CHARACTERISTIC EFFECTS OF DRYING PROCESSES ON BIOACTIVE COMPOUNDS IN AFRICAN EGGPLANT (*Solanum aethiopicum* L.)

NAOMI NAMMAIYAN MBONDO

MASTER OF SCIENCE

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Characteristic Effects of Drying Processes on Bioactive Compounds in African Eggplant *(Solanum aethiopicum* L.*)*

Naomi Nammaiyan Mbondo

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DECLARATION

I hereby declare that this thesis is my original work and that it has not been presented to any other university or institution for the award of a degree.

Signature.....Date.....

Naomi Nammaiyan Mbondo

This thesis has been submitted for examination with our approval as university supervisors.

Signature.....Date.....

Prof. Willis O. Owino, PhD

JKUAT, Kenya

Signature……..Date…….....

Prof. Daniel N. Sila, PhD

JKUAT, Kenya

Signature……..Date……

Dr. Jane Ambuko, PhD

UoN, Kenya

DEDICATION

Specially dedicated to my beloved husband Paul Njihia, for inspiring me.

To my precious children Esther, Benard and Jason for their tender emotional and spiritual support.

To my dear Aunty Rhoda Mueni, thank you for initiating this and believing in me.

To my dear parents Jason Mbondo and Mary Mbondo, thank you for your encouragement and prayers.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEAC	Antioxidant equivalent ascorbic capacity
ABTS	2,2-Azinobis 3-ethylbenzothiazoline-6-sulfonate
ANOVA	Analysis of variance
AVDRC	African Vegetable Research and Development Center
BHT	Butylated hydroxytoluene
cm	Centimeter
DNA	Deoxyribonucleic acid
DPPH	2,2-diphenyl-1-picryl hyrazyl
FAO	Food and Agricultural Organization
g	Grams
h^{-1}	Per hour
µl	Microliter
GAE	Gallic acid equivalent
GIZ	Deutsche Gesellschaft fu¨r Internationale Zusammenarbeit
HDL	High density lipoproteins
HPLC	High pressure liquid chromatography
J/mol	Joule per mole
kJ/mol	Kilo joule per mole
LDL	Low density lipoproteins
Ln	Natural logarithm
M	Molar
mbar	Millibar
mg	Milligram
ml	Milliters
ml/min	Milliter per minute
mm	Millimeter
mM	Millimolar

m/s	Meter per second
n	Number of replicates
nm	Nanometer
NPK	Nitrogen, phosphorus and potassium
PHLs	Postharvest losses
PPO	Poly phenol oxidase
r	Regression coefficient
RCF	Relative centrifugal force
RAPD	Random Amplification of Polymorphic DNA
SSA	Sub-Saharan Africa
SE	Standard error
TEAC	Trolox equivalent ascorbic acid
TPC	Total phenolic content
USD	United States dollar
UV-VIS	Ultra violet to visible light
v/v	Volume by volume ratio
w/v	Weight by volume ratio
db	Dry basis
$\mathbf{IC}_{50}$	Concentration at 50% inhibition
k	Reaction constant
p	Level of significance
Q_{10}	Temperature coefficient
$t_{½}$	Half-life
wb	Wet basis
E_a	Activation energy
R	Ideal gas constant
T	Temperature in degree Kelvin
~	Approximately
°C	Degrees celsius

ABSTRACT

African eggplant (*Solanum aethiopicum L.*) is a rich source of bioactive compounds and functional constituents that are beneficial to human health. However, the short (3-5 days) shelf life can be a major cause of postharvest losses especially during peak harvesting season. Drying technology is a convenient way of producing shelf stable food products, but can lead to thermal degradation of available nutrients and bioactive compounds depending on the drying method and temperature conditions. Monitoring the changes in bioactive compounds is important for optimizing and choosing drying methods and conditions.The objective of this study was to investigate the effect of harvesting maturity on the drying characteristics; to determine the effect of four drying methods (solar, hot air oven, vacuum oven and freeze) on the retention of total phenolics, beta carotene, antioxidant capacity, vitamin C and lycopene; to determine the degradation kinetics of total phenolics, beta carotene and antioxidant activity during hot air oven and vacuum oven drying; and to establish consumer acceptability of the dried and reconstituted products through sensory evaluation. Five African eggplant (*Solanum aethiopicum*) accessions (sangawili, manyire green, S00047A, AB2 and aubergine blanche) were used in the study. Harvesting was carried out at two maturity stages defined by the peel shininess, colour and number of days between planting and harvest. Stage 1 maturity had a shiny peel while stage 2 maturity had a non-shiny peel. Samples were dried up to ~10% moisture content in a single layer. Random sampling was done at regular intervals as the drying process progressed. Subsequently, fresh and dried samples were analyzed for moisture content, total phenolics, beta carotene content, vitamin C, lycopene content and antioxidant capacity. Affective testing using 7 point hedonic scale was used for sensory evaluation through a consumer panel to establish the likability scores for the dried and reconstituted samples. The results showed that harvesting maturity significantly ($p<0.05$) effected the moisture content and the drying rate of the five accessions. Moisture content decreased from stage 1 maturity to stage 2 by up to 2.01% with the exception of AB2. The drying rates were higher for stage 1 maturity in comparison to stage 2. The drying time for stage 1 and stage 2 maturities was 360-840 and 360-960 minutes, respectively. In the fresh state, beta carotene, total phenolics and antioxidant activity ranged between 14.75-29.50 mg/100g db, 751.21-1363.95mg/100g gallic acid equivalent (GAE) db and 99.58-325.61mg/ml db percentage inhibition at 50% (IC_{50}) value, respectively. The results showed a significant ($p=0.001$) positive correlation ($r=0.822$) between the total phenolics and the antioxidant equivalent ascorbic acid capacity. However, drying processes significantly ($p<0.05$) reduced the total phenolics, beta carotene and antioxidant capacity with freeze drying presenting the highest retention rate. Overall, 36.26 – 95.05% (total phenolics) and 31.44 – 99.27% (beta carotene) was retained during freeze drying. Lycopene was only detected in the dried samples of the accession manyire green. Also, vitamin C was undetected in both fresh and dried samples. The kinetics of degradation of total phenolics, beta carotene content and antioxidant activity followed a first-order reaction for both hot air oven and vacuum oven drying. The range of reaction rate constant was 0.018-0.067, 0.016-0.226,

and 0.0237-0.453 h^{-1} for total phenolics, beta carotene and antioxidant activity, respectively. Activation energy range was 8.246-23.548, 15.994-60.845, 11.111-25.764 kJ/mol for total phenolics, beta carotene and antioxidant activity, respectively. Regarding the sensorial evaluation, it was not possible to clearly distinguish the sensory profiles of the five accessions statistically. The drying characteristics and degradation kinetics information from this study may be applied by farmers and industrialists in the development of optimum drying controls plan.

CHAPTER ONE

INTRODUCTION

1.1 Background information

African eggplants are wild relatives of the common eggplant (*Solanum melongena*) (Schippers, 2000). They belong to the *Solanum* genus, and comprises of cultivated species such as the S*olanum macrocarpon L.*, *Solanum aethiopicum L.* and *Solanum anguivi*; which are grown mostly in Africa for their fruits and leaves. Both *S. aethiopicum L.* and *S. macrocarporn L.* are native to Africa (Daunay, Lester, & Ano, 2001) whereas common eggplant (*S. melongena)* is of Asian origin (Meyer *et al.,* 2012).

The *S. aethiopicum* L. is one of the five most important vegetables of tropical Africa, together with tomato, onion, pepper and okra (Lim, 2015; Maundu, Achigan-Dako, & Morimoto, 2009; Schippers, 2000). In Kenya, Tanzania, Uganda and Rwanda, it is considered a common vegetable consumed for nutrition, besides medicinal and economic purposes (Lester & Daunay, 2003; Weinberger & Msuya, 2004). *S. aethiopicum* L. is a phenotypically diverse species which is subdivided into four cultivar groups (Gilo, Kumba, Shum, and Aculeatum) (Lester, 1986). Gilo is the commonly cultivated group in Africa and together with Kumba; they are used for their fruits while Kumba and Shum are used for their leaves. Aculeatum group is utilized as ornamental as well as a rootstock (Daunay, 2008; Lester & Daunay, 2003; Schippers, 2000).

Nutritionally, reports have indicated that African eggplant as a vegetable, is recommended for tackling malnutrition problem in Africa, especially among women of child bearing age and children under 5 years old (Chadha & Oluoch, 2003). In addition and of interest, African eggplants are a rich source of phytochemicals including the anthocyanin as well as the phenolic acids (Daunay, 2008). These contribute to the fruit organoleptic properties by imparting a bitter taste and interfering with other molecules during the cooking process (Daunay *et al.*, 2001a). Furthermore, these phytochemical components are high in antioxidant and antiradical activities that are responsible for

reducing the risk of radical-mediated pathogenesis such as carcinogenesis, atherosclerosis, diabetes, Alzheimer, cataracts and age-related functional decline (Atoui, *et al.,* 2005; Stommel & Whitaker, 2003; Zhang & Hamauzu, 2004). Medical research studies have proven that African eggplant possess anti-inflammatory property, hypo-lipidemic effect, antispasmodic activity and anti-ulcerogenic property (Anosike *et al.*, 2012; Chioma *et al.,* 2011; Hassan *et al.,* 2006; Odetola *et al.,* 2004). These reports support the various traditional uses of the plant in different parts of Africa where either the roots, leaves, flowers or the fruits are used to treat various conditions such as colic, high blood pressure, uterine complaints, throat infections, gastric ailments, getting rid of hookworms, as a sedative and a laxative. (Lim, 2015). Economically, African eggplant offers gainful employment among the rural households and its cultivation is not limited to any age or sex. Women, in particular, use the eggplants as an additional source of income. (Anuebunwa, 2007).

Recently, there has been increase in consumer awareness towards bioactive components and their potential health benefits, leading to preference of foods which contain more functional bioactive compounds. Consequently, food processors are increasingly focusing on food products with higher bioactive compounds and their maximal retention during processing to meet the market trend (Nambi, *et al.,* 2016). With regard to this, African eggplant has increased in its demand and production. On the flip side, increased production is accompanied by increase in postharvest losses due to their perishable nature.

Previously, attention focused on increased food production while reduction of food loss and food wastage which comes hand in hand with increased production was neglected (Hodges, Buzby & Bennett, 2011). Postharvest losses reduction is a quick impact intervention for enhancing food availability, alleviating poverty, and improving nutrition (GIZ, 2013a). Furthermore, reducing postharvest losses has positive impacts on the environment and climate as it enhances farm-level productivity and reduces the

utilization of production resources or expansion into fragile ecosystems to produce food that will be lost and not consumed (GIZ, 2013b; Hodges *et al.,* 2011).

Due to the relatively short postharvest life in fresh form, vegetables can be converted to shelf stable forms through processing (Vicente *et al.,* 2009). One of the most commonly used processing methods is drying (Swanson & McCurdy, 2009). However, drying process can induce negative changes in the physical and chemical properties of the product in question (Muthukumarappan & Tiwari, 2010). Some chemical compounds such as the bioactive compounds are considered as markers of nutritional quality and can be monitored during drying to show the extent of degradation (Vicente *et al.,* 2009).

Several studies have described the drying characteristics and its effects on phytonutrients of various vegetable products such as tomato (Kingsly *et al.,* 2007; Movagharnejad & Nikzad, 2007; Mwende, Owino, & Imathiu, 2018), red chilli (Hossain, Woods, & Bala, 2007), sweet pepper (Vengaiah & Pandey, 2007), okra (Doymaz, 2005), carrot (Zielinska & Markowski, 2007), and common eggplant (Doymaz, 2011). However, information on drying of African eggplant is scanty. This study sought to reduce post-harvest losses in African eggplants through application of drying technology and using the predominant bioactive compounds as markers of nutritional quality to show the effect of different drying methods.

1.2 Problem statement

There is limited literature on the nutritional, economical and value addition of African eggplant, despite its inclusion in the top five list of important vegetables in tropical Africa (Ismail *et al.,* 2004; Jiménez *et al.,* 2009). There have been reports showing that African eggplants are rich in phytochemicals which possess antioxidant and antiradical activities responsible for reducing the risk of radical-mediated pathogenesis such as cancer, atherosclerosis, diabetes, Alzheimer, cataracts and age-related functional decline (Atoui *et al.,* 2005; Lim, 2015; Stommel & Whitaker, 2003; Zhang & Hamauzu, 2004). The increasing interest in the health and nutritional benefits associated with

phytochemicals has led to increased demand of foods that are rich in bioactive compounds (Nambi *et al.*, 2016).

