EFFECT OF PROCESSING ON CRUDE FAT AND BETA-CAROTENE CONTENT IN THREE SWEET POTATO VARIETIES

By

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Approval Form

This is to certify that the dissertation entitled "Effect of processing on crude fat and beta-carotene content of sweet potato", submitted in partial fulfillment of the requirements for Bachelor of Science Honors Degree in Applied Biological Sciences and Biotechnology at Midlands State University, is a record of the original research carried out by Doreen Valerie Chingwaru R142262M under my supervision and no part of the dissertation has been submitted for any other degree or diploma.

The assistance and the help received during the course of this research have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the dissertation requirements.

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ABSTRACT

Sweet potato (*Ipomoea batatas*) is one of the crops being considered for the diversification of the staple diet to enhance food security in Zimbabwe in the face of climate change and economic challenges. One of the hurdles preventing adoption of sweet potato as a staple food is its short shelf-life. There has been a call to explore means of preserving sweet potato hence increasing its shelf-life and one method of preservation is processing sweet potato into flour. However, this method has not been embraced because the effect of processing on sweet potato nutrient content is not known. A study was carried out to determine the effect of two methods of post-harvest processing (oven-drying and sun-drying) on fat and beta-carotene content of sweet potato in line with the ZIM ASSET clusters on food security under value addition and beneficiation. Three sweet potato cultivars -Chingovha (crème-fleshed), Germany II (white-fleshed) and Resisto (orange-fleshed) were studied. The Soxhlet extraction method was used for fat content determination and the beta carotene content was determined using spectrophotometry. Sun-dried Germany II retained the highest fat content (0.09±.002g/100g) after processing. The fat content was below the threshold required for absorption of beta-carotene by the body (5g/100g). Resisto and Chingovha retained similar fat contents (0.02±.002g/100g – 0.04±.004g/100g). There were significant differences in fat content across the three cultivars and between fresh and processed sweet potato (ANOVA $p<0.05$). Resisto retained the most beta-carotene (8.33±0.039 mg/100g) after processing whereas Chingovha and Germany II had similar beta-carotene contents (0.7±0.039 – 0.75±0.039 mg/100g). There were significant differences in beta-carotene content across the three cultivars (ANOVA $p<0.05$) which lied between Resisto and Chingovha (Tukey multiple comparisons $p=0.00$) and between Resisto and Germany II (Tukey multiple comparisons $p=0.00$). Beta-carotene content in all three cultivars was converted to meet the average daily beta-carotene content intake requirements called Retinol Activity Equivalents (RAE) at a ratio of 1 µg/100g beta-carotene: 12 µg/100g RAE. Resisto had a RAE of 694-697.5µg/100g which met the average daily intake requirements for males and females aged 0-13 (400-600µg/100g). Resisto must be grown on a large scale because of its high beta-carotene content. Chingovha and Germany II had beta-carotene contents below the required RAE of 400 µg/100g therefore they need artificial fortification. When eating sweet potato, an accompaniment with a dietary fat of 3-5g/100g must be consumed for intestinal absorption of beta-carotene. Resisto was the best in terms of beta-carotene content after processing, therefore it is the most suitable cultivar for food security. Both sun-drying and oven-drying had similar effects on beta-carotene content although sun-drying yielded less losses in fat content in Resisto and Germany II, therefore sun-drying is a more effective method to use for sweet potato processing.

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DEDICATION

This work is dedicated to my sister and brother-in-law, Sonia and Marshall Mutandwa, my parents, Edward and Janemary Chingwaru, and my dear grandmother, Lydia Mupambwi.

Contents

List of figures

List of Appendices

List of tables

CHAPTER 1: INTRODUCTION

1.1 Background

Sweet potato, *Ipomoea batatas*, belongs to the morning glory family *Convolvulaceae* and is a perennial crop (Department of Agriculture, Forestry and Fisheries South Africa, 2011). It has thick, starchy roots which later develop into tubers, which is the edible part (Department of Agriculture, Forestry and Fisheries South Africa, 2011). It produces higher yields per hectare than any cultivated crop including corn, thus it is regarded as the crop of the future yet it is under-exploited (Karyeija *et al.*, 1998). Sweet potato is a seasonal staple in cases where there is shortage of other foodstuffs, yet it has much potential of being a major staple crop (Karyeija *et al.*, 1998). Sweet potato possesses exceptional attributes which make it an excellent alternative for food security. These include its ability to grow on soils with limited fertility, drought-tolerance, provision of good ground cover; and that it is usually cultivated without the need for pesticides or fertilizer (K'osambo *et al.*, 1999). *Ipomoea batatas* is grown in developing countries including Zimbabwe and Nigeria, and is a source of food in many Zimbabwean households. Rated by FAOSTAT (2004) as the fourth most important food crop in the tropics and the sixth most important food crop in the world, sweet potato is therefore a suitable target for food security in the face of climate change and economic challenges in Zimbabwe. As a target crop for food security, sweet potato needs post-harvest processing because of its short shelf-life. The commonly consumed state of sweet potato is the boiled, roasted or fried state. However, sweet potato can be processed into flour, which can be used for baking, preparing pasta and preparing porridge.

Sweet potato is typically a small farmer crop and is currently cultivated in more than 100 countries, mostly throughout tropical and subtropical Asia (FAOSTAT, 2004). The world sweet

potato annual production was >127 million metric tons, with 95.5% being credited to developing countries (FAOSTAT, 2004). Of the 95.5%, 11.5 million metric tons was accounted for by African farmers. Sweet potato consumption varies across nations, with Asia using it mainly for animal feed and Africa having it for human consumption. Sweet potato consumption has been associated with poor households, with the average annual per capita supply of fresh tubers being estimated at 112kg in Africa, 16kg in Asia, 18kg in Oceania, 2kg in North and South America and less than 0.5kg in Europe (FAOSTAT, 2004). This points to the evidence that despite its potential, sweet potato is under-appreciated.

