played a major role in addressing hunger and drought mitigation after biotic and abiotic stresses in different parts of the world, including after the floods in Mozambique in 2000.⁴⁰ Its use as a lifesaver is evidence that sweet potato is indeed a food security crop.^{2,12,13,26,39}

Sweet potato for combating vitamin A deficiencies

Raw and cooked sweet potato roots are highly nutritious.^{1,2,20,39} Moreover, orange-fleshed sweet potato is reported to contain high amounts of β -carotene, a precursor for vitamin A. The β -carotene content increases with the intensity of orange colour of the sweet potato flesh.^{2,20,41} Leighton⁴¹ tested for β -carotene in different South African orange-fleshed sweet potato varieties (Table 3) and found that indeed, β -carotene concentration varied with depth of colour. Low et al.⁴² reported that studies conducted in sub-Saharan Africa demonstrated that consumption of boiled orange-fleshed sweet potato improved vitamin A status of children. A separate study by Amagloh⁴³ confirmed that orange-fleshed sweet potato was high in vitamin A and could be used as a complementary food in infant feeding. To improve the consumption of this vitamin A rich type of sweet potato, Laurie and Van Heerden⁴⁴ prepared different food types (chips, doughnuts, juice from the roots and a green leafy dish from the leaves) from orange-fleshed sweet potato to determine consumer acceptability. They reported that 92% of the consumers liked the colour of the food products while 88% indicated that they would buy sweet potato products or prepare them at home.

Table 3: Concentration of β -carotene in different varieties of orange-fleshed sweet potato in South Africa

Variety	Flesh colour	μ RAE*/100 g (uncooked)	μ RAE/100 g (boiled root)
Resisto	Dark orange	1371	1165
Khano	Dark orange	1170	995
2001-5-1	Dark orange	983	836
W-119	Orange	872	741
Beauregard	Dark orange	804	683
1999-1-7	Dark orange to pale orange	797	677
Excel	Orange, yellow cortex	433	368
Serolane	Orange with yellow ring	426	362
Impilo	Orange to pale orange	424	360

Source: Adopted from Laurie et al.¹³ and Laurie⁹.

RAE, retinol activity equivalents

Drought and water stress on plants

Stress is defined as an alteration in physiological condition caused by factors that tend to disrupt the equilibrium.^{45,46} Strain, on the other hand, is any physical and chemical change produced by stress.⁴⁶ Drought is a meteorological term commonly defined as a period without significant rainfall.⁴⁵ The crop physiologists' understanding of drought stress is that it occurs when available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration and evaporation.^{23,45} Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Desiccation is a much more extensive loss of water which can potentially lead to gross disruption of metabolism and cell structure and eventually to the cessation of enzyme catalysed reactions.⁴⁶⁻⁴⁸ It is characterised by a reduction in soil water content, diminished leaf water potential and turgor loss, closure of stomata and a decrease in cell enlargement and growth.⁴⁸ According to Sairam et al.⁴⁹, drought is not only the lack of rainfall; it can also be defined by its impacts such as crop shortages and indirect

impact, for example, food price increases. Sairam et al.⁴⁹ further explained drought as 'an exogenous supply side-shock that causes marked declines in agricultural output, export earnings, employment and income levels'. It affects all facets of economy because of close sectorial linkages.

The four main categories of drought (meteorological, agricultural, hydrological and socio-economic) have a direct impact on food security in the sense that they challenge the whole notion of food availability, accessibility, utilisation and stability. The fact that South Africa is a drought prone region already provides reason to focus on drought. Additionally, climate change predictions that there will be increased frequency and severity of such droughts²⁵ gives an even greater sense of urgency to identify crops that are resilient and can produce under such adverse conditions⁵⁰. These crops should not only possess drought tolerant characteristics, but should also be nutritious. It is in this context that sweet potato is being touted as a possible fit. However, before one can successfully promote the crop as drought tolerant and nutritious, one needs to generate empirical information detailing the crop's responses to such conditions.

Effect of drought on plant growth

Plant roots interconnect the physiological and biochemical reactions in stems and general plant growth to changes in plant nutrition, photosynthesis, water relations, respiration, nutrient metabolism and growth promoters.^{23,46} Water stress inhibits cell enlargement more than cell division. A prolific root system has the advantage of supporting accelerated plant growth during early crop growth stages and extracts water from shallow soil layers that is otherwise easily lost to evaporation.²³

The prolific root system of sweet potato makes it a drought tolerant crop, although supplementary irrigation is required at the time of planting for proper sprouting and establishment.^{13,41} Water stress reduces stem extension and internode diameter of sweet potato cultivars. The severity of this reduction is reported to differ with different cultivars.⁵¹ Inhibition of cell expansion and cell growth is mainly the result of low turgor pressure under water stress conditions. Osmotic regulation can enable the maintenance of cell turgor for survival or can assist plant growth under severe drought conditions.⁵² Water stress reduces leaf growth which in turn reduces the leaf area of plants.^{23,46,52}

Diminished biomass caused by water stress was observed in almost all cultivars of sweet potato; however some cultivars showed better stress tolerance than others.^{53,54} The fact that water stress inhibits leaf expansion and vine extension^{39,51} suggests that general vegetative growth in sweet potato would be compromised because the canopy represents the only source of biomass for subsequent partitioning to the storage root.