In Kenya, cultivation and consumption of African eggplants is popular in the coastal region and is slowly spreading to other parts. African eggplants are rich in phytochemicals and are high yielding crops with about 10kg per plant (National Research Council, 2006). However, increased production is accompanied by post-harvest losses (PHLs) estimated to be up to 25% due to poor post-harvest handling practices (Chadha, 2006; Hornal, Timpo & Guillaume, 2007). Perishable commodities such as African eggplants have a limited shelf life in fresh state and normally require cold chain systems during handling, transport and distribution to prevent PHLs and maintain quality. Unfortunately, these facilities are inadequate or poorly established in developing countries such as Kenya. Furthermore, perishable commodities are sensitive to chilling injury (Yahia, Barry-Ryan, & Dris, 2004). Exposure to prolonged periods of chilling stress lead to irreversible symptoms such as surface lesions and pitting, internal discoloration, water-soaking of the tissue, off- flavour, failure to ripen, and decay (Yahia, *et al.,* 2004).

Drying of African eggplants can be used to minimize PHLs and improve their shelf life stability. However, drying can plausibly cause damage to the inherent nutrients and bioactive compounds through food degradation (oxidation, discoloration, shrinkage, or loss of tissue) and change the food's nutritional value (Chang *et al.,* 2006; Mayor & Sereno, 2004; Swanson & McCurdy, 2009) depending on the drying method and treatment conditions. A study on the drying characteristics of African eggplants is critical in conceptualizing the drying process and setting dryer controls. The choice of the drying method and optimization of the drying process is important for bioactive compounds retention (Akdaş & Başlar, 2015). Therefore, drying requires optimization of a number of procedures including the time of harvest, the slice sizes, the temperature time combinations and the packaging and its effects on nutrition (Doymaz, 2009; Zaro, *et al.,* 2015).

1.3 Justification

Recently, there has been increase in consumer awareness towards bioactive components and their potential health benefits, leading to preference for foods which contain more functional bioactive compounds. Consequently, food processors are increasingly focusing on food products with higher bioactive compounds and their maximal retention during processing to meet the market trend (Nambi *et al.*, 2016). Postharvest losses (PHLs) reduction is a quick impact intervention for enhancing food security (GIZ, 2013a). The FAO and World Bank, approximated that up to 47% of USD 940 billion needed to eradicate hunger in Sub-Saharan Africa (SSA) by 2050 will be required in the postharvest sector (FAO–World Bank, 2010). Reducing food losses therefore offers an important pathway of availing food, alleviating poverty, and improving nutrition. Many global food security initiatives and organizations such as the World Bank's Global Agriculture and Food Security Program have positioned themselves to tackle PHLs. In Sub-Saharan Africa, PHLs reduction is also prioritized in the agricultural and food security strategic plans of national governments. Ever since the first World Food Conference of 1974, various approaches and technologies have been applied and promoted to counter PHLs (Affognon *et al.*, 2015). In line with this, the development of adequate postharvest treatments for fresh produce, and their optimum use are of great necessity and economic importance. Adequate postharvest treatments should reduce losses, and preserve perishable foods to meet consumer demands for constant availability and good quality throughout the year.

Drying technology is simple, safe and easy to learn. Drying reduces the water activity thus preventing microbial activity from thriving. In addition, drying slows down or inactivates the enzymes action, reduces the weight and volume of commodities thus reducing the packaging and transportation costs. (Clark, 2009; Yahia *et al.*, 2004; Swanson & McCurdy, 2009). Enormous losses in terms of money and labour besides steep rise in prices of commodities during the off season are also reduced (Sagar & Suresh, 2010). PHLs in African eggplant could be minimized through drying since the

shelf life is stabilized. As a result, African eggplants potentiality as an income source and availability during off seasons and drought periods might be improved.

Application of drying technology provides a suitable alternative to cold chains systems which are absent or inadequate in Kenya. Optimization of the drying process is critical for a quality dried product to be achieved and also for cost effectiveness as it shortens drying time and minimizes damage to the product (Sagar & Suresh, 2010). The community and industrialists may benefit by using the findings of this study to add value to the African eggplants. In addition, the reports from this study are an addition into the body of knowledge acting as a point of reference for future researchers who venture into related projects.

1.4 Objectives

1.4.1 General objective

To investigate the drying characteristics and the effect of drying techniques on the retention of major bioactive compounds in selected African eggplant accessions.

1.4.2 Specific objectives

I. To determine the effect of harvest maturity on drying characteristics (drying time and drying rate) of five African eggplant accessions.

II. To determine the effect of different drying methods (Solar, Vacuum oven, Freeze and Hot air oven drying) on the retention of predominant bioactive compounds in African eggplant.

III. To determine the degradation kinetics of the predominant bioactive compounds (namely total phenolic content, beta-carotene) and antioxidant capacity in African eggplant during hot air oven and vacuum oven drying processes.

IV. To determine consumer acceptability for the dried product and the reconstituted product through sensory analysis.

1.4.3 Hypothesis

I. Harvest maturity has no significant effect on the drying characteristics (drying time and drying rate) of different African eggplants.

II. Different drying methods (Solar, Vacuum oven, Freeze and Hot air oven drying) have no significant effect on the retention of predominant bioactive compounds in African eggplant.

III. Hot air oven and vacuum oven drying have no significant effect on the degradation kinetics of the predominant bioactive compounds (namely total phenolic content, beta-carotene) and antioxidant capacity in African eggplants.

IV. Dried and reconstituted African eggplants have no significant effect on consumer acceptability through sensory analysis.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin, distribution and production of African eggplants

Solanum aethiopicum is reported to have been domesticated from the wild *Solanum anguivi* Lam., through the semi-domesticated *Solanum distichum* Schumach and Thonn. (Lim, 2015). These two ancestral species occur throughout tropical Africa, *S. anguivi* in disturbed vegetation and *S. distichum* in gardens. Other areas where *S. aethiopicum* cultivation spread are Brazil and the Caribbean in South America, where it is believed to have been introduced probably through the slave trade several centuries ago (Carney, 2013). Occasionally it has been found in southernmost France, Italy and southeast Asia (Lim, 2015). On the other hand, *S. macrocarpon* L. was domesticated from a wild and very prickly ancestor *S. dasyphyllum* Schum and Thonn. (Bukenya & Carasco, 1994), which is found in non-arid tropical areas of Africa. It has less popularity than *S. aethiopicum*, but has local importance in several parts of Eastern and Central Africa (Bukenya-Ziraba & Bonsu, 2004; Nyadanu & Lowor, 2015; Schippers, 2000). Its cultivation has remotely been found in the Caribbean (Carney, 2013), as well as in Southeast Asia (Malkanthi *et al.,* 2014). There are no statistics related to the productivity, growing area and yields of *S. aethiopicum* and *S. macrocarpon* despite being the most popular traditional vegetables in East, West and Central Africa and of commercial importance in the African continent (Lester & Daunay, 2003; Maundu *et al.,* 2009; Nyadanu & Lowor, 2015; Schippers, 2000; Sękara, Cebula, & Kunicki, 2007).

2.2 Taxonomy of African eggplants

The taxonomy of eggplant relatives still remain a challenge due to the continuum of morphological variation, cross compatibility, and genetic distances that exist between advanced and primitive cultivars of eggplant, with weedy and wild relatives (Daunay, 2008). This provides a model system for the study of gene flow of traits affected by domestication between a crop and its spontaneous forms (Daunay, 2008).

2.2.1 *Solanum aethiopicum* L. (Scarlet eggplant)

There are many varieties of the African eggplant, with different shapes, sizes, and colors but the most commonly cultivated species across Sub-Saharan Africa is *S. aethiopicum* (Amanda *et al*., 2011). *S. aethiopicum* is a phenotypically diverse species which can be subdivided into four cultivar groups (Lester, 1986).

The first group is gilo. It has edible fruits while the leaves are hairy and inedible. Its fruits are normally oval or spherical, with a fruit diameter between 2.5 cm and 12 cm and have a white, green, or even purple colour at the commercial stage as shown in Figure 2.1. Gilo group is the most commonly cultivated group.

Figure 2.1: Representative fruit vegetable pictures for gilo group of *S. aethiopicum*

The second group is Shum which is characterized by glabrous leaves normally consumed in same way as spinach depending on consumer preference. The fruits are very small and spherical usually between 1.2 and 2.0 cm in diameter as illustrated in Figure 2.2. The extremely bitter fruits are inedible.

Figure 2.2: Representative fruit vegetable picture for shum group of *S. aethiopicum*

Kumba is the third group whose fruits and leaves are consumed. The leaves are large and glabrous, while the fruits are flattened, ribbed, and have a variable diameter from 3 to 20 cm which, like the Gilo group, are variable in colour. A fruit vegetable picture of Kumba group is shown in Figure 2.3.

Figure 2.3: Representative fruit vegetable pictures for kumba group of *S. aethiopicum*

The forth group is Aculeatum. It is utilized as an ornamental. It has hairy leaves and large fruits as shown in Figure 2.4. Aculeatum group is oftenly used for disease resistance breeding under the synonym *S. integrifolium* (Daunay, 2008; Lester, 1986; Lester & Daunay, 2003; Schippers, 2000).

Figure 2.4: Representative fruit vegetable picture for acualetum group of *S. aethiopicum*

2.2.2 *Solanum macrocarpon* L. (Gboma eggplant)

Solanum macrocarpon is cultivated both for its fruits and leaves. The fruits are flat in shape, non-ribbed, with a smooth surface and a diameter of between 3 and 10 cm. At the commercially mature stage the fruit colour is either white or green. Its leaves are used in the same way as spinach (Nyadanu & Lowor, 2015).

2.3 Agro ecology of *S. aethiopicum* and *S. macrocarpon*

Solanum aethiopicum is strictly a tropical crop species, thus is intolerant of low cold temperatures and frost or extremely wet conditions. It is also intolerant of water-logging and some tolerance of irrigation-induced salinity is reported from Senegal (Lim, 2015). The three edible groups (Gilo, Kumba and Shum) are adapted to different areas depending on the climate. The Gilo group is mostly found in humid areas throughout tropical Africa where its members grow best at the full sun of woodland savanna on fairly deep and well-drained soils with pH 5.5–6.8, and 25–35°C and 20–27°C day and night temperatures, respectively (Kouassi *et al.,* 2014). The Kumba Group which is commonly cultivated in semi-arid areas from Occidental Sahel to the north of Nigeria tolerates hotter conditions (up to 45°C day temperature) with air humidity sometimes as

low as 20%, especially if irrigated (Kouassi *et al.*, 2014). The Shum Group prefers warm, humid conditions and will shed its leaves when it gets dry. It is mainly found at high altitude and very humid areas of Africa in Uganda and south east of Nigeria (Kouassi *et al.*, 2014). In Uganda, it is grown in swamps during the dry season (Lim, 2015; Kouassi *et al.*, 2014; Maundu *et al*., 2009; Nyadanu & Lowor, 2015; Schippers, 2000). Cultivation of *S. macrocarpon* for its fruits takes place in the more humid areas on the western coast of Africa, while cultivation for its leaves is common in the Eastern and Central parts of Africa (Lester & Daunay, 2003; Maundu *et al.,* 2009; Nyadanu & Lowor, 2015; Schippers, 2000).

2.4 Hybridization of African eggplants

New *S. aethiopicum* cultivars are bred on a small scale in some African countries. This is due to economic, sociological, and political challenges in the African continent. On the other hand, *S. macrocarpon* cultivars are improved locally by growers, mainly in Africa. The two species are of interest for genetic improvement of *S. melongena*, considering the presence of several traits of agronomic interest in its germplasm (Alba *et al.*, 2005; Sękara *et al.,* 2007). Previous research studies have reported on the possibility of improved hybrids possessing pest and disease resistance as well as that of obtaining large variation in shape and colour of the fruits (Daunay *et al.,* 1993; Gowda *et al.*, 1990; Rizza *et al.*, 2002; Schaff *et al.*, 1982)

The Gilo cultivar group might have evolved from the Shum cultivar group through hybridization and selection (Anaso, 1991). Variation in 39 random amplification of polymorphic DNA (RAPD) markers for 18 populations of *S. anguivi* and *S. aethiopicum* (Gilo and Shum Group) was studied by Stedje and Bukenya-Ziraba (2003) where they reported that variation among the species and groups was less than 10%, while the variation within the species and groups was more than 90%.