There has been a report of Vitamin A deficiency in developing countries (O'Connor *et al.*, 1946). As a way to combat this, foods rich in ß-carotene can be consumed and these include sweet potato. An important attribute of sweet potato is that it contains beta-carotene, a Vitamin A precursor required by the body as an aid for the synthesis of Vitamin A because the human body does not naturally synthesize Vitamin A *de novo* (O'Connor *et al.*, 1946). Vitamin A refers to a group of fat-soluble retinoids with an immune function, as well as functions in vision, reproduction and cellular communication (O'Connor *et al.*, 1946). In addition, Vitamin A supports cell growth and differentiation and has a role in the normal formation and maintenance of lungs, kidney, heart and other organs (O'Connor *et al.*, 1946). Vitamin A can be split into two different categories, preformed Vitamin A and provitamin A carotenoids (O'Connor *et al.*, 1946). While preformed Vitamin A is obtained from animal sources, including dairy products and fish, provitamin A carotenoids are found in fruits and vegetables such as tomatoes and sweet potato (O'Connor *et al.*, 1946). Both categories of Vitamin A must be metabolized intracellularly to retinal and retinoic acids, which are the active Vitamin A forms responsible for carrying out important biological

functions (O'Connor *et al.*, 1946). This study will place emphasis on sweet potato as a source of a provitamin A carotenoid called beta-carotene (ß-carotene).

ß-carotene is found in an important group of micronutrients known as carotenoids (Nestel *et al.,* 2006). Carotenoids are natural pigments synthesized by plants, and are responsible for the yellow-to-deep red colours of a number of fruits and vegetables (Nestel *et al.,* 2006). These pigments possess antioxidant activity, including eradication of free radicals, which are molecules which contribute to the damage of both cells and cell membranes and are associated with development of conditions such as colon cancer, atherosclerosis and heart disease (Nestel *et al.,* 2006). Of the over 75different carotenoids which are known, ß-carotene has the highest provitamin A activity, and is the most important and widely studied provitamin A (Nestel *et al.,* 2006). This is the predominant carotenoid; found in sweet potato, with more levels in the orange fleshed variety than in the white or crème-fleshed varieties (Nestel *et al.,* 2006).

Sweet potato is known as a low fat crop (Nestel *et al.*, 2006). The amount of dietary fat intake is expected to meet energy needs, as well as the requirements for essential fatty acids and fat-soluble vitamins. It has been reported that ß-carotene absorption by the body is made easier by the presence of fat and fat-soluble vitamins (Ribaya-Mercado, 2002). The fat content needed for absorption; referred to as bioavailability, is approximately 3-5kg (Nestel *et al.*, 2006). This fat is obtained from the diet, thus it can be referred to as dietary fat. Another aspect which this study will focus on is the dietary fat content of sweet potato. Ribaya-Mercado (2002) reported that low fat diets are often high in antioxidants on the basis of serum ß-carotene and retinol responses after meal ingestion of carotene and fat sources.

1.2 Problem Statement

Currently, the main staple crop in Zimbabwe is maize. However, climate change and economic challenges have led to the need for diversification of staple foods to enhance food security. One way of diversifying food sources is looking into the possibility of growing sweet potato on a larger scale. The challenge presented by sweet potato is its short shelf-life of three to four weeks, hence the need to come up with preservation methods to prolong shelf-life. Processing sweet potato into flour is one method of prolonging shelf-life. While nutritional content of fresh sweet potato is known, the effect which processing has on its nutritional content is not known. Consequently, uptake of this crop is low because people under-appreciate it. Anecdotal studies have been carried out in countries like Nigeria, Kenya and Tanzania to show nutrient content of sweet potato after processing, yet this has not been done in Zimbabwe.

1.3 Justification

This study is in line with the ZIMASSET cluster on food security and nutrition, and value addition and beneficiation. As an aid to food security enhancement, the aim of this study is to characterize sweet potato in terms of fat and beta-carotene content after processing. Furthermore, this study contributes towards providing nutritional information on locally produced sweet potato cultivars in order to increase its appreciation by the local population.

Sweet potato processing increases shelf-life to a period of up to 10 months. Knowledge of the effect of processing on nutritional content of sweet potato can help in showing whether there may be need to supplement depleted nutrients or not.

1.4 Objectives

The main objective of this study was to determine the effect of sun-drying and oven-drying on fat and beta-carotene content of sweet potato.

The specific objectives of this study were:

i) to determine the fat content of each sweet potato cultivar after processing

ii) to extract ß-carotene from processed sweet potato and determine the sweet potato cultivar with the highest level of beta-carotene after processing, and

iii) to determine the sweet potato cultivar with sufficient beta-carotene to meet the required daily intake of beta-carotene called Retinol Activity Equivalents (RAE)

CHAPTER 2: LITERATURE REVIEW2.1 Sweet potato processing in Zimbabwe

Sweet potato has minimal input requirements, yet it yields highly and this has put it at a greater advantage over other root and tuber crops (Nyarumbu, 2016). The increased effects of climate change on crops in Zimbabwe have led to the need for food security for the future. This means that instead of solely relying on cereals which are the main carbohydrate source in the local diet, the nation invests in sweet potato; resorting to processing as a way of increasing shelf-life (Nyarumbu, 2016). As such, the Zimbabwean government and local Non-governmental Organizations (NGOs) have resorted to promoting root and tuber crop production, especially sweet potato, in order to complement the nation's carbohydrate requirements. The nudge sustainability reporter Trish Nyarumbu (2016) highlights the need to enlighten farmers on the best methods of achieving quality and gaining maximum value of sweet potato and this is one of the objectives of this study. The reporter goes on to highlight the need to encourage farmers to grow what the market demands. The article mentions how the orange-fleshed sweet potato varieties are preferred due to high ß- carotene content which is known to be good for eyes and is a good source of provitamin A. This can be a call to resort to a phenomenon referred to as biofortification.

2.2 Biofortification

Biofortification refers to the development of micronutrient-dense staple crops using the best traditional breeding practices and modern biotechnology (Nestel *et al.*, 2006). This method involves sharing planting material amongst farmers, such that new seeds or planting material is only bought for the first time, after which germplasm can be shared even as wide as internationally (International Potato Center, 2016). This ensures that even in the absence of funding, nutritionally improved varieties can still be grown annually because there will be little recurrent costs, thus

making it cost-effective. This phenomenon has been used by researchers in many countries, including Kenya, Tanzania and Malaysia.

The approach of biofortification capitalizes on the regular intake of a consistent large amount of food staples by all family members because staple foods are predominant in the diet of the poor. This follows up on a report by Woolfe (2015)which mentioned that Vitamin A deficiencies, among other micronutrients, affect over one half of the world population especially women and pre-school children.

There is a high possibility of increased farm productivity in developing countries resulting from biofortification, with an added advantage of plant disease resistance and environmental stress-resistance caused by the presence of trace elements in plants and seeds (Woolfe, 2015). This ensures food security stemming from high yields because of resistance of the plant to detrimental conditions such as environmental stress. The biofortified crop system is thus highly-sustainable and undernourished populations in remote areas are able to adopt the concept of biofortification; ensuring that limited access to commercially marketed fortified foods readily available in urban areas is no longer a barrier (Woolfe, 2015).