Studies by Jaleel et al.²³ indicated that water stress can reduce yield in many crop plants and that different crops respond differently to water stress. As the canopy represents the only source of biomass for subsequent partitioning to the storage root in sweet potato, if biomass is limited, it would consequently impose a source limitation of assimilates to storage roots thus lowering final yield. Little information or literature is available which details the extent to which sweet potato yield would be affected if vegetative growth was inhibited by water stress. Saraswati et al.⁵¹ only reported on morpho-physiological characteristics of sweet potato when exposed to water stress; they did not report on the effects of water stress on yield. According to Lebot³⁹, attempts to demonstrate relationships between yields and particular morphological or physiological characteristics have so far been unsuccessful. However, varieties with small canopies, short stem length and small leaves were reported to have the capability of giving higher yields than those with long stems and numerous broad leaves.⁵⁵ The higher yields in small canopy varieties might be a result of plants maximising storage root development and expansion over shoot extension. Given that different genotypes will respond differently, there is a need to evaluate available genotypes across the range of climates where sweet potato can be grown, to allow for the formulation of better recommendations to assist farmers with variety selection. Plants exposed to environmental stresses such as drought and heat stress respond by showing ingenious adaptations at physiological level, which may be accompanied by

changes in various gene expressions.⁵⁶ The biological response and tolerance of plants to drought stress such as physiological, biochemical and transgenic tolerance also need to be understood.

Physiological responses to drought and water stress

Sweet potato exposed to drought stress recorded low photosynthesis by reducing chlorophyll 'a' fluorescence, stomatal conductance, intercellular carbon dioxide (CO₂) concentration and CO₂ assimilation rate primarily through stomatal closure.⁵⁷ Photosynthetic pigments are important for harvesting light and producing reducing powers in plants.⁴⁸ Chlorophyll 'a' and 'b' are reported to be susceptible to soil drying.^{48,54} Foliar photosynthetic rate of higher plants is known to decrease as relative water content and leaf water potential decrease. Severe levels of drought are capable of causing irreversible damage to photosynthetic apparatus. Both stomatal and non-stomatal limitations were generally accepted to be the main determinants of reduced photosynthesis under drought stress conditions.^{28,46,48} Bray⁵⁶ also reported a reduction of both chlorophylls a and b, and total chlorophyll at high water stress. This reduction was reported to be associated with an increase in electrolyte leakage caused by leaf senescence and reduced water use in plants.

The C3 plants of tropical origin, such as sweet potato, colonise easily in a drought environment because they have high phenotypic plasticity. Phenotypic plasticity refers to the ability of the plant to alter its characteristics in order to acclimate to variable environmental conditions. In sweet potato and other C3 plants, all photosynthetic cells are functionally equivalent, thus allowing each cell to acclimate to new environments in a more autonomous manner than those of C4 plants. This functional equivalence allows for photosynthetic plasticity at cellular rather than tissue level, resulting in a greater acclimation ability of C3 plants in general. This C3 metabolism allows sweet potato to be classified as a drought-tolerant plant.^{54,58} Earlier studies on C3 plants also indicated that maximum rate of assimilation was more strongly temperature dependent than water dependent and that considerable photorespiration takes place in sunlit photosynthetic organs. Where light intensity is low, there would be 1% decrease in light use efficiency for every degree of temperature increase.⁵⁹ This report emphasises the importance of light and temperature in sweet potato production. Increases in photosynthetic plasticity and assimilation results in higher yields and this plasticity may also explain why sweet potato possesses wide adaptability when compared to common C4 staple crops such as maize.