Superior varieties of *S. aethiopicum* are yet to be identified or developed. The researches on new, promising varieties are led at the African branch of the Asian Vegetable Research and Development Center (AVRDC). The best known indigenous cultivars are:

'Manyire Green' – a popular cultivar of East Africa, 'Tengeru White', 'Jaxatu Soxna', 'N'Goyo', and 'N'Galam'. (Sękara *et al.*, 2007).

The Aculeatum group is believed to have risen from hybridization between the Kumba group and the wild *S. anguivi* (Lester & Daunay, 2003). *S. aethiopicum* and common eggplants can be easily hybridized (Daunay *et al.,* 1991; Prohens *et al.,* 2012; Rotino *et al.,* 2014), and actually interspecific hybrids between the two species are used as rootstocks for commercial cultivation of common eggplant (Gisbert *et al.,* 2011). Furthermore, interspecific hybrids between both species can be backcrossed to both parental species, facilitating introgression from one species into the genetic background of the other (Daunay *et al.,* 1991; Prohens *et al.,* 2012; Rotino *et al.,* 2014). There is a possibility for interspecific hybrids between *S. macrocarpon* and common eggplants. However, they are normally highly sterile (Bletsos *et al.,* 2004; Daunay *et al.,* 1991; Khan *et al.,* 2013) and backcross breeding with common eggplant has been unsuccessful. Thus, *S. macrocarpon* presents more difficulties than *S. aethiopicum* for introgression breeding with common eggplant (Rotino *et al.,* 2014).

2.5 Nutritional value of African eggplants

African eggplants contains a lot of mineral, vitamins, carbohydrate and water substances which are important and highly beneficial for the maintenance of health and prevention of diseases (Maraizu, 2007; Okafor, 1981; Onuoha, 2006). According to Dougnon *et al.,* (2012), very few studies have explored the usefulness of *S. macrocarpon* scientifically. However, the following nutrients were found per 100g of edible portion of the fruit: 92.9 g moisture, 0.016 g fat, 1.47 g proteins, 3.77 mg calcium, 2.43 mg magnesium and 0.20 mg iron (Dougnon *et al.,* 2012). *Solanum macrocarpon* was found to have high proportions of alkaloids, mucilages and reducing compounds while hydrolysable tannins and coumarins presence was moderate (Dougnon *et al.,* 2012). On the other hand, several reports have documented varied data on the nutritional composition of *S. aethiopicum* (AVRDC 2004; Edem *et al.,* 2009; Hornal *et al*., 2007; Sánchez-Mata *et al.,* 2010; Voon & Kueh 1999). The most recent report by Chinedu *et al.,* (2011) on

proximate analysis of fresh fruits of *S. aethiopicum* (per 100 g of edible portion) showed: 89.27 g moisture, 2.24 g protein, 0.52 g fat, 0.87 g ash, 2.96 g crude fibre, 4.14 g carbohydrate, 498.47 mg calcium, 1.98 mg magnesium and 1.02 mg iron. Alkaloids, flavonoids phytosterols, saponins, vitamin C, moderate presence of cardiac glycosides, steroids, tannins, and trace amount of terpenoids were also found in the fruits (Chinedu *et al.,* 2009).

The proportion of α-solamargine in *S. aethiopicum* was variable (48–89%). The glycoalkaloid levels of *S. aethiopicum* were found to be similar to those of *S. melongena* (about 14% of values considered as toxic) and could be considered as safe for human consumption (Sánchez-Mata *et al.,* 2010). Four groups of phenolic acids were found in *S. aethiopicum* fruit (Stommel & Whitaker 2003). Group 1 comprised chlorogenic acid isomers and four compounds were identified 3-O-*trans*, 5-O-*trans*, 5-O-*cis* isomers of caffeoylquinic acid (3CQA, neochlorogenic acid; 5-CQA, chlorogenic acid; 4-CQA, cryptochlorogenic acid and 5-(Z)-CQA, *cis*-chlorogenic acid) respectively. Chlorogenic acid was the predominant compound in Group 1, with average levels 176-, 28.9-, and 92.5- fold higher than levels of neochlorogenic acid, cryptochlorogenic acid and *cis*-chlorogenic acid, respectively (Stommel & Whitaker 2003). Group 2 consisted of two phenolics 3,5-diCQA and 4,5-diCQA. Group 3 comprised four compounds: – N, N″-dicaffeoylspermidine (predominated); N-caffeoylputrescine and their isomers; and Group 4 comprised 3-O-actyl-5-O-caffeoylquinic acid (3-acetyl-5CQA), 3-O-actyl-4-O-caffeoylquinic acid (3-actetyl-4-CQA) (Stommel & Whitaker 2003). The leaves were reported to contain oxalate and alkaloids such as solasodine, with reported glycocorticoid effects (Lester & Seck, 2004). Their concentration could be reduced by cooking (Lim, 2015). The characteristic bitter taste was attributed to furostanol glycosides (Lim, 2015).

2.6 Medicinal value of African eggplants

Anosike *et al.,* (2012) reported that *S. aethiopicum* fruit had anti-inflammatory property. Their study showed that the fruit extract significantly reduced the fresh egg albumin-

induced rat paw oedema and also reduced the granuloma tissue formation in the fruit treated groups significantly when compared to the control. Another study by Odetola *et al.*, (2004) showed that supplementation of hypercholesterolemic rabbits with *Solanum melongena* and *Solanum gilo* significantly reduced serum total cholesterol by 65.40% and 52.69% respectively, triglyceride by 47.7% and 27%, low density lipoproteins (LDL) cholesterol by 85% and 83%, respectively. They also increased significantly serum high density lipoproteins (HDL) by 24.7% and 25% respectively leading to increased HDL/LDL cholesterol ratio (3.37 and 3.25 respectively). This trend was also similar with liver lipid levels. Histopathological examination of the liver and aorta paraffin section showed fewer lesions in the hypercholesterolemic rabbits treated with *Solanum* fruits compared with control hypercholesterolemic rabbits (Odetola *et al.,* 2004). These observations demonstrated that *Solanum melongena* and *Solanum gilo* had strong hypo-lipidemic effect and could be useful in the treatment of diseases associated with hyperlipidemia such as ischemic heart diseases and arteriosclerosis (Odetola *et al.,* 2004).

Antispasmodic activity property by methanol fruit extracts which showed a dose-dependent relaxation of the rhythmic contraction of the isolated rabbit jejunum was reported by Hassan *et al.,* (2006). The extract also reduced histamine and barium chloride induced contractions of the isolated rabbit jejunum. This supported the traditional use of the plant in alleviating intestinal complaints. Further, Chioma *et al.*, (2011) found that *S. aethiopicum* fruit extract had anti-ulcerogenic property since macerated methanol fruit extract produced higher ulcer inhibition in a dose-dependent manner rats than ranitidine in the indomethacin and acid-ethanol models.

Traditionally, fruits of bitter cultivars are used as medicine in many tropical African countries (Sodipo *et al.,* 2012). In different parts of Africa, the roots and fruits are used as a sedative, and to treat colic and high blood pressure while the juice obtained by macerating the leaves is used to treat uterine complaints (Grubben & Denton, 2004). The extract of the leaves is used as a sedative and anti-emetic and to treat tetanus associated

with miscarriages (Grubben & Denton, 2004). The crushed and macerated fruits serve as an enema (Lim, 2015). The leaves, when heated, are chewed to treat throat infections (Grubben & Denton, 2004). The fruits are taken as a laxative, and to treat cardiac diseases, while flowers and fruits are chewed to clean the teeth (Grubben & Denton, 2004). The juice of boiled roots is drunk to get rid of hookworms, while crushed leaves are taken to treat gastric ailments (Lim, 2015).

2.7 Economic value of African eggplants

Eggplants are species of economic importance mainly in Asian and African countries. Over 50.19 million tons of common eggplant (*S.melongena L.*) is produced globally (FAO, 2014). On the other hand, comprehensive production statistics of African eggplants is lacking (Sękara *et al.,* 2007). In Sub Saharan Africa (SSA), African eggplants are cultivated by small scale farmers and are the most traded indigenous vegetables in the local markets. Small scale farming accounts for 80% of total production. (Amanda *et al.,* 2011; Chadha, 2006; Sękara *et al.,* 2007).

2.8 Postharvest losses (PHLs) in African eggplants

It is estimated that about one third of the food produced globally is lost or wasted (FAO–World Bank, 2010; Prusky, 2011), which translates to a loss of 1.3 billion tons of food per year in a world where over 870 million people go hungry (Gustavsson *et al.,* 2011). Amongst the losses, it is suggested that more than one third of the perishable food crops produced in the world are lost after harvest (Yahia *et al.,* 2004). Based on these reasons, experts now agree that investing in postharvest losses reduction is a quick impact intervention for enhancing food security (GIZ, 2013a).

Post-harvest losses in African eggplants are caused by poor post-harvest handling practices and are estimated to be at 25% depending on the harvesting stage and storage environment (Chadha, 2006; Hornal *et al.,* 2007). High rates of skin bruising, water loss and decays decrease nutritional quality in African eggplants during postharvest handling (Kader, 2005). Lumpkin, (2009) and Abbasi *et al.,* (2011) reported that inappropriate

post-harvest storage management practices cause up to 50% losses of horticultural crops, between harvesting and consumption in developing countries. Consequently, postharvest and storage practices affect quantity, quality and market value of fruits (Majubwa, Msogoya & Maerere, 2015). This gap open several possibilities to address PHLs.

2.9 Application of drying technology in fruits and vegetables

Since the moisture content of fresh fruits and vegetables is more than 80%, they are classified as highly perishable commodities (Orsat *et al.*, 2006). Keeping the product fresh is the best way to maintain its nutritional value. However, this requires cold chain systems which are inadequate and or lacking. Drying is a suitable alternative for postharvest management since it reduces the water activity, preventing microbial damage and reduces transportation and storage costs (Ratti, 2001).

The most applicable methods of drying include freeze, vacuum, osmotic, hot air, Ohmic, micro wave and combination thereof (George *et al.*, 2004). Except for freeze drying, applying heat during drying through conduction, convection and radiation are the basic techniques used to force water to vaporize, while forced air is applied to encourage the removal of vapor (Munjumdar, 2015). Freeze drying of biological materials is one of the best methods of water removal which results in final product of the highest quality (Ratti, 2001; Sagar & Suresh, 2010). Freeze drying is sublimation of ice fraction where water passes from solid to gaseous state. Due to very low temperature, all the deterioration activity as a result of enzyme and microbial activity are stopped and provide better quality to the final product (Ratti, 2001). Recently the market for organic products is increasing. Therefore, the use of freeze drying of fruits and vegetables is not only increasing in volume but also diversifying (Brown, 1999).

Vacuum drying is an important process for heat sensitive materials. The process of vacuum drying can be considered according to physical condition used to add heat and remove water vapor (Parikh, 2015). Low temperature can be used under vacuum for certain commodities that might discolor or decompose at high temperature. A comparison of drying technologies in reviews by Sagar and Suresh, (2010) and Khin *et*

al., (2005) showed that freeze drying, vacuum drying and osmotic dehydration are considered too costly for large scale production of commodity.

Thin, uniform, peeled slices dry the fastest. The peel can be left on the fruit, but unpeeled fruit takes the longer to dry. Pretreatments prevent fruits from darkening. Many light-colored fruits, such as apples, darken rapidly when cut and exposed to air. If not pretreated, these fruits will continue to darken after they have dried (Swanson & McCurdy, 2009).

The have been reports on the drying of eggplants where sun drying and convective hot-air drying have been applied (Amanda *et al.,* 2011; Çağındı *&* Gürhayta, 2016). Santacatalina *et al.,* (2011) reported that drying processes led to changes in textural properties and rehydration patterns in common eggplants and recommended atmospheric freeze drying for intermediate hardness and rehydration rate. According to Guiné *et al.,* (2018), drying common eggplants at low temperatures (50 °C) prompted highest volumetric shrinkage and rehydration rate with storage time in comparison to higher drying temperatures (80 ºC). Also, it was reported that water activity of eggplant samples dried at 50 °C was > 0.7, which does not guarantee absence of microbial growth eventually (Guiné *et al.,* 2018). Flour from convective air oven and tunnel dried common eggplant have been shown to maintain its crude fibre, protein and fat contents (Rodriguez-Jimenez *et al.,* 2018). The dried eggplant is used as a key ingredient in soups and sauces. Many efforts are being put towards drying processes and operating conditions that allow obtaining products with a high quality (Adiletta *et al.,* 2014). The choice of drying method depends on various factors such as the type of product, availability of dryer, cost of dehydration and final quality of desiccated product. Energy consumption and quality of dried products are other critical parameters in the selection of a drying process (De lima *et al.,* 2015).