2.3 Economic significance of sweet potato

It is evident that the poor populations need a financial boost and are the ones who are said to consume large amounts of sweet potato. They can therefore resort to sweet potato for famine relief. An example is that of East Africa's semiarid, densely populated plains where thousands of villages depend on sweet potato for food security (Amante and O'Sullivan, 2009). Sweet potato thus provides an additional source of cash for poor families, directly and indirectly due to its diversified use.

The diversified utilization of sweet potato in Africa and Asia contributes towards improving local economies (Loebeinstein, 2009). Apart from sweet potato being a subsistence crop, it contributes largely to livestock production in many areas. For instance, the share used as feed in Asia went from 14.5% in 1961-1963 to 44% in 1993-1995 (Loebeinstein, 2009). Industrial use of sweet potato for starch and other processed goods has also been reported by the International Potato Centre to be more localized but expanding (International Potato Center, 2005). In addition, the Japanese used sweet potato when typhoons demolished their rice fields (Loebeinstein, 2009). In 1594, a huge area of crops was destroyed by famine in and the Fujian governor ordered farmers to grow sweet potatoes as a way to stave off famine (Loebeinstein, 2009).

Rabirou (2011) reported that cost and returns analysis indicates that labour accounted for 68% of total cost production, and that sweet potato production is profitable. This was concluded following analysis of profitability, scale and resource use efficiency in sweet potato using data from 90 producers (Rabirou, 2011).

2.4 Nomenclature

There is no universal name for sweet potato varieties worldwide. The naming system is just dependent on the area in which the sweet potato is found. For instance, the orange-fleshed variety is called Beauregard in South Africa and in the United States of America, while it is referred to as Germany II in Zimbabwe and Resisto in Mozambique (Department of Agriculture, Forestry and Fisheries, 2011). The same variety is called Karoti and Ejumula in Tanzania; according to Nicanuru *et al.* (2015), and Kakamega in some parts of Kenya (K'osambo *et al.*, 1999).

2.5 Effects of food processing on nutrients

There are other factors which affect nutritional content of sweet potato besides post-harvest processing and storage. These need to be accounted for and they include environmental conditions and biological stress from farming sites, although the impact of farming site on ß-carotene content has not been conclusively established (K'osambo *et al.,* 1999). Almost all methods of processing food; particularly those which expose the food to conditions such as high temperatures, light and oxygen reduce the nutrient content of food (United States Department of Agriculture, 2003). Actual losses, however, depend on the type of food and specific conditions to which the food would have been exposed. ß-carotene is reasonably stable during processing. Its losses are expected to occur when dehydrated food in which it is contained is exposed to light and air (United States Department of Agriculture, 2003). It is anticipated that freezing reduces ß-carotene content by 5%, while drying reduces the same micronutrient by 50% (United States Department of Agriculture, 2003).

2.6 Recommended nutrient intakes

Dietary Vitamin A deficiency leads to debilitating health problems which include xerophthalmia, corneal lesions, kerotamalace and even death (The National Institute of Health, 2016). In the 1990s, the major strategy to combat such deficiencies was the distribution of capsules (The National Institute of Health, 2016). The same effect can however be achieved by consumption of vitamin A rich foods in which the major carotenoid, ß-carotene, is contained. This is a safe and sustainable approach, especially in rural areas of developing countries where deficiencies of vitamin A are most common (The National Institute of Health, 2016). This is also a cheap method, considering that most populations cannot afford food such as meat and dairy products containing preformed vitamin A. Consequently, it is of great importance that the food

sources containing provitamin A be made more sustainable by improving production and increasing shelf-life and consumer acceptance. Shelf-life extension is achieved by one of many methods, that is, processing sweet potato into flour. Many countries depend on the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) for human nutrient requirements. This information is continually being gathered from around the world and is a never-ending task. This therefore serves as the base for the standards of these countries. The nutrients include energy, carbohydrates, protein, lipids, fats, vitamins, and a wide range of minerals and trace elements.

A board known as the Food and Nutrition Board (FNB) at the Institute of Medicine and National Academies (formerly National Academy of Sciences) has developed Vitamin A intake recommendations and these are provided in the Dietary References Intakes (DRI) (Food and Agriculture Organization of the United Nations, 1994). The term DRI is a general term for a set of reference values used in planning and assessing nutrient intakes of healthy people (Food and Agriculture Organization of the United Nations, 1994). These DRIs vary depending on age and gender, and they include Recommended Dietary Allowance (RDA), Adequate Intake (AI), Estimated Average Requirement (EAR) and Tolerable Upper Intake Level (UL) (Food and Agriculture Organization of the United Nations, 1994). RDA is the average daily intake level sufficient to meet the nutrient requirements of nearly all healthy individuals (Food and Agriculture Organization of the United Nations, 1994). The AI is established where there is insufficient evidence to develop RDA and is set at a level assumed to ensure nutritional adequacy (Food and Agriculture Organization of the United Nations, 1994). The average daily level of intake estimated to meet the requirements of 50% of healthy individuals is the EAR, which is usually used in the assessment of nutrient intake adequacy in population groups, not individuals (Food and

Agriculture Organization of the United Nations, 1994). The UL is the maximum daily intake which is not likely to cause adverse health effects (Food and Agriculture Organization of the United Nations, 1994).

Daily intake requirements for beta-carotene are given by the Food and Nutrition Board(2016) as a measure of Retinol Activity Equivalents (RAE) conversions from beta-carotene content in food (Table 2.1, Appendix 3). The daily intake requirements of beta-carotene are distinguished by age and gender, as well as on the basis of the state of whether one is pregnant or undergoing lactation (Institute of Medicine).

2.7 Excessive ß-carotene health risks

Due to primary storage of Vitamin A in the liver, levels of Vitamin A can accumulate, resulting from its fat-soluble nature (Food and Drug Administration, 2015). Large amounts of ß-carotene are not associated with major unwanted side effects (Brucker and King, 2017). The most significant effect of long-term excess ß-carotene is carotenodermia, which is a harmless condition in which the skin becomes yellow-orange (Food and Drug Administration, 2015). Discontinued ingestion of ß-carotene can reverse the condition (Food and Drug Administration, 2015). The dosage which is considered to be large ranges from 20-30mg per day, that is, 20 000-30 000µg per day. There has not been a Tolerable Upper Intake Level report for ß-carotene (Brucker and King, 2017).