Other anatomical adaptation characteristics of drought tolerance in plants include the development of spongy tissues that act as water reservoirs. Impaired growth and reduced folia area limit water loss through transpiration.^{52,54} Some plants may have floral induction which is associated with long-distance movement of Flowering Locus T (FT) proteins, a trait observed in sweet potato plants grown under water stress.^{3,13}

Plant adaptive responses to drought and water stress are based on complex changes mainly focused on maintaining water potential in key tissues. Earlier reports indicated that osmotic adjustment^{60,55} is a common biochemical adaptation strategy in plants as it results in newly synthesised metabolites. These metabolites include hydrophilic (highly soluble) molecules that are able to produce a resuscitating surface that captures water molecules to be available later during water limitations.⁵² Examples of these osmolytes are proteins (amino acids), sugars and sugar alcohols.^{54,57} Some of the osmolytes have additional functions such as coping with oxidative stress by suppressing reactive oxygen species.^{48,57}

Protein expression, accumulation and synthesis are modified in plants exposed to drought stress. According to Bray⁵⁶, these drought-induced proteins are important for physiological adaptation of plants to water stress. The drought-induced proteins are referred to as dehydrins and belong to the group II late embryogenesis abundant (LEA) proteins.^{56,60} Studies performed on plants (wild watermelon and maize) under mild water stress reported more than 16 proteins involved in water stress responses.^{60,61} Proline is one of the proteinogenic amino acids with exceptional conformational rigidity and is essential for primary metabolism in plants.⁶² It is involved in the synthesis of proteins that are necessary for a stress response. This amino acid is of particular

interest in stressed plants and is usually considered an osmoprotectant and accumulates in cells to obtain suitable conditions for water uptake under limited water conditions in the roots. It is also involved in reducing oxidative damage by scavenging and/or reducing free radicals.

Proline was found to be involved in tolerance mechanisms against oxidative stress and was the main strategy by which plants avoided detrimental effects of water stress. A study conducted on the influence of water stress on proline accumulation concluded that increases in proline levels helped protect cell membranes from oxidation instead of osmotic regulation as an initial response to water stress.^{54,62} Proline accumulation can influence stress tolerance in multiple ways because it functions as a molecular chaperone, able to protect protein integrity and enhance the activities of different enzymes.^{61,62} While there are two schools of thoughts in as far as proline accumulation is concerned, the bottom line is that it will accumulate in response to environmental stresses. Whether or not its accumulation is a sign of stress tolerance or rather a symptom of the severity of the stress is still debatable and is an avenue that needs to be explored, especially in food security crops like sweet potato. Modi and Mabhaudhi⁵⁰ suggested that, despite the controversy surrounding its exact role, proline accumulation could still be a useful index in drought tolerance. However, the authors went on to state that its value as an index could only be fully understood if other stress metabolites were also quantified alongside it.

Phytochemicals are secondary metabolites that are widespread in the plant kingdom. Phytochemicals protect plants against bacteria, viruses and fungi invasion.⁶³ The different compounds constituting phytochemicals are considered to have biological significance but are not established as essential nutrients in human or animal diets. They have, however, been reported to possess bioactive properties with potential health benefits.²⁵ Phytochemicals such as antioxidants, carotenoids, anthocyanins and flavonoids can be classified into different categories depending on their structure and have been associated with flavour and colour characteristics of fruits and vegetables.³⁶ Antioxidants such as ascorbic acid and glutathione, commonly found in chloroplasts and other cellular compartments in plants are crucial for plant defence against oxidative stress and have been reported to be indicators of plants' hypersensitivity to stress conditions.^{25,36,63} Earlier findings by Sairam et al.⁴⁹ indicated that enzymatic and non-enzymatic antioxidants in plant cells played an important role in avoiding detrimental effects of free radicals. In addition to their high antioxidant and antiradical activities in humans, the health beneficial properties have also been attributed to many other mechanisms such as anti-inflammatory properties, inhibition of enzymes and induction of detoxification enzymes. Antioxidants were reported to be vital in protection against cancer and cardiovascular diseases in humans.^{28,29,36}

Carotenoids are plant pigments that can partially help plants withstand the adversities of drought.²³ They form a key part of the plant's antioxidant defence system.⁴⁸ Carotenoids are divided into hydrocarbon carotenenes (lycopene and β -carotene) and xanthophylls (lutein).^{36,48} β -carotene is present in all chloroplasts of green plants and is exclusively bound to the complexes of photosystems one (PSI) and two (PSII). β -carotene functions as an accessory pigment, an effective antioxidant and plays a unique role in protecting and sustaining photochemical processes.²³ The protective role of β -carotene in photosynthetic tissue is achieved through direct quenching of triplet chlorophyll, thus preventing the generation of singlet oxygen and protecting against oxidative damage.⁵²

As a phytochemical, carotenoids were reported to protect against the eye disease, macular degeneration.³⁶ β -carotene is of particular importance because it is a precursor for vitamin A. Vitamin A is important in human nutrition because of the role it plays in improving vision, bone growth, reproduction, maintenance of epithelia and overall growth.⁶⁴ The orange-fleshed sweet potato varieties contain high amounts of β -carotene and are being promoted in vitamin A deficiency alleviation programmes in South Africa and other developing countries. The fact that sweet potato can synthesise β -carotene to protect itself from oxidation stress and further store the β -carotene in both leaves and storage roots, is an indication that it is an important food security crop which can withstand drought stress conditions and still alleviate chronic malnutrition diseases associated with vitamin A deficiencies.