2.10 Quality aspect in drying of fruits and vegetables

Drying processes cause changes in physiochemical properties of fruits and vegetables such as colour, texture shrinkage and nutrient losses (Nindo *et al.,* 2003). Heat processing leads to degradation and or isomerization of most chemical compounds. Some chemical compounds are considered as markers of nutritional quality (Vicente *et al.,* 2009). In fruits and vegetables they are ascorbic acid (vitamin C), carotenoids, vitamin E, and phenolic content. During thermal processing, these components are modified, thus affecting the color, sensory, nutritional and functional quality of the dried product (Vicente *et al.,* 2009).

In carotenoids, heat induces isomerization from *trans* to *cis* form which is more susceptible to oxidation (Strati & Oreopoulou, 2016). Combining blanching and drying processes have been shown to release carotenoids from lipid membranes and complexes, leading to better bio-availability (Strati & Oreopoulou, 2016). However, lycopene has been reported to decrease more in freeze drying than hot air drying and microwave drying in marigold flower (Siriamornpun *et al.,* 2012). Exposure to long drying time and higher temperatures during hot air drying have been shown to cause higher losses of phenolics (An *et al.,* 2016). Vitamin E is highly susceptible to oxygen and light exposure during processing and storage (Vicente *et al.,* 2009) while vitamin C is strongly affected by high temperatures, long drying cycle and exposure to sunlight (Ashebir *et al.*, 2009).

On the other hand, chlorophyll and carotenoids contribute to colour of fruits and vegetables but are easily degraded by light, heat, oxygen and enzymes. Chlorophyll degradation is related to fat peroxidation (Brennan, 2006; Cui, Xu & Sun, 2004). Polyphenol oxidases and peroxidases are major contributors of enzymatic browning. The action of the two enzymes leads to formation of melanins (brown pigments) which cause tissue browning and off flavours at high concentrations. Heat processing is used to inactivate these enzymes (Grncarevic & Hawker, 1971; Yingsanga *et al.*, 2008).

High temperature during the drying process is an important cause for loss of quality. Lowering the process temperature has great potential for improving the quality of dried products (Beaudry *et al.,* 2004; Nindo *et al.,* 2003). The changes in bioactive compounds are becoming important for optimizing and choosing drying methods and conditions (Akdaş & Başlar, 2015). Lycopene, vitamin C, total phenolics, antioxidant capacity and beta carotene content in eggplant can therefore be considered as good quality indicators of the drying process. Hence, it is of paramount importance to minimize the losses of these compounds during dehydration. The degradation kinetics related to bioactive compounds and antioxidant activities have been examined in some fruits and vegetables such as tomato (Marfil *et al.,* 2008), pomegranate (Karaaslan *et al*., 2014) and apricot (Fratianni *et al*., 2013) under different drying methods. However, to our knowledge, no research on the kinetic degradation of bioactive compounds in African eggplant has been conducted. To predict the losses, knowledge of kinetics of degradation, which include reaction order, rate constant and activation energy are critical.

2.11 Harvest maturity aspect on drying characteristics

Some fruits and vegetables can be consumed at various maturity stages depending on the consumer preference. African eggplants have been consumed at immature stage as a snack and later at mature stage in soups and for medicinal purposes (Amanda *et al.,* 2011). The physical, structural and chemicals properties of plants have been shown to differ with maturity (Msogoya *et al.,* 2014). Younger African eggplant fruits are soft, smaller in size and brighter in color compared to older ones which are firmer, bigger and have distinct colors (Msogoya *et al.,* 2014). Delayed harvesting leads to fruit over-maturity and color development while still on the plants (Hornal *et al*., 2007; Kader, 1995). Conversely, fruit harvest at immaturity stage results in faster shriveling and fruit susceptibility to mechanical damages (Kader, 1997). Furthermore, maturity stage at harvest is second after genotype in influencing flavor and shelf life qualities of fruits (Kader, 2008).

Drying involves a heat and mass transfer process which result in the removal of moisture though evaporation. Moisture occurs in bound and unbound forms. Factors that affect the removal of unbound moisture include external conditions of air or gas temperature, flow, humidity, area of exposed surface and pressure (Parikh, 2015). On the other hand, the movement of bound moisture depends on the nature of the product being dried and the extent of moisture within the product (Parikh, 2015). Early maturity fruits are fragile which eases the disruption and collapse of cell wall and cell tissues by heat energy (Ramos, Brandão & Silva, 2003). Unbound moisture is normally removed by evaporation and vaporization. Raising the temperature facilitates the evaporation and air draws the moisture away (Parikh, 2015).

The knowledge of the distribution of water in the product and the behavior of moisture loss in drying time and temperature of the drying air is essential in conceptualizing the drying process, product manipulation and energy savings (Parikh, 2015). This is critical in optimizing the conduct and control of industrial dryers. Several studies have described the drying characteristics of various vegetable products such as tomato (Kingsly *et al.*, 2007; Movagharnejad & Nikzad 2007; Mwende *et al.,* 2018), red chilli (Hossain, Woods & Bala, 2007), sweet pepper (Vengaiah & Pandey, 2007), okra (Doymaz, 2005), carrot (Zielinska & Markowski, 2007), and common eggplant (*S. melongena*) (Doymaz, 2011). However, a devoted study on the drying characteristics of African eggplant is lacking.

2.12 Consumer acceptability of dried fruits and vegetables

Quality attributes associated with dried foods are appearance, colour, shape, texture, flavor, rehydration properties, freedom from off odours among others (Perera, 2005). Drying processes have been shown to affect the quality attributes of foods. Despite consumption of dried fruits and vegetables being occasional (Jesionkowska *et al.*, 2008), some studies have recognized consumer preferences related to these foods. Aroma, colour and availability have been shown to significantly influence consumption of dried fruits (Mikisa, Okilya & Kaaya, 2010).

In solar and cabinet dried plantain bananas, sensory acceptability of colour and texture was shown to decrease with storage time (Sahoo *et al.*, 2015). This was attributed to the degradation of colour and texture during drying (Yingsanga *et al.,* 2008). Colour acceptability may be improved by minimizing browning reactions and carotenoid degradation as well as addition of food grade colours (Mikisa *et al.,* 2010). Poor consumer ratings in aroma after reconstitution of sun and solar dried okra were attributed to loss of volatile aroma components due to prolonged exposure to air (Falade & Omojola, 2010). Aroma is as a result of volatile substances such as esters, ketones, terpenes and aldehydes whose degradation reduces aroma detection (Mikisa *et al.*, 2010). Although fair amount of work has been done on volatile compounds analysis, relating volatile markers with quality attributes is dubious due to lack of data correlating volatile markers to consumer satisfaction (Barrett, Beaulieu & Shewfelt 2010).

In eggplants (*S. melongena*), drying process was shown to affect texture and rehydration did not recover the initial texture thus affecting consumer acceptability (Santacatalina *et al.,* 2011). Regardless the drying method, dried and rehydrated eggplant samples were much softer than fresh eggplant (Santacatalina *et al.,* 2011). Guiné *et al.,* (2018), reported that drying temperature during convective air drying of common eggplant (*S. melongena*), did not significantly influence the sensorial attributes of colour, intensity, homogeneity and roughness for appearance; aroma intensity; sweet, acid and bitter for taste; crunchy, elasticity, adhesiveness and hardness for texture; and overall acceptability. To our knowledge, sensorial testing on the effect of drying process on African eggplant (*S. aethiopicum*) has not been reported.

Consumer acceptability is determined through sensory evaluation which involves inspection of products by sense, i.e., sight, smell, taste, touch and hearing for various attributes (Stone & Sidel, 1993). Sensory evaluation is important during product development, evaluation and modification of existing product's recipe (Amerine, Pangborn & Roessler, 2013; Kilcast, 2010). However, contrary to sensory gadgets,

psychological or physiological factors can easily affect human decisions (Amerine *et al.*, 2013).

CHAPTER THREE

METHODOLOGY

3.1 Materials and methods

3.1.1 Plant material

Five selected African eggplant accessions with different characteristics as shown in Table 3.1 were used in the present study. Accession is "A distinct, uniquely identifiable sample of seeds representing a cultivar, breeding line or a population, which is maintained in storage for conservation and use" (FAO, n.d). These accessions were obtained from the African Vegetable Research and Development Center (AVRDC), Arusha, Tanzania. The accessions were chosen on the basis of size and survival rate in the open air field. The accessions with small sized fruits were avoided since large quantities would have been required for drying. The selected accessions included: AB2, Manyire green, Sangawili, Aubergine blanche and S00047A. Sixteen plants of each accession were grown in three replicates in a randomized complete block design during the month of May 2016, in an open-air field plot at the Jomo Kenyatta University of Agriculture and Technology, (Juja, Kenya) experimental research farm. Plants were spaced 75 cm by 75 cm between and within the rows and irrigated. Appropriate fertilization was carried out to ensure growth of healthy plants. During transplanting, well decomposed manure was mixed with the soil before placing the seedlings. The first basal application of nitrogen phosphorus potassium (NPK 17:17:17) fertilizer at a rate of 5 g/plant was done two weeks after transplanting the seedlings while the second basal application was done at the flowering stage using the same application rate.

Table 3.1: Accessions that were used and their physical characteristics

Accession registration code used at AVRDC	**Genus and species**	**Accession Name**	**Fruit Shape**	**Color at stage 1 maturity**	**Color at stage 2 maturity**
RV100380	*Solanum aethiopicum*	AB2	Oval	Shiny light green	Non shining red
RV100161	*Solanum aethiopicum*	Manyire green	Flattened and ribbed	Shiny green	Non shining red
RVI00333	*Solanum aethiopicum*	Sangawili	Spherical and lightly ribbed	Shiny yellow	Non shining red
RVI00327	*Solanum aethiopicum*	Aubergine blanche	Flattened and ribbed	Shiny yellow	Non shining red
RV100455	*Solanum spp*	S00047A	Semi long	Shiny purple	Non shining pale purple

3.1.2 Harvesting and sample preparation

Harvesting of the five accessions was done 75 and 85 days from planting for maturity stage 1 and stage 2, respectively. Also, maturity stage 1 fruits were characterized by a shiny peel colour while stage 2 fruits were characterized by non-shining peel colour at time of harvest. Figures 3.1 and 3.2 illustrate the five accessions that were studied at maturity stage 1 and stage 2, respectively. The harvested fruits were stored overnight at a room temperature of 20 - 23 ^{o}C and 28 - 42% relative humidity to dissipate the field heat. At the start of each experiment, manyire green, AB2, sangawili and aubergine blanche were washed in water, allowed to dry and cut longitudinally into equal quarters. S00047A was cut into slices having the dimensions of 0.5 cm thickness. The cutting/slicing procedure was the same for all the drying experiments. The slices were

subjected to drying using hot air oven, vacuum oven, solar and freeze drying methods. Desired temperature conditions inside the drying chambers for hot air oven and vacuum oven drying were obtained for at least 1 hour before each experiment. The sample weight for drying was kept constant at 300±0.5 g for all the drying experiments.

Figure 3.1: Fruit vegetable pictures for African eggplant accessions that were evaluated at stage 1 maturity; a) AB2, b) Manyire green, c) Sangawili, d) Aubergine blanche, e) S00047A

Figure 3.2: Fruit vegetable pictures for African eggplant accessions that were evaluated at stage 2 maturity; a) AB2, b) Manyire green, c) Sangawili, d) Aubergine blanche, e) S00047A

3.1.3 Drying processes

3.1.3.1 Hot air oven drying

The drying experiment was carried out at three temperatures (50, 60, and 70 $^{\circ}$C) in an oven drier (Memmert UF 110 model, Memmert GmbH + Co. KG, Schwabach, Germany) with a constant air-flow rate of 2 m/s. The African eggplant accession slices were spread in rectangular chambers of 45 cm length by 30 cm width in single layer drying. The drying temperatures were chosen on the basis of a low, moderate and high drying temperature.