2.8 Fat intake

Dietary fat intake is expected to meet energy needs, as well as the requirements for essential fatty acids and fat-soluble vitamins (Food and Agriculture Organization of the United Nations, 1994). The minimum intake varies with individuals, depending on age, although adequate dietary

fat intake is important prior to pregnancy and lactation. For adults, recommended dietary fat supply put forward by the Food and Agriculture Organization of the United Nations (1994) should be at least 15% of their energy intake; while women of reproductive age should consume at least 20% of their energy from fat. Unlike infants, there is no nutritional advantage to consuming high-fat diets as long as essential energy and nutrient needs are met.

In infants and young children, the consumption of dietary fat can affect child growth and development. Breast milk is responsible for providing 50%-60% energy as fat; therefore it is important that rapid decrease in dietary fat content be looked out for upon weaning (Food and Agriculture Organization of the United Nations, 1994). These levels must also not fall below the required levels of 30%-40% of energy which must be from fat, thus providing levels similar to those found in breast milk (Food and Agriculture Organization of the United Nations, 1994). This applies to children up to the age of two. Likewise, fatty acid composition of infant formula needs to correspond to that found in breast milk (Food and Agriculture Organization of the United Nations, 1994).

It is important to avoid excessive fat intake at all costs, as this has been linked to a high risk of coronary heart disease, obesity and certain types of cancer such as colon cancer (Food and Agriculture Organization of the United Nations, 1994). The degree of risk varies, depending on factors such as intakes of dietary fibre and antioxidants, activity levels and health status. Active individuals may therefore consume up to 35% of their total energy intake from dietary fibre, while sedentary individuals who are involved in little physical activity should not consume more than 30% of their energy from fat (Food and Agriculture Organization of the United Nations, 1994).

2.9 Methods used in testing for beta-carotene in sweet potato

Different researchers use different approaches to test for ß-carotene and these are mostly dependent on availability of resources. A study which was carried out in Kenya in 2001 which led to the introduction of the orange-fleshed sweet potato to the human diet made use of a longitudinal study approach. In this study, five groups of children below the age of five received nutrition education to promote Vitamin A consumption, while five other groups served as the control without receiving any treatment. The treatment group was then administered with the orange-fleshed sweet potato and assessments of both groups were made after a period of one year by testing for retinol levels in the blood of the two groups (Woolfe, 2015). Therefore, unlike extracting ß-carotene from the plant itself, samples can be drawn from treatment groups and the retinol levels can be converted to ß-carotene levels.

In most cases, High Performance Liquid Chromatography (HPLC) is used, where peaks of ß-carotene are obtained, together with retention times. The results are then plotted in a graph and this method has proven to be a rapid, efficient and sensitive technique for carotenoid analysis (Ahamad *et al.,* 2007). In this study, the approach which was used conformed to the limited resources available, thus UV spectrophotometry was used where absorbance at 450nm was measured.

CHAPTER 3: MATERIALS AND METHODS

3.1 Cultivars under study

Three cultivars of sweet potato grown in Zimbabwe were studied, namely, Chingovha, Resisto and Germany II (Fig. 3.1-3.3). Sweet potatoes were randomly dug out from a farm in Bindura, Zimbabwe in April 2017. These had been planted mid-November 2016.

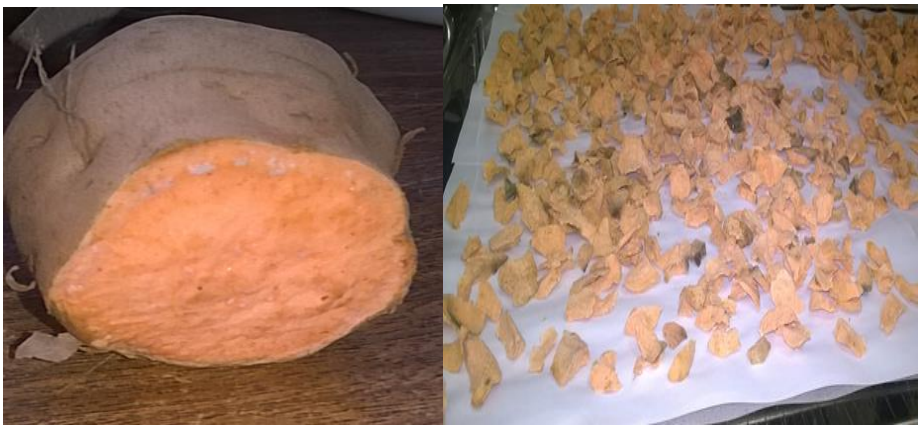


Figure 3.1: Resisto, an orange-fleshed variety

Figure 3.2: Chingovha, a crème-fleshed variety

Figure 3.3: Germany II, a white-fleshed variety

3.2 Sample preparation

Samples from the three varieties of sweet potato were washed under running water, peeled and grated to increase the volume-to-surface ratio. Equal amounts of 900 g each of raw sweet potato for each of the three cultivars were weighed before they were oven-dried or sun-dried. Oven-drying and sun-drying were done for 10 h at 60°C, and 12 h, respectively. The dried sweet potato was then ground using an electrical grinding mill, packed in re-sealable bags and stored in a cool, dry place prior to laboratory analyses for determination of crude fat content and ß-carotene content. Fresh sweet potato was used as the control in all three cultivars and was also tested for fat and beta-carotene.