Genes expressed during drought stress

Many responses to water stress are controlled by a number of genes with different functions. Many regulatory processes are initiated the minute water is lost from plant cells, to help adjust cellular metabolism, and result in changes in gene expression.⁵⁶ Changes in expression patterns have been monitored on the plant when drought stress is perceived. These changes range from genes whose products are involved in early responses such as signal transduction, transcription and translation factors; to late response genes, such as water transport, osmotic balance, oxidative stress and damage repair.⁵⁴ Whether these water stress induced genes perform an adaptive role or not is still to be investigated.

Genetic engineers have tried to develop transgenic sweet potato plants by gene coding for spermidine synthase which is used to improve environmental stress. The transgenic sweet potato from this genetic coding showed high tolerance to drought, salt, chilling and heat stresses.⁶⁵ Recent reports indicate that transgenic sweet potato, containing the gene which is important for osmoregulation and abiotic stress, showed tolerance to multiple environmental stresses such as protection against cell damage, improved photosynthetic activity and increased activity of free radical scavenging enzymes.⁶⁰ These reports are proof of good progress in genetic engineering in as far as sweet potato drought tolerance is concerned, but there is still a shortage of successful screening methods and multidisciplinary approaches and genotype by environment interaction.¹⁴ It is therefore believed that with the existence of these strength-enhanced drought tolerant varieties, food security will improve as long as the genotype by environment interaction selection is carried out in the environment in which the varieties will be released and grown.

Crop management for drought mitigation

Increased productivity in rain-fed agriculture reduces pressure on the limited arable land and water resources. Knowledge of weather and climate can reduce the impact of drought on communities, and this can be achieved by employing two distinct strategies. The first is long term planning in which strategies can be devised, and precautions taken to reduce impact. This planning includes climate and weather evaluation using scientific systems research tools such as simulation models, optimisation techniques, geographic information systems and databases.⁶⁶ The FAO AquaCrop model has already been calibrated and validated on OFSP varieties and proved to be useful in exploring irrigation options in sweet potato.⁶⁷ Adjusting planting dates (or timing of planting) and harvesting, substituting cultivars and, where necessary, modifying or changing the cropping system altogether, has also been identified as a long term strategy.⁶⁸ Adjusting planting dates for sweet potato production in KZN so as to allow yield maximisation could be a suitable management strategy.

The second phase where application of weather and climate knowledge can reduce impacts of drought is by taking action during the onset of the event (planting/growing season) to reduce adverse effects.^{68,69} This action may include, but not be limited to, adopting proper crop management strategies such as water conservation strategies, manipulation of plant population, water recycling, rainfall harvesting into ponds or village tanks and even mid-season corrections.^{23,69} Farooq et al.⁵² further recommended adoption of strategies such as mass screening and breeding, marker-assisted selection and exogenous application of hormones and osmoprotectants to seed or growing plants, as well as engineering for drought tolerance. The two phases suggested by Das⁶⁶ of using weather and climate to mitigate and plan for drought; adaptation of agriculture to stability and resilience of production and conservation tillage^{68,69} and other best practices, all form part of climate-smart agriculture. According to the FAO⁶⁹, the aim of climate-smart agriculture is to increase productivity in an environmentally and socially sustainable way, strengthen farmer's resilience to climate change, and reduce agriculture's contribution to climate change by reducing greenhouse gas emissions and increasing carbon storage of farmland.

Conclusions

Sweet potato remains an important root crop with an inherent ability to produce more edible energy than most major food crops. It is suitable for production on marginal lands and can play an important role as a food security crop. The importance of OFSP varieties in supplementing vitamin A deficiencies cannot be overemphasised. And production of the OFSP varieties in areas with a prevalence of vitamin A deficiency should be promoted. It is possible to produce this crop and have it available all year round in the tropical and subtropical areas of South Africa where warm conditions prevail, even if drought is a challenge for staple crops such as cereals. Rain-fed crops are always subjected to water stress during the course of growth because of the unpredictability of rainfall in subtropical environments. Sweet potato has the advantage of being drought tolerant after establishment. Hence, its yield potential is generally greater than that of popular staple crops of South Africa, such as maize. In addition to yield advantage, the higher nutritional value of sweet potato is of benefit to farmers producing under conditions that are susceptible to drought stress. While this review has identified sweet potato as a potential food security crop for dryland production, there are still challenges that may limit its potential to fully contribute towards food security. There is a need to introduce more participatory research and extension to educate smallholder farmers about the value of sweet potato as a major crop for subsistence and rural economic development.

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Authors' contributions

N.M.M. performed and wrote the literature review. A.T.M. was the project leader and supervisor and provided conceptual direction for the review. T.M. provided guidance and mentorship.

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