3.1.3.2 Vacuum oven drying

A vacuum drier **(**VDO-4SO model, Mitamura Riken Kogyo Inc., Tokyo, Japan) was used at 50, 60, and 70 $^{\circ}$C temperature and 60 mbar pressure conditions. Below 60 mbar

pressure was too low for drying. The African eggplant accession slices were spread in square chambers of 30 cm width and length in single layer drying.

3.1.3.3 Freeze drying

This was done using a small scale freeze drier **(**Alpha1-4 LD plus-Martin Christ Model-101541, Germany). Samples slices were placed in air tight zip lock bags and frozen in a deep freezer at -21 $^{\circ}$C for 72 hours. The zip lock bags were pierced with several holes and placed in the freeze drier. The holes allowed good balance of pressure and temperature inside and outside the zip lock bags during drying. Initial drying was done at -41 $^{\circ}$C and 0.11 mbar while final drying was carried out at -47 $^{\circ}$C and 0.055 mbar. In total, the freeze drying was done for a period of 72 hours. The temperature and pressure conditions used are a recommendation by the drier manufacturer.

3.1.3.4 Solar drying

A small scale locally made solar drier was used in this experiment. The African eggplant slices were spread in rectangular chambers of 60 cm length by 40 cm width in single layer drying. The solar drier measured 185 cm wide, 273 cm long and 255 cm high. The top part of this structure was semi-circular in shape with a radius of 50 cm and was entirely covered with a polyvinyl chloride (PVC) material. The dimensions of the door were 60 cm wide and 180 cm high. The PVC material was preferred because it filters radiations such as ultraviolet, which can destroy light sensitive nutrients in the material being dried (Leon, Kumar, & Bhattacharya, 2002). The drying temperature varied depending on weather conditions and ranged between 50 and 60 $^{\circ}$C. Drying was stopped when the moisture content decreased to ~10%. All the experiments were carried out in three replicates and the results expressed on dry weight basis (db).

3.1.4 Sampling for drying characteristics and degradation kinetics

During hot air oven and vacuum oven drying, the drying accessions were randomly sampled on one hour intervals for a period ranging from 360 to 960 minutes depending on attainment of ~10% moisture content. One set of the samples were immediately

wrapped in aluminum foil and taken for moisture determination. Another set was taken for determination of beta carotene, lycopene, TPC, antioxidant capacity and vitamin C. Samples that were not analyzed immediately were stored in zip lock bags at -25 $^{\circ}$C away from light until further analysis. The data results were used to plot drying curves and graphically determine reaction order for the study of drying characteristics and degradation kinetics, respectively. In freeze and solar drying, sampling was done at the end of the drying experiment and analyzed to determine the retention rates.

Since stage 1 maturity is consumed in raw form as snacks, it was assumed that its PHLs risk was low in comparison with stage 2 maturity. Therefore, subsequent study on the effect of drying method on the retention and degradation kinetics of bioactive compounds was conducted on stage 2 maturity accessions.

3.1.5 Determination of moisture content

The moisture content was determined according to method 984.25 (AOAC, 2005). Five grams of each sample was weighed and placed into pre-weighed aluminum moisture determination dish. The samples were dried to constant weight in an oven (Model WFO-1000ND, Tokyo Rikakikai Co., Limited, Japan) at 105 $^{\circ}$C for 5 hours under vacuum.
Percentage moisture content was calculated using the following formula:

$$\frac{(\text{Weight of dish} + \text{weight of sample before drying}) - (\text{Weight of dish} + \text{weight of sample after drying})}{\text{Weight of sample}} * 100$$

3.1.6 Determination of beta carotene

Five grams of each of the fresh and dried samples were weighed and approximately 1.5 g of celite added together with 10 ml of cold acetone. The mixture was ground in a mortar and pestle and transferred into 50 ml volumetric flask using a glass funnel plugged with cotton wool. The residue was filtered and washed with cold acetone until devoid of color. Fifteen milliliters of petroleum spirit was dispensed into a separating funnel and the acetone extract slowly added followed by distilled water to eliminate residual acetone. The two phases were allowed to separate and the lower aqueous layer carefully removed and discarded. The petroleum spirit fraction containing carotenoids

was collected into a conical flask through a funnel having anhydrous sodium sulphate (Na_2SO_4) to dry the layer and topped up to 50 ml with petroleum spirit. Beta carotene was determined at 440 nm using UV-Vis spectrophotometer (UV-1601 PC model, Shimadzu Corp., Kyoto, Japan). The absorbance of standard solutions were used to generate the standard curves (Rodriguez-Amaya & Kimura, 2004).

3.1.7 Extraction of antioxidants and total phenols

Extracts were prepared according to Wojdylo, Oszmiański and Czemerys (2007) with a few modifications. Five grams of samples were weighed into amber colored bottles containing 50 ml of analytical grade methanol and vortexed for 3 hours. The solution was incubated in darkness for 48-72 hours at room temperature. The extracts were centrifuged (Kokusan H-200, Tokyo, Japan) for 10 min at 13,000 ×g/relative centrifugal force (RCF) and supernatants used to determine the total phenolic content and antioxidant capacity.

3.1.8 Determination of total phenolic content

Total phenolic content (TPC) was determined by the Folin–Ciocalteu colorimetric method (Wojdylo *et al.*, 2007) with gallic acid as the standard. Two milliliters of 10% (v/v) Folin–Ciocalteu reagent and 4 ml of 0.7 M sodium carbonate were added onto 1ml of prepared sample extract. The mixture was vortexed and allowed to stand at room temperature for 2 hours. The absorbance was measured at 765 nm using UV-Vis spectrophotometer (Shimadzu UV–1601 PC) and results were expressed as gallic acid equivalent (GAE), milligrams per 100 g of dry matter (db). A standard curve was generated using the absorbances of the gallic acid standards.

3.1.9 Determination of antioxidant activity by radical scavenging effect of DPPH (2,2-diphenyl-1-picryl hyrazyl)

The antioxidant activity of the extracts and the standard was assessed on the basis of the radical scavenging effect of the stable 1, 1-diphenyl-2-picrylhydrazyl (DPPH) free radical activity (Sreenivasan, *et al.*, 2007) with some modifications. The following

concentrations of the extracts were prepared; 0.1, 1.0, 2.0 and 5 mg/ml in methanol (analytical grade). One milliliter of the prepared sample extract was mixed with 0.5 ml of a 1 mM solution of DPPH and 3 ml of methanol. L-Ascorbic acid was used as the standard. The solution mixtures were incubated for 5 min and absorbance was measured using UV-Vis spectrophotometer (Shimadzu UV–1601 PC) at 517 nm. A blank solution was prepared containing the same amount (3 ml) of methanol and DPPH (0.5 ml) to zero the spectrophotometer.

The % inhibition was calculated using the formula given below:

$$(\%)\ \text{Inhibition of DPPH activity} = \left[\frac{(A_0 - A_1)}{A_0}\right] * 100$$

Where A_o was the absorbance of the blank and A_1 was the absorbance in the presence of the sample. IC_{50} value was calculated using the dose inhibition curve. IC_{50} values indicated the concentration of sample, which was required to scavenge 50% of DPPH free radicals.

The results were also expressed as ascorbic acid equivalent antioxidant capacity (AEAC) in mg ascorbic acid/100 g of sample in dry basis using the following equation:

$$\text{AEAC mg ascorbic acid/100g} = \left[\frac{IC_{50}\ (ascorbic\ acid)}{IC_{50}\ (sample)}\right] * 100{,}000$$

3.1.10 Determination of lycopene content

Lycopene content was determined using the method described by Chen, (2005) with some modifications. About 5 g of crushed eggplant sample was mixed with hexane-acetone-ethanol solution (2:1:1 v/v/v) containing 1% butylated hydroxytoluene (BHT) (w/v) in amber coloured sample bottles. The content was then agitated for 20 minutes after which 15 ml of distilled water was added to the mixture and agitated for 10 minutes. The solution was separated into polar and a non-polar phase using a separating funnel. A 50 ml of the upper hexane layer was collected and 1.5 ml aliquot micro-filtered using 0.45 µl membrane filters. Lycopene was analyzed using a HPLC (Shimadzu 10A model, Tokyo, Japan) fitted with SPD-10AV UV-Vis detector and a C18 ODS (250 mm*4.6

mm*5 µl) column. The mobile phase contained acetonitrile: methanol: dichloromethane: hexane (40:20:20:20, v/v/v/v) at a flow rate of 1.5 ml/min. Injection volume used was 20 µl while the detection wavelength for lycopene was 470 nm. The temperature of the oven was maintained at 30 ^{o}C. Lycopene in the sample was identified by comparing the retention time of pure lycopene from Sigma Aldrich.

3.1.11 Determination of vitamin C

Vitamin C content in the samples was determined by HPLC method (Vikram *et al.*, 2005). About 2 g of crushed eggplant was weighed and extraction done with 0.8% metaphosphoric acid. This was topped up to 20 ml and the solution was centrifuged at 10000 rpm. The supernatant was filtered and diluted with 10 ml of 0.8% metaphosphoric acid. This was passed through 0.45 µ filter and 20 µl injected into the HPLC machine (Shimadzu 10A model, Tokyo, Japan). Various concentrations of ascorbic acid standard were also made to make a calibration curve. HPLC analysis was done using Shimadzu UV-VIS detector. The mobile phase was 0.8% metaphosphoric acid, at 1.2 ml/min flow rate and wavelength of 266.0 nm.

3.1.12 Thermal degradation kinetics

Thermal degradation of the bioactive compounds was determined experimentally by plotting graphs of bioactive compound against drying time for each temperature condition of hot air oven and vacuum oven drying. The slope of the linear graph determining the reaction order and gave the reaction rate constant, *k* at >0.9 regression coefficient.

$$\frac{\partial C}{\partial t} = kC^{\mathrm{n}}$$

Where *C* is concentration of bioactive compound.

Half-life ($t_{1/2}$) value was calculated using the formula below:

$$t_{1/2} = Ln\ (0.5) * k^{-1}$$

Temperature coefficient (Q_{10}) was the criterion used to indicate the effect of raising the temperature by 10 °C on the rate of reaction, and was calculated using the formula below.

$$Q_{10} = \left({}^{k_2}/_{k_1} \right)^{10/(T_2 - T_1)}$$

Where k_1 and k_2 are reaction rate constants at temperatures T_1 and T_2, respectively (h^{-1}).

The effect of temperature on the degradation of bioactive compounds was predicted by the Arrhenius equation:

$$k = Ae^{-E_a/RT}$$

Where *k* is the degradation rate, *Ea* is the activation energy (J/mol), *R* is the ideal gas constant (J/mol K), and *T* is the temperature in degree Kelvin.

3.1.13 Sensory evaluation of the dried and reconstituted accessions

Affective testing method using 7 point hedonic scale was used in this study (Peryam & Pilgrim, 1957). A consumer type of panelists was involved and consisted of 80 participants; 46 females and 34 males of 20-30years in age. The panelists were randomly selected and composed of technicians and students from JKUAT. Prior to the sensory evaluation exercise, the consumer panel members were verbally briefed about the study in order for them to make informed decision. A consent form (Appendix 2) was used to seek the participants' permission voluntarily. It assured confidentiality of the participants' personal details on gender, age and African eggplant consumption frequency. Members were allowed to withdraw from the sensory test anytime in case they wished not to proceed.

Each of the reconstituted accession was prepared by soaking the sample in 500 ml of tap water for 15minutes followed by boiling for 15 minutes and addition of 0.01 g of salt. Fresh accessions were prepared by boiling in 500 ml of tap water and were included in the test for reference and comparison. The 7-point scale is as shown in Table 3.2 while the sensory analysis questionnaires are as shown in Appendix 2. Identical disposable

order free dishes were used to serve the samples at 23 °C room temperature. The dried and reconstituted samples were coded with three digits and presented in a random order as shown in Figures 3.3 and 3.4. Deionized drinking water was used as a palate cleanser in between the samples. Sessions were conducted at 4.00 pm at the Food science sensory evaluation room under air conditioned and well lighted environment. Two sets of sensory analysis was done; dried accessions and reconstituted accessions. The number of samples was five and ten for dried and reconstituted accessions, respectively. Attributes of colour, appearance, texture and overall score were tested for dried accession. With regard to fresh and reconstituted samples, the appearance, taste, aroma, texture and overall score was tested.

Table 3.2: 7-point hedonic scale that was used during sensory evaluation for the five dried and reconstituted African eggplant accessions.