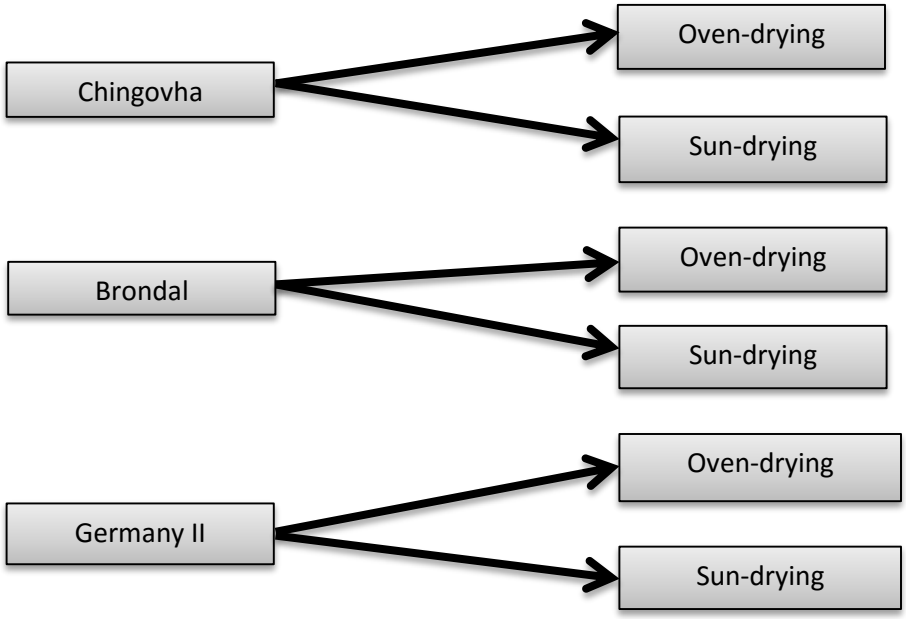


Figure 3.4: Allocation of sweet potatoes to methods of drying

3.3 Soxhlet extraction for fat determination

Soxhlet extraction was carried out in accordance to the protocol used by Nicanuru *et al.* (2015). An amount of 5 g of each of the three cultivars of raw and processed sweet potato was weighed out and each sample was wrapped in filter paper and placed in a separate thimble, into which 10 ml of petroleum ether was added, after which the thimble was covered using cotton wool and placed in a condenser. Empty heating flasks were weighed. An amount of 125 ml of petroleum ether was added to each heating flask. The Soxhlet apparatus was set up, while placing the heating flasks in a water bath set at 65°C. The process was run for 6 h and the fat was collected in the heating flasks containing petroleum ether, after which the petroleum ether containing the fat extract was evaporated on a hot plate for 15 minutes, and the heating flasks containing fat were weighed. The fat content was determined by finding the difference between the weight of the

empty heating flasks and the weight of the heating flask containing the extracted fat. This procedure was carried out in triplicate.

3.4 Determination of ß-carotene

ß-carotene determination was done in accordance to the protocol by Amandangi and Farida (2013). An amount of 1.25 g was weighed out for fresh and processed sweet potato samples. Fresh samples were crushed using pestle and mortar. An amount of 0.025 g magnesium carbonate was weighed out and added to each beaker containing sweet potato samples. Total volumes of 10 ml acetone and 15 ml *n*-hexane were added to the beakers. Each beaker was stirred vigorously for 2 minutes, after which the samples were filtered. The residue was washed off twice using 6 ml acetone, then with 6 ml *n*-hexane and the extracts were combined. Acetone was washed off five times from the extract using 125 ml distilled water per wash in a 500 ml separatory funnel. The upper layer was transferred to a 25 ml volumetric flask containing 3 ml acetone and hexane was used to fill up to the mark. Absorbance was determined using a UV spectrophotometer at a wavelength of 450 nm; with *n*-hexane as the blank. ß-carotene content was determined using the following formula:**Content of ß-carotene in sample (g/100g) =**

$$\frac{\mathbf{Csample\ x}\ Va}{\mathbf{W}}\ \mathbf{x\ 100}\%$$

Where C_{sample} = sample concentration in µg/ml

W = sample weight in grams

V_a = final volume in millilitres

3.4.1 Conversion of beta-carotene to Retinol Activity Equivalents (RAE)

Beta-carotene content (µg/100) was converted to RAE (µg/100g) using the following formula:

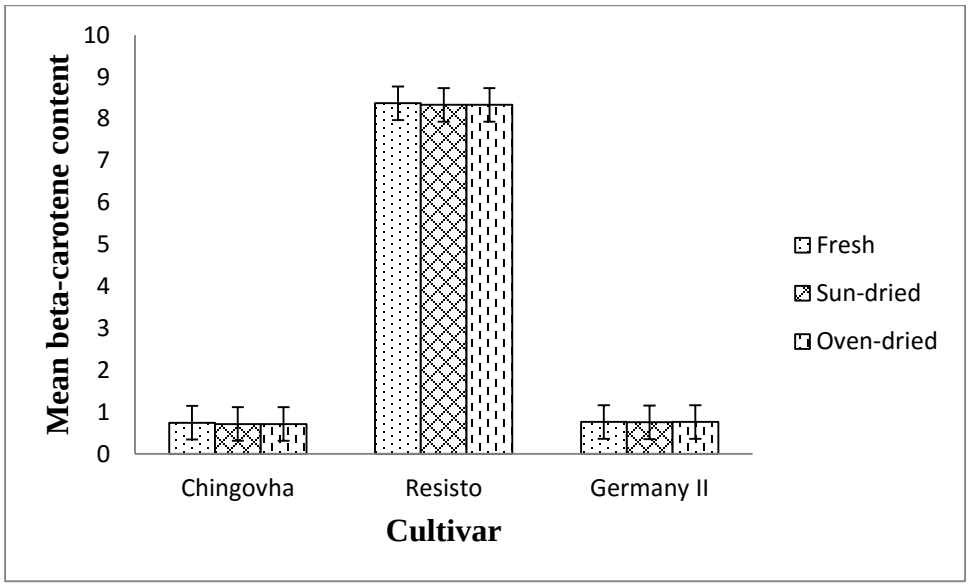
12 µg/100 beta carotene = 1 µg/100

3.5 Data analyses

Data analyses focused on comparing the change in fat and ß-carotene content within and across groups of sweet potato cultivars, as well as within and across the two drying methods. The study had two categorical predictor variables (drying method and sweet potato cultivar) and two quantitative response variables (fat and beta-carotene). All statistical analyses were done in SPSS using two-way analysis of variance (ANOVA) for each response variable and Tukey test for multiple comparisons of means.

CHAPTER 4: RESULTS

4.1 Beta-carotene contentBeta-carotene content in sun-dried and oven-dried Resisto decreased by 0.04% from 8.37±0.039 mg/100g to 8.33±0.039 mg/100g (Figure 4.1). Beta-carotene content in Resisto differed significantly from beta-carotene in both Chingovha and Germany II (Tukey multiple comparisons p>0.05, Appendix 1). Resisto retained higher beta-carotene content of 8.33±0.039 mg/100g after oven-drying and sun-drying than Chingovha and Germany II (Tukey multiple comparisons, Appendix 1). Chingovha and Germany II lost beta-carotene content ranging between 0±0.039 mg/100g and 0.03±0.039 mg/100g (Figure 4.1). There were no significant differences in beta-carotene content between fresh and sun-dried sweet potato (ANOVA p>0.05, Appendix 1) and between fresh and oven-dried sweet potato (ANOVA p>0.05, Appendix 1). Chingovha and Germany II beta-carotene content means were not significantly different (Tukey multiple comparisons p=0.414, Appendix 1). The highest Retinol Activity Equivalents (RAE) was recorded for sun-died and oven-dried Resisto at 697.5 µg/100g RAE (Table 4.1).