Description	Score
Like extremely	7
Like moderately	6
Like slightly	5
Neither like nor dislike	4
Dislike slightly	3
Dislike moderately	2
Dislike extremely	1

Figure 3.3: Five coded samples of dried African eggplant accessions presented in a random order for sensory evaluation.

Figure 3.4: Ten coded samples of fresh and reconstituted African eggplant accessions presented in a random order for sensory evaluation

3.1.14 Statistical analysis

Comparisons among the five accessions on the effect of harvest maturity on moisture content, effect of drying method and temperature on the dependable variables (beta carotene, total phenolics, lycopene and antioxidant activity), and the effect of drying and reconstitution on various quality attributes were determined by ANOVA using Stata version 12 software (Stata Corp., College Station, Texas 77845 USA). The mean variations were separated using Tukey test at α=0.05 significance level.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Effect of harvest maturity stage on moisture content of five African eggplant accessions

The percentage moisture content on wet basis (w.b) of the five accessions at two maturity stages is as shown in Table 4.1. The results show that moisture content ranged between 88.67% (manyire green stage 2) and 92.82% (aubergine blanche stage 1). AB2 presented insignificant change in its moisture content at both maturity stages. On the other hand, there were significant differences ($p<0.05$) of moisture content at both maturity stages for sangawili and aubergine blanche. The moisture contents slightly declined from maturity stage 1 to maturity stage 2 with the exception of AB2 which remained almost constant. This decline in moisture content with maturity may be attributed to the increase in other nutrients which constitutes the dry matter as growth and development progresses from maturity stage 1 to maturity stage 2. Carbohydrates and fiber contents have been shown to increase with fruit development in three African eggplant accessions (Tengeru white, manyire green and AB2) as reported by Msogoya *et al.,* (2014). The results show that the five African eggplant accessions are high moisture fruit vegetables and thus highly perishable. Commodities whose moisture content is greater than 80% are categorized as highly perishable (Yahia *et al.,* 2004). Moisture contents from this study are a comparable to those of various *S. aethiopicum, S. macrocarpon* and *S. melongena* cultivars as reported by Jos and Prohens, (2013) and San José *et al.*, (2016).

Table 4.1: Percentage moisture content for fresh fruit vegetables of the five accessions at stage 1 and 2 maturities expressed in wet basis (w.b)

Accession	Stage 1 maturity	Stage 2 maturity
Sangawili	92.38 ± 0.17^{de}	90.52 ± 0.26^{bc}
Manyire green	89.63 ± 0.05^{ab}	88.67 ± 0.29^{a}
S00047A	91.20 ± 0.53^{cd}	90.52 ± 0.23^{bc}
AB2	90.93 ± 0.31^{bcd}	90.94 ± 0.29^{bcd}
Aubergine blanche	92.82 ± 0.14^{e}	91.02 ± 0.36^{bcd}
Mean±SE	91.39±0.32	90.33±0.25
p value	0.0001	0.0001

Values represent mean ± SE of three replicates. Values with different letters within the two columns indicate significant differences based on a Tukey test at $p < 0.05$ level of significance.

4.2 Drying characteristics of five African eggplant accessions

The five accessions' samples of stage 1 and stage 2 maturities were dried using hot air oven and vacuum oven drying at 50, 60 and 70 $^{\circ}$C up to final moisture content of ~10% (w.b). The drying process exhibited a progressive decrease in the moisture content followed by stabilization to reach a constant value as illustrated in Figure 4.1 for sangawili. Similar drying behavior was observed for the rest of the accessions (Figure 4.2 to Figure 4.10). Vacuum oven drying took shorter time to reach final moisture content at any particular temperature in comparison to hot air oven drying. The drying times ranged between 420 minutes (S00047A at stage 1 in Figure 4.7) and 960 minutes (aubergine blanche at stage 2 in Figure 4.9) during hot air oven drying and between 360 minutes (S00047A at stage 1 in Figure 4.8) and 840 minutes (aubergine blanche at stage 2 in Figure 4.10) during vacuum oven drying. In addition, the drying time decreased with increasing drying temperature as shown in Figure 4.1 whereby, drying time was

540 minutes at 70 °C and 780 minutes at 50 °C for hot air drying of sangawili stage 1 maturity fruits. Therefore, it can be concluded that drying method and drying temperature had a significant influence in the drying process of the five African eggplants accessions. Similar results were reported on the drying characteristics of okra, tomatoes and mandarin by Doymaz, (2005); Sana and Salah, (2014); and Akdaş and Başlar, (2015), respectively.

The drying temperature influenced the drying rate curve for each accession. Figure 4.11, Figure 4.17, Figure 4.19 and Figure 4.20 shows characteristic accelerating rate period, constant rate period and falling rate period for hot air dried sangawili, AB2, aubergine; and vacuum oven dried aubergine, respectively. The drying periods are as illustrated in Figure 4.19. Manyire green (Figure 4.13, Figure 4.14) and S00047A (Figure 4.15, Figure 4.16) lacked a constant rate period and showed an accelerating rate period and the falling rate period only. This means that the constant rate period was too short to be recognized in the curve. At constant rate period the drying rate was almost constant while at the falling rate period the drying rate decreased gradually. The short accelerating period may be attributed to the sample overheating due to the difference of initial temperature between the sample and the drying air. On the other hand, constant rate period may be attributed to the presence of a free water film surrounding the samples at the beginning of drying which progressively reduces to the point of falling rate period where the free water film has reduced sufficiently to cause a decreasing drying rate (Sana & Salah, 2014).

The increase in drying rate with increase in drying temperature may be attributed to increased water molecules energy due to high temperature, which facilitates the movement of water inside the samples. This in turn leads to increased heat transfer intensity (Sana & Salah, 2014). On the other hand, vacuum drying creates a large water vapor pressure gradient thus increasing water movement process from the samples to the outside. As a result, the heat and mass transfer between the samples and the drying air is increased (Akdaş & Başlar, 2015). Similar drying characteristics have been reported in

the drying of tomatoes, jujubes and mandarin (Akdaş & Başlar, 2015; Sana & Salah, 2014; Yi, *et al.*, 2012).

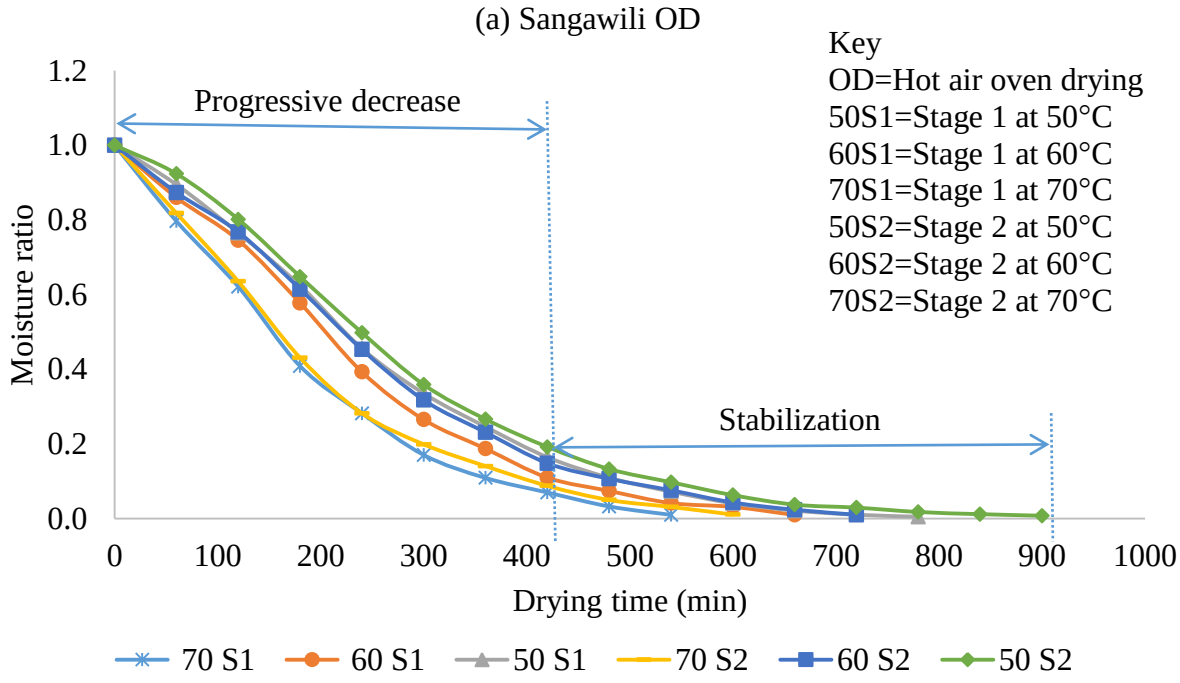


Figure 4.1: Variation of moisture ratio for the accession sangawili over drying time at different temperatures and maturities during hot air oven drying.

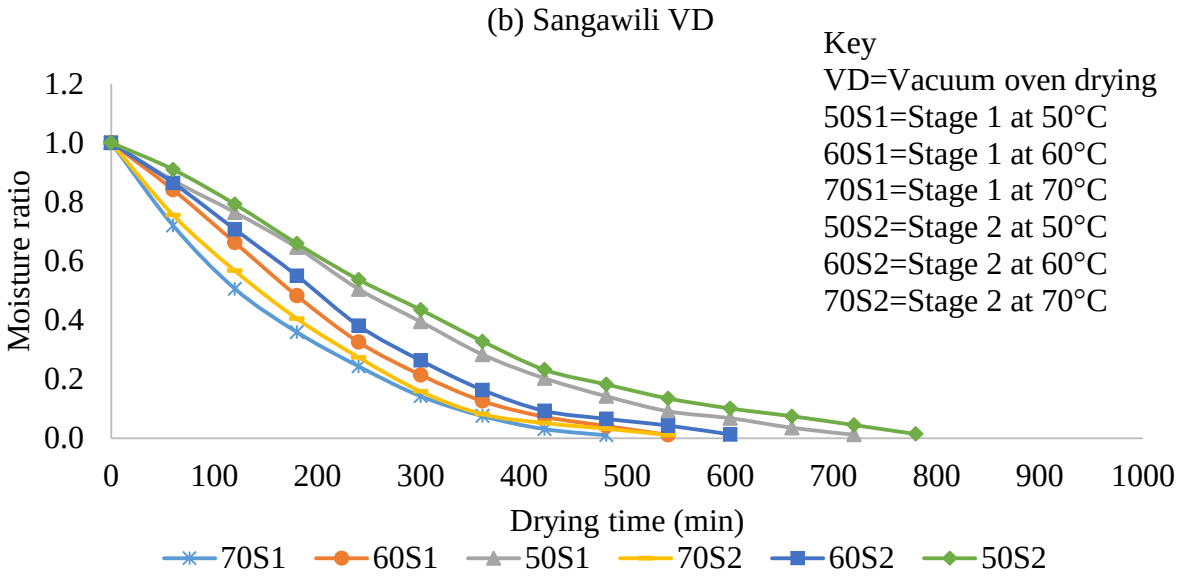


Figure 4.2: Variation of moisture ratio for the accession sangawili over drying time at different temperatures and maturities during vacuum oven drying.

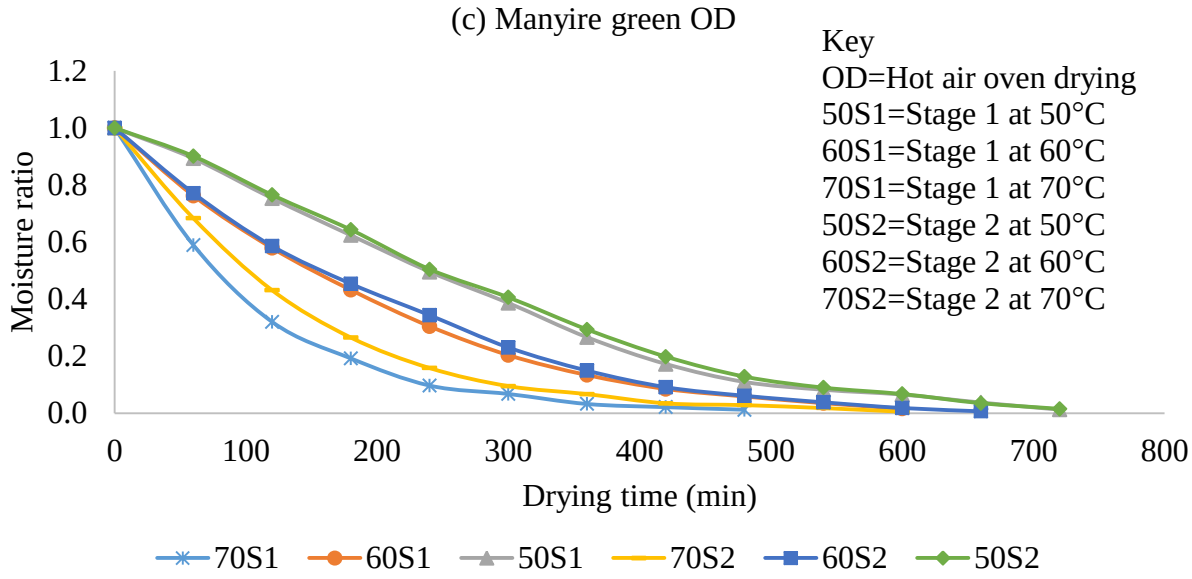


Figure 4.3: Variation of moisture ratio for the accession manyire green over drying time at different temperatures and maturities during hot air oven drying.