Error bars: 95% Confidence Interval

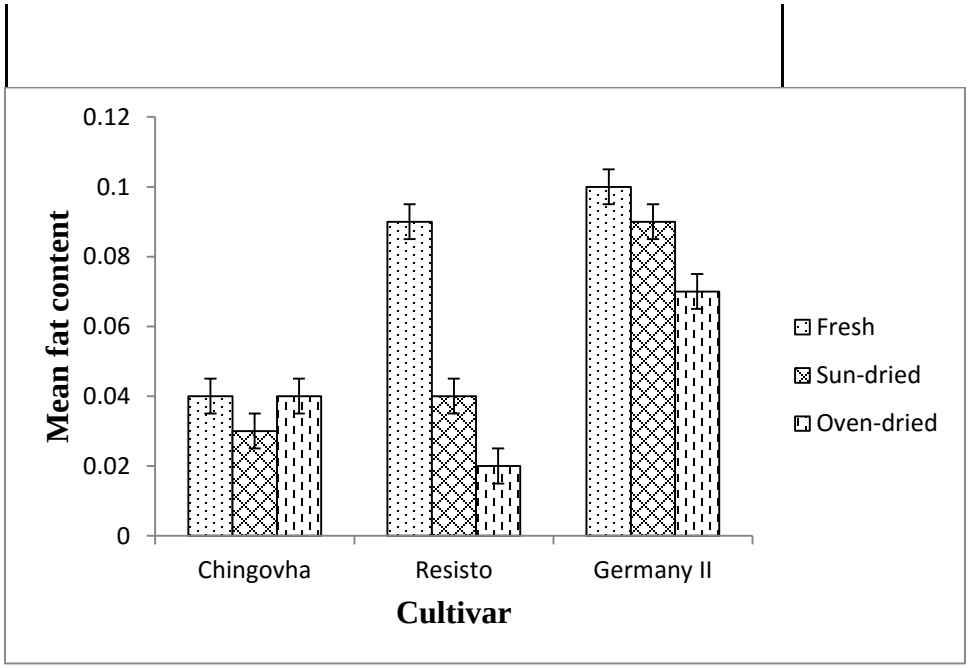
Figure 4.1 Mean values for beta-carotene content of fresh and processed sweet potato (mg/100g)

Table 4.1 Mean ß-carotene and RAE values for three sweet potato varieties

Cultivar	State	ß-carotene content (mg/100g)	ß-carotene content (µg/100g)	RAE (µg/100g)
Chingovha	Fresh	0.74	740	61.67
	Sun-dried	0.71	710	59.17
	Oven-dried	0.71	710	59.17
Germany II	Fresh	0.76	760	63.33
	Sun-dried	0.75	750	62.50
	Oven-dried	0.76	760	63.33
Resisto	Fresh	8.37	8 370	697.5
	Sun-dried	8.33	8 330	694.17
	Oven-dried	8.33	8 330	694.17

4.2 Fat content

Fat content ranged from 0.04 g/100g to 0.1 g/100g in fresh samples across Resisto, Chingovha and Germany II. In Germany II, fat content decreased from 0.1±0.003 g/100g to 0.09±0.002 g/100g after sun-drying and from 0.1 g/100g to 0.07g/100g after oven-drying (Figure 4.2). The least fat content loss of 0% was recorded for oven-dried Chingovha (Figure 4.2). A total of 0.05 g/100g loss in fat content resulted after sun-drying in Resisto, which was less than the 0.07 g/100g loss which resulted from oven-drying (Figure 4.2). Sun-dried Germany II retained the highest fat content (Tukey multiple comparisons, Appendix 2). There were significant differences in mean fat content across all three cultivars (ANOVA $p<0.05$, Appendix 2) and between fresh and dried samples (ANOVA $p<0.05$, Appendix 2).



Error bars: 95% Confidence Interval

Figure 4.2: Mean values for fat content of three fresh and processed sweet potato varietiesCHAPTER 5: DISCUSSION

5.1 Beta-carotene content

Resisto had the highest beta-carotene content of 8.33±0.039mg/100g for both oven-dried and sun-dried samples after processing (Figure 4.1). Nicanuru *et al.* (2015) obtained similar results for dried samples; ranging from 8.2±0.52 to 59.8±0.04 mg/100g. Stability of beta-carotene is exhibited by the 0% - 0.04% loss in beta-carotene content after sun-drying and oven-drying (Maiani *et al.*, 2009). The findings imply that beta-carotene is not lost with loss in moisture, because it is not water-soluble (Maiani *et al.*, 2009). Therefore, neither sun-drying nor oven-drying has a greater effect on beta-carotene content of sweet potato than the other. They possess equal impact. There was therefore no significant difference in beta-carotene content between fresh and processed sweet potato (ANOVA $p>0.05$, Appendix 1).

Upon conversion to retinol activity equivalence (RAE), Resisto had 697.5±0.039 µg/100g of Retinol Activity Equivalents (RAE) after processing (Table 4.1). Food and Drug Administration (2015) highlights that Vitamin A is given as a measure of the micrograms (µg) of retinol activity equivalents (RAE) to account for the different bioactivities of retinol and provitamin A carotenoids. The body converts all dietary sources of Vitamin A into retinol, therefore, 1µg of physiologically available retinol is equivalent to 12µg of ß-carotene (Food and Drug Administration, 2015). The daily RAE requirements are distinguished by age and gender, as well as on the basis of the state of whether one is pregnant or undergoing lactation (Institute of Medicine, 2001). The average daily intake of beta-carotene ranges from 400-900µg/100g RAE for males aged 0-51+, 400-700 µg RAE for females aged 0-51+ and from 750-100 µg/100g RAE for pregnant and lactating women (Table 2.1, Appendix 3). Sun-dried and oven-dried Resisto had enough RAE to cater for the daily beta-carotene intake requirements for males and females aged 0-13 after processing (Table 2.1, Appendix 3). Males and females aged above 13 would need 150g

servings of processed Resisto in order to meet their daily RAE, while pregnant and lactating women would need 200g servings of processed Resisto daily in order to meet their daily beta-carotene intake requirements (Table 2.1, Appendix 3). Germany II and Chingovha produced RAE values (59.17±0.039 µg/100g- 63.33±0.039 µg/100g RAE) below the required daily beta-carotene intake (Table 2.1, Appendix 3). The two cultivars are therefore not fit to combat Vitamin A deficiency. The results obained in this study (Figure 4.1) echo the findings of Maiani *et al*. (2009), Nicanuru *et al.* (2015) and Carvalho *et al.* (2012).

The beta-carotene levels of Resisto are safe as they do not exceed the range which is considered as being large; that is, 20 000 to 30 000µg per day (Food and Drug Administration, 2015). This means that there are little-to-no chances of carotenodermia development; caused by excess intake of Resisto.

The insignificant differences in beta-carotene content between fresh and processed samples (Tukey multiple comparisons, Appendix 1)are in harmony with the findings of Lyimo *et al.* (2010), which showed no effect of sun-drying and oven-drying on beta-carotene content. Burri (2011) further supports this by concluding that post-harvest processing results in minimal reduction in beta-carotene content, ranging from 0-12% and these findings are in line with those of Chandler and Schwartz (1988). However, this contradicts the results of Nicanuru (2016), which revealed a threefold reduction in beta-carotene content after drying. Furthermore, Ruttarattanamongkol (2015) observed an increase in loss of beta-carotene content of orange-fleshed sweet potato with an increase in time when oven-drying at 60°C, which is similar to the temperature which was used to obtain beta-carotene content in Figure 4.1. The reason for the insignificant differences between fresh and processed sweet potato samples (Figure 4.1) may be that beta-carotene molecules are stable or there may have been an error with the spectrophotometer such that biased readings were

obtained (Lyimo *et al.*, 2010). High Performance Liquid Chromatography used in other studies may have been the reason for observing losses in beta-carotene content (Ahamad *et al.*, 2007). In contrast, Nicanuru *et al.* (2016) and Ruttarattanamongkol *et al.* (2015) may have observed low beta-carotene content after processing may be because they overlooked key factors which led to loss in beta-carotene content after processing. For instance, storage of samples at a temperature of -20°C prior to analytical tests may have actually degraded beta-carotene (K'osambo, 1999). Freezing reduces beta-carotene content by 5% (United States Department of Agriculture, 2003). Perhaps low temperatures below 0°C had a degradative effect on beta-carotene and should have been a blocking variable. Furthermore K'osambo (1999) packaged samples under Nitrogen. Nitrogen may also have degraded beta-carotene. Processing exposes carotenoids to degradative conditions, including free radical formation (Goodwin, 1980, Mlokozi and Svanberg, 2002). While carotenoids are susceptible to degradation by heat, alkali, metal ions and light because they are highly conjugated, beta-carotene levels did not decrease greatly after processing (Wong, 1989). This means that beta-carotene is not easily degraded by light, heat, oxygen, acids, prooxidant metals and active surfaces (Maiani *et al.*, 2009). Significant differences were noted across the three cultivars; which may be accounted for by variations in genotype composition, which affect composition and content of carotenoids in different cultivars (Maiani *et al.*, 2009).

It is important to leave room for error because errors may be introduced during each processing step; for instance, during sample preparation, extraction, drying and quantification (Maiani *et al.*, 2009). Researchers such as K'osambo (1999) had measures to avoid degradation of beta-carotene; which included storage of samples at -20°C prior to analytical tests, packaging samples under Nitrogen, extracting carotenoids under ice to mminimize possible thermal degradation and isomerization, and the use of pure beta-carotene as a standard (K'osambo, 1999). On the contrary,

the aforementioned precaution measures were not observed in this study, yet beta-carotene was not degraded after processing (Figure 4.1), thus it is safe to consider beta-carotene as a stable molecule which is not easily degraded or isomerized.

5.2 Fat content

The fresh sweet potato fat content range of 0.04±0.038- 0.1±0.026g/100g (Figure 4.2) is enough to show that sweet potato is a low fat crop, as supported by the Department of Agriculture, Forestry and Fisheries South Africa (2011). Results obtained in this study (Figure 4.2) are not consistent with the findings of Ji *et al.* (2015) and Lyimo *et al.* (2015) who reported fat content values of 0.56-0.76g/100g and 0.03-0.95g/100, respectively. Lyimo *et al.* (2010) focused on six varieties of sweet potato grown in Tanzania, and concluded that sweet potato is a poor source of fat. Deviations in fat content across varieties grown in different countries may be accounted for by environmental conditions, as well as farming site; which affect nutritional quality (K'osambo *et al.*, 1999).

Sun-dried Germany II retained the highest fat content of 0.09±.002g/100g after processing, which is similar to the results of Olatunde *et al.* (2015) and Nicanuru *et al.* (2015) who obtained fat content range of 0.04-1.45g/100g and 0.56-1.93g/100g respectively. The significant differences in fat content between fresh and processed sweet potato (Tukey multiple comparisons, Appendix 2), are contrary to the observation of Lyimo *et al.* (2015) of sun-drying having no effect on fat content.

Fat is a dietary factor which has an effect on bioavailability of beta-carotene, that is, it is required by the body for absorptions of beta-carotene because beta-carotene is fat-soluble (van het Hof *et al.*, 2000). The implication of low fat content in sweet potato is low absorpion of beta-

carotene and other fat-soluble vitamins by the body (Burri, 2011). A diet with no fat results in 0.5-1.1% beta-carotene absorption by the human body (Burri, 2011). Low fat content (Figure 4.2) will only result in approximately 2% beta-carotene absorption by the body (Burri, 2011). Ingestion of fat along with beta-carotene increases bioavailability of beta-carotene (Jayarajan *et al.*, 1980).The amount of dietary fat required to ensure carotenoid absorption is 3-5g per meal (Dimitrov *et al.*, 1988). Dietary fat forms a micelle in the intestines through which beta-carotene is absorbed (Koonvitsky, 1997). Low fat therefore means no micelle formation, hence no beta-carotene absorption, resulting in no improvement of the human plasma retinol concentration (Koonvitsky, 1997). The fat content results obtained after processing (Figure 4.2) indicate that sweet potato fat (0.02 g/100g- 0.09 g/100g) is not enough for enhancing bioavailability of beta-carotene in the human body, therefore there is need to add a source of dietary fat with 3-5 g/100g fat when eating a meal of processed sweet potato (Prince *et al.*, 1991). An example of supplementing dietary fat is adding a dash of butter of sprinkling one or two teaspoons of virgin oil (Borel *et al.*, 1998).

While there is no added advantage for consuming high fat diets for children, their expected fat intake of 30-40% is not met by the fat content (Figure 4.2) of processed sweet potato (Food and Agriculture Organization of the United Nations, 1994). Adults are recommended to obtain 15% of their energy intake from dietary fat, while women of reproductive should consume at least 20% of their energy from fat (Food and Agriculture Organization of the United Nations, 1994). The advantage of low fat, however, is low risk of diseases such as cancer or coronary heart disease (Burri, 2011). In that regard, sweet potato can be classified as a healthy food source.