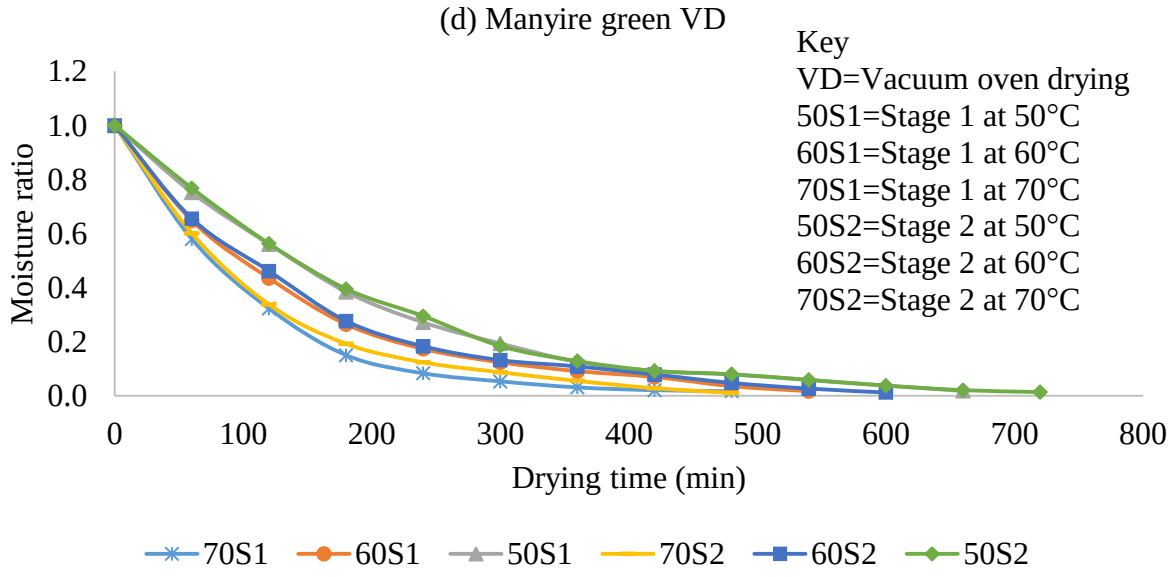


Figure 4.4: Variation of moisture ratio for the accession manyire green over drying time at different temperatures and maturities during vacuum oven drying.

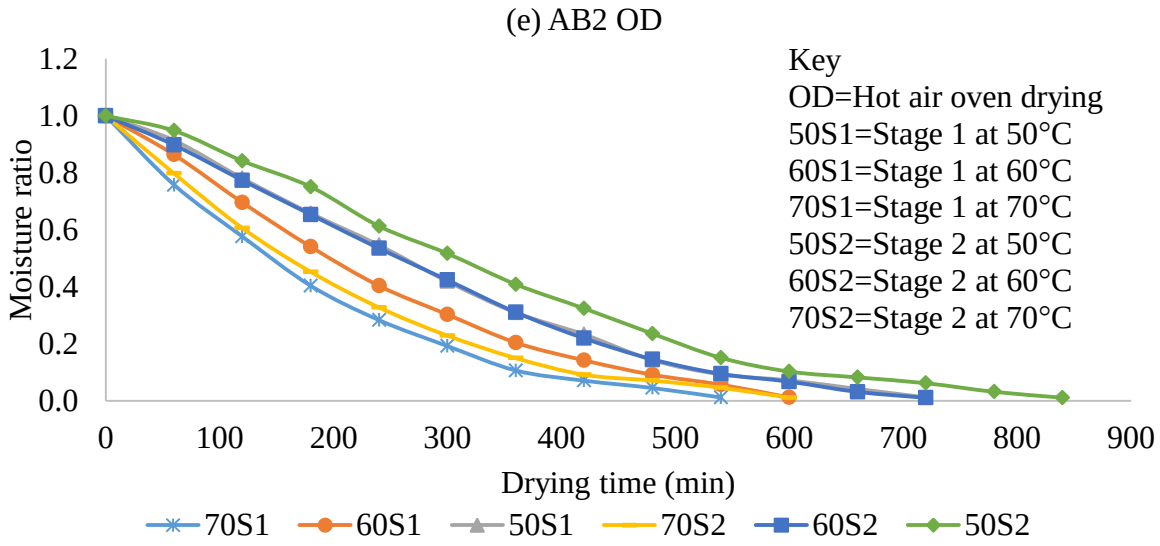


Figure 4.5: Variation of moisture ratio for the accession aubergine blanche over drying time at different temperatures and maturities during hot air oven drying.

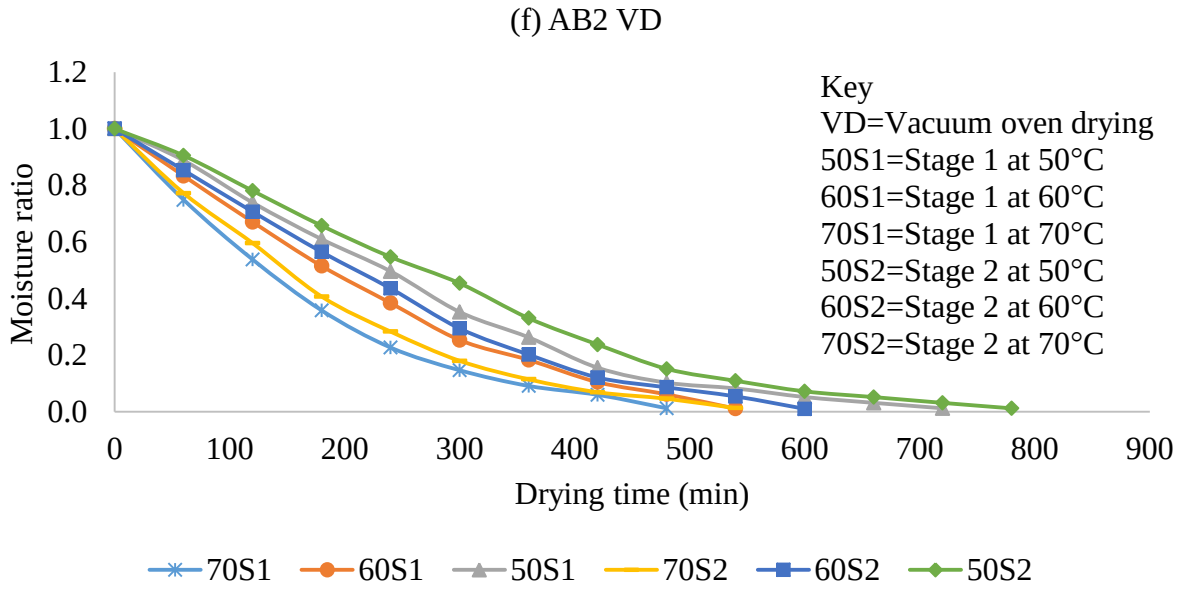


Figure 4.6: Variation of moisture ratio for the accession AB2 over drying time at different temperatures and maturities during vacuum oven drying.

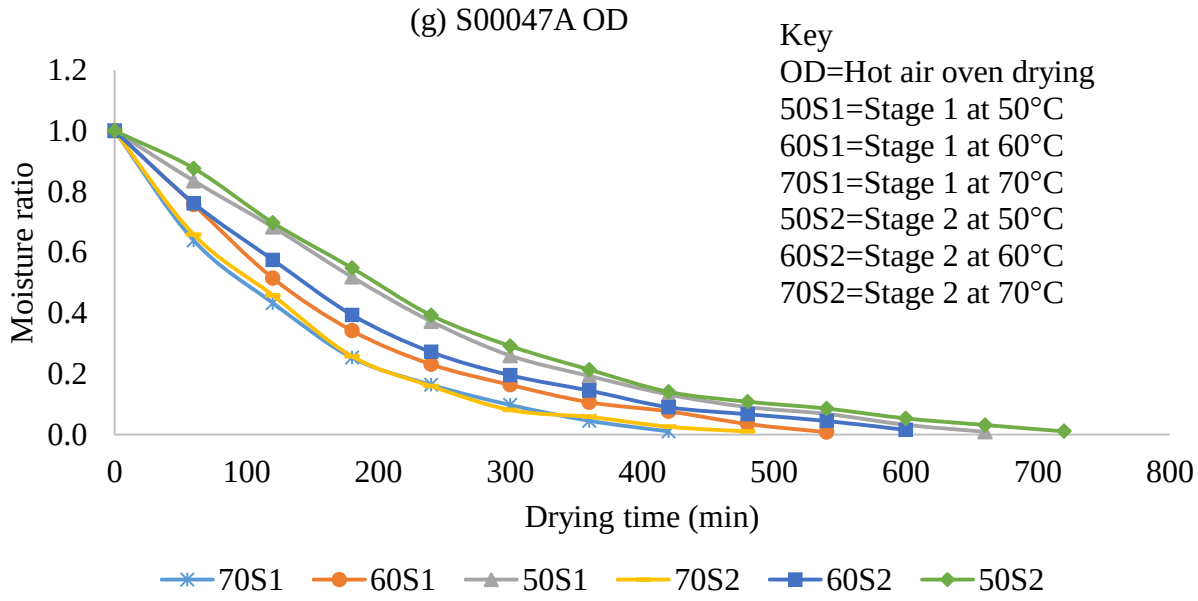


Figure 4.7: Variation of moisture ratio for the accession S00047A over drying time at different temperatures and maturities during hot air oven drying.

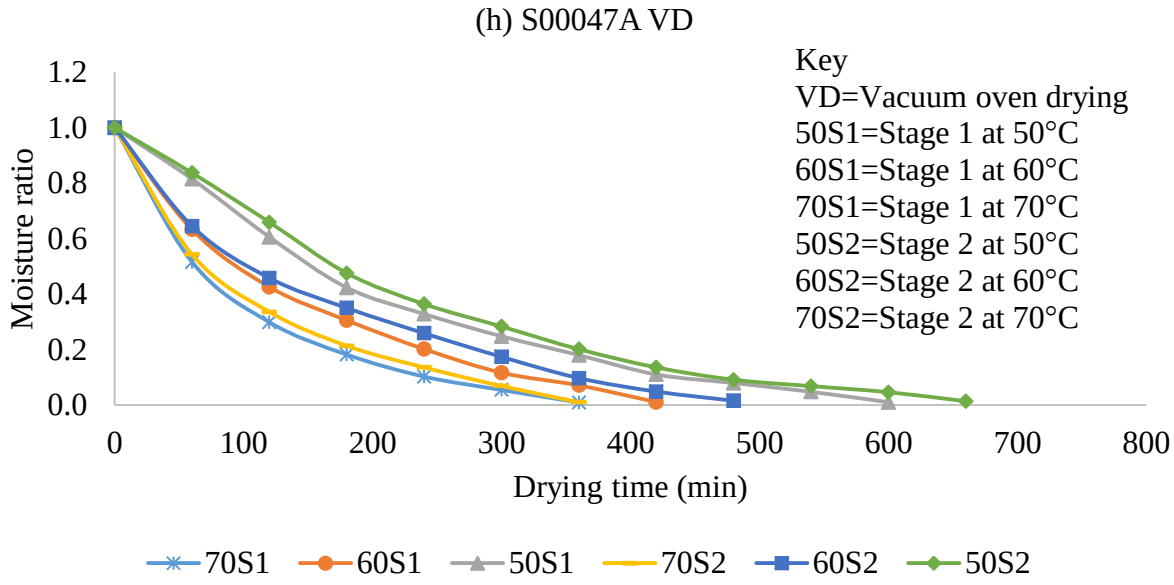
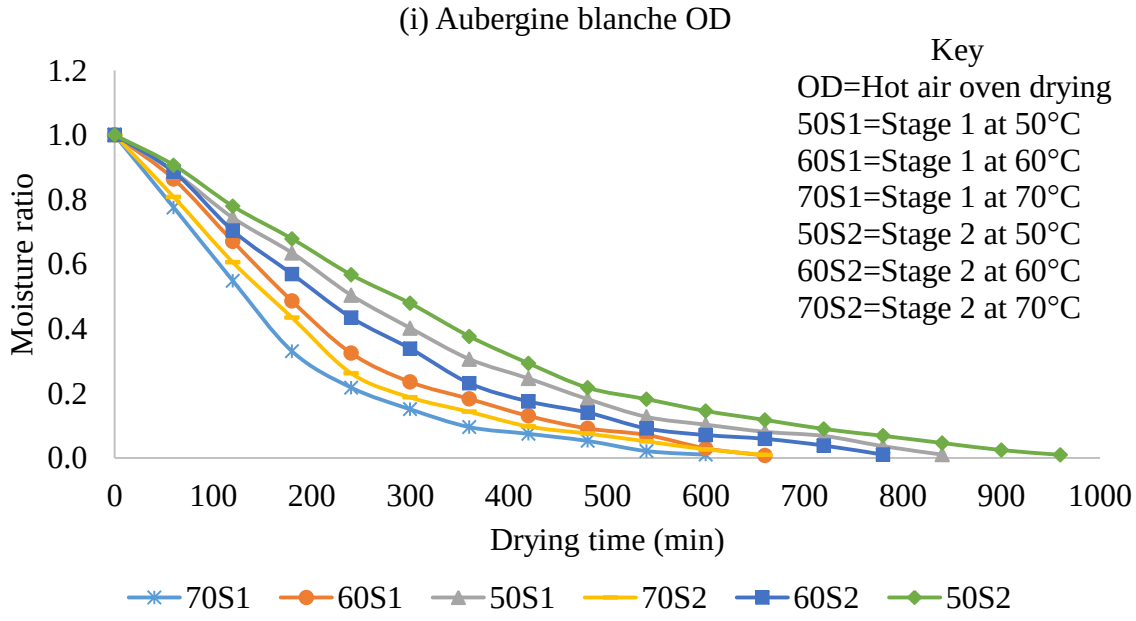


Figure 4.8: Variation of moisture ratio for the accession S00047A over drying time at different temperatures and maturities during vacuum oven drying.



qFigure 4.9: Variation of moisture ratio for the accession aubergine blanche over drying time at different temperatures and maturities during hot air oven drying.

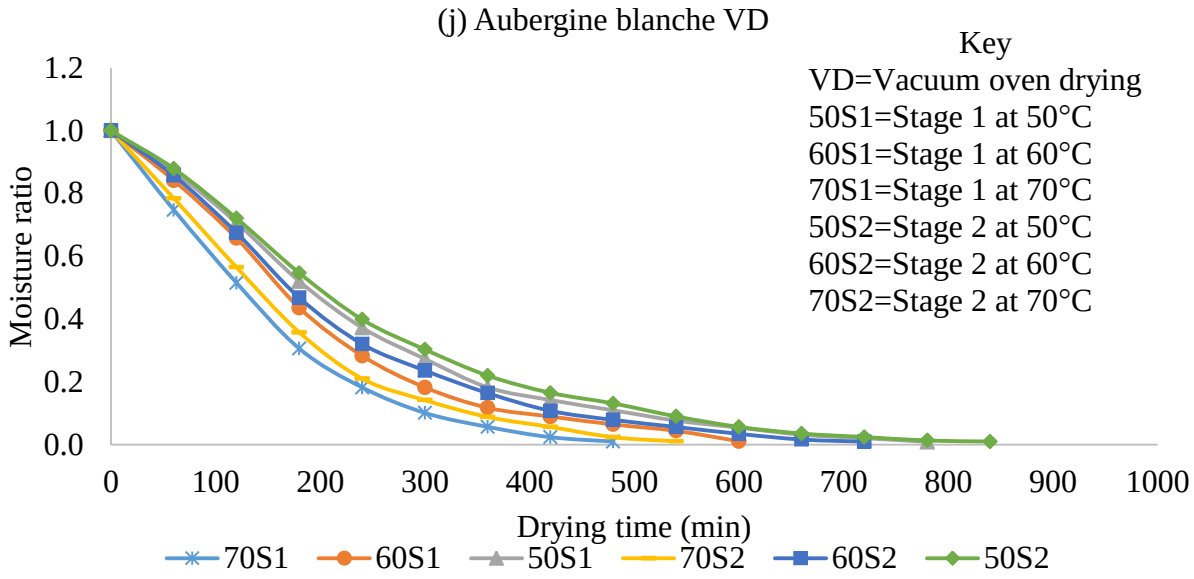


Figure 4.10: Variation of moisture ratio for the accession aubergine blanche over drying time at different temperatures and maturities during vacuum oven drying.

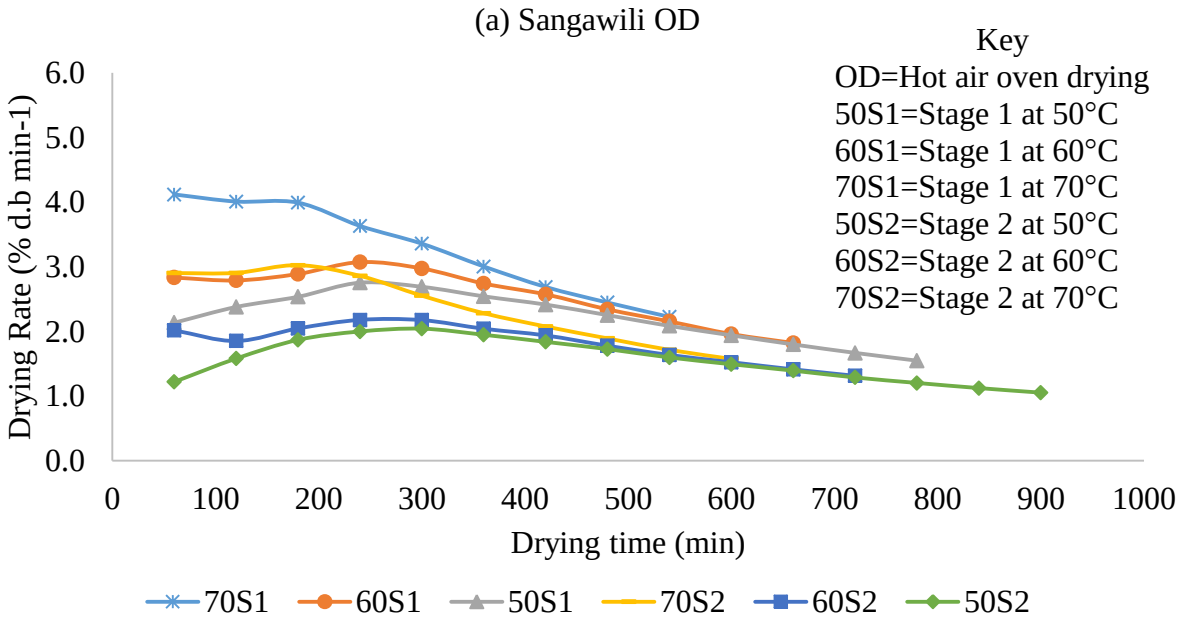


Figure 4.11: Variation of drying rates for the accession sangawili over drying time at different temperatures and maturities during hot air oven drying

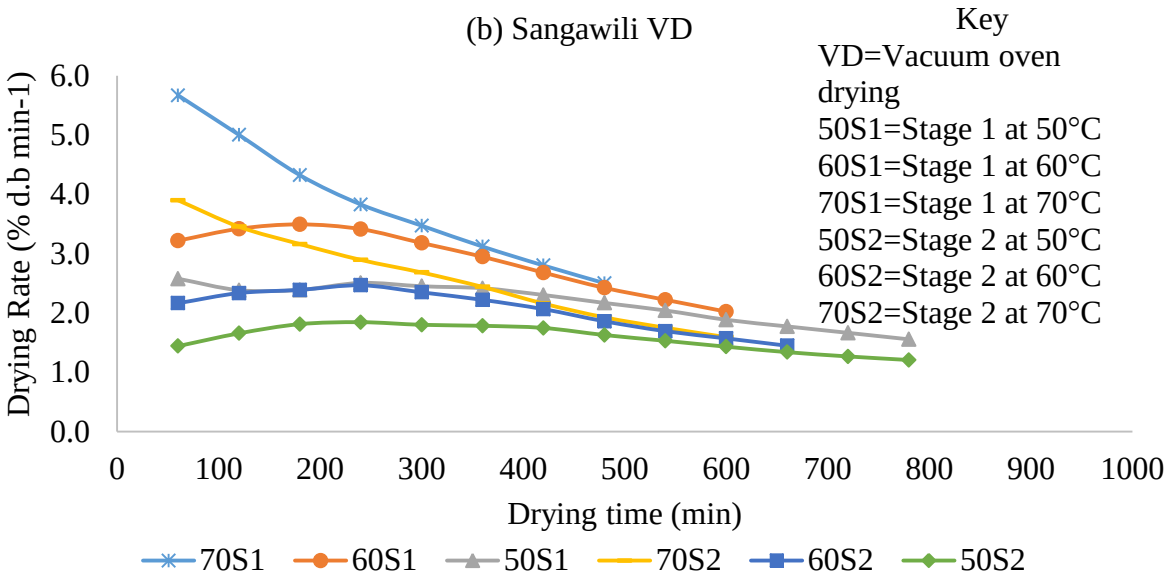


Figure 4.12: Variation of drying rates for the accession sangawili over drying time at different temperatures and maturities during vacuum oven drying

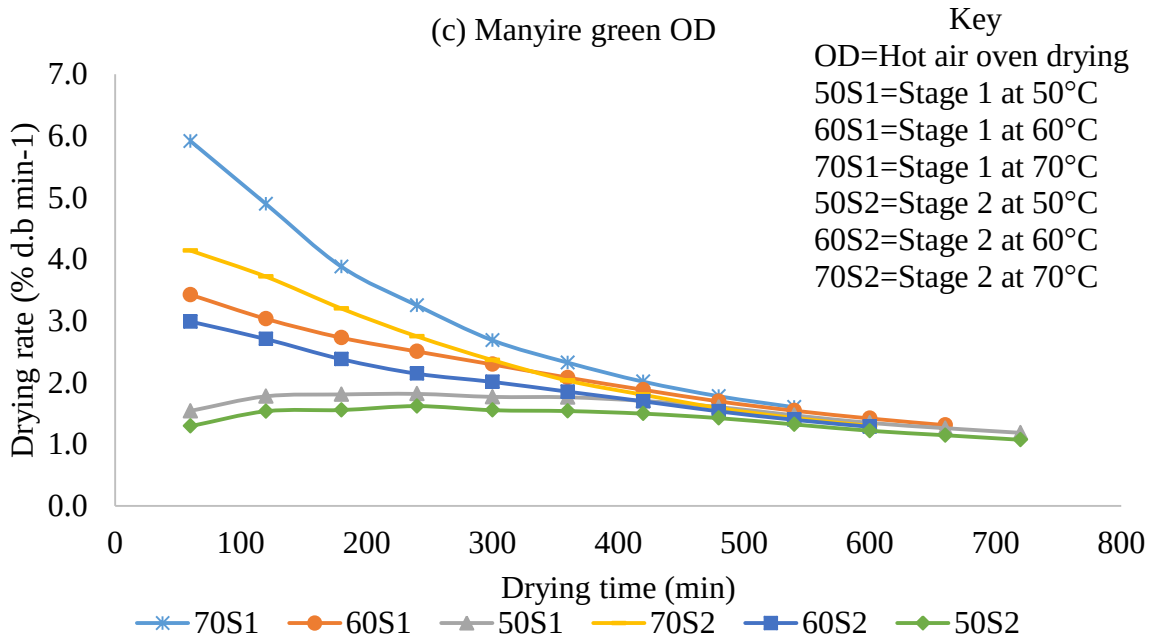


Figure 4.13: Variation of drying rates for the accession manyire green over drying time at different temperatures and maturities during hot air oven drying