5.3 Recommendations

5.3.1 Beta-carotene

Resisto is high in beta-carotene content therefore it must be biofortified, while Chingovha and Germany II which are low in beta-carotene must be artificially fortified. In addition to using most of the surplus sweet potato to produce baby food, processing into flour would be an excellent alternative because processing caters for all age groups, for example, porridge prepared using sweet potato flour is consumed by all age groups. Nutritional information of fresh and processed sweet potato needs to be made available to everyone, especially those in remote areas to improve appreciation.

5.3.2 Fat

The fat content in all three sweet potato cultivars was below the threshold required for absorption of beta-carotene by the body. Consequently, processed sweet potato must be eaten with an accompaniment which contains 3-5g/100g dietary fat.

5.3.3 Sun-drying and oven-drying

Both sun-drying and oven-drying can be used in post-harvest processing of sweet potato because both have no effect on crude fat and beta-carotene content. People with no access to ovens can resort to sun-drying. During rainy seasons, oven-drying can be used.

5.4 Conclusion

Resisto retained the most beta-carotene content after processing, therefore it is best suited for post-harvest processing in comparison to Chingovha and Germany II. Both sun-drying and oven-drying had similar effects on beta-carotene content across all three cultivars although sun-drying yielded

less losses in fat content in Resisto and Germany II, therefore sun-drying is more effective to use for post-harvest processing.

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Appendix 1: SPSS output for mean values and standard deviation of beta-carotene

3. Cultivar * State

Dependent Variable: Beta-carotene

Cultivar	State	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Chingovha	Fresh	.735	.039	.652	.817
	Sun-dried	.705	.039	.622	.787
	Oven-dried	.709	.039	.627	.792
Germany II	Fresh	.762	.039	.679	.845
	Sun-dried	.753	.039	.671	.836
	Oven-dried	.759	.039	.676	.841
Resisto	Fresh	8.373	.039	8.291	8.456
	Sun-dried	8.327	.039	8.244	8.409
	Oven-dried	8.327	.039	8.244	8.409

SPSS output for mean differences of beta-carotene content across all three varieties

Multiple Comparisons

Dependent Variable: Beta-carotene

Tukey HSD

(I) Cultivar	(J) Cultivar	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Chingovha	Germany II	-.04178	.032152	.414	-.12383	.04028
	Resisto	-7.62600*	.032152	.000	-7.70806	-7.54394
Germany II	Chingovha	.04178	.032152	.414	-.04028	.12383
	Resisto	-7.58422*	.032152	.000	-7.66628	-7.50217
Resisto	Chingovha	7.62600*	.032152	.000	7.54394	7.70806
	Germany II	7.58422*	.032152	.000	7.50217	7.66628

Based on observed means.

The error term is Mean Square(Error) = .005.

*. The mean difference is significant at the .05 level.

SPSS output for mean differences of beta-carotene content for the three states of sweet potato

Multiple Comparisons

Dependent Variable: Beta-carotene

Tukey HSD

(I) State	(J) State	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Fresh	Sun-dried	.02844	.032152	.657	-.05361	.11050
	Oven-dried	.02511	.032152	.719	-.05695	.10717
Sun-dried	Fresh	-.02844	.032152	.657	-.11050	.05361
	Oven-dried	-.00333	.032152	.994	-.08539	.07872
Oven-dried	Fresh	-.02511	.032152	.719	-.10717	.05695
	Sun-dried	.00333	.032152	.994	-.07872	.08539

Based on observed means.

The error term is Mean Square(Error) = .005.

Appendix 2: SPSS output for mean values and standard deviation for fat content

Descriptive Statistics

Dependent Variable: Fat

Cultivar	State	Mean	Std. Deviation	N
Chingovha	Fresh	.04300	.003606	3
	Sun-dried	.03100	.002646	3
	Oven-dried	.03667	.001155	3
	Total	.03689	.005689	9
Germany II	Fresh	.10000	.002646	3
	Sun-dried	.09067	.001528	3
	Oven-dried	.06567	.003055	3
	Total	.08544	.015525	9
Resisto	Fresh	.08967	.003786	3
	Sun-dried	.04300	.003606	3
	Oven-dried	.01700	.001732	3
	Total	.04989	.032006	9
Total	Fresh	.07756	.026463	9
	Sun-dried	.05489	.027434	9
	Oven-dried	.03978	.021282	9
	Total	.05741	.028926	27

SPSS output for mean differences across the three states of sweet potato

Multiple Comparisons

Dependent Variable: Fat

Tukey HSD

(I) State	(J) State	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Fresh	Sun-dried	.02267*	.001318	.000	.01930	.02603
	Oven-dried	.03778*	.001318	.000	.03441	.04114
Sun-dried	Fresh	-.02267*	.001318	.000	-.02603	-.01930
	Oven-dried	.01511*	.001318	.000	.01175	.01847
Oven-dried	Fresh	-.03778*	.001318	.000	-.04114	-.03441
	Sun-dried	-.01511*	.001318	.000	-.01847	-.01175

Based on observed means.

The error term is Mean Square(Error) = 7.815E-006.

*. The mean difference is significant at the .05 level.

SPSS output for mean differences across the three sweet potato cultivars

Multiple Comparisons

Dependent Variable: Fat

Tukey HSD

(I) Cultivar	(J) Cultivar	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Chingovha	Germany II	-.04856*	.001318	.000	-.05192	-.04519
	Resisto	-.01300*	.001318	.000	-.01636	-.00964
Germany II	Chingovha	.04856*	.001318	.000	.04519	.05192
	Resisto	.03556*	.001318	.000	.03219	.03892
Resisto	Chingovha	.01300*	.001318	.000	.00964	.01636
	Germany II	-.03556*	.001318	.000	-.03892	-.03219

Based on observed means.

The error term is Mean Square(Error) = 7.815E-006.

*. The mean difference is significant at the .05 level.

Appendix 3

Table 2.1: Average daily intake level of ß-carotene

Source: Institute of Medicine, Food and Nutrition Board (2001)

AGE	MALE	FEMALE	PREGNANCY	LACTATION
0-6 months	400 µg RAE	400 µg RAE		
7-12 months	500 µg RAE	500 µg RAE		
1-3 years	300 µg RAE	300 µg RAE		
4-8 years	400 µg RAE	400 µg RAE		
9-13 years	600 µg RAE	600 µg RAE		
14-18 years	900 µg RAE	700 µg RAE	750 µg RAE	1 200 µg RAE
19-50 years	900 µg RAE	700 µg RAE	770 µg RAE	1 300 µg RAE
51+ years	900 µg RAE	700 µg RAE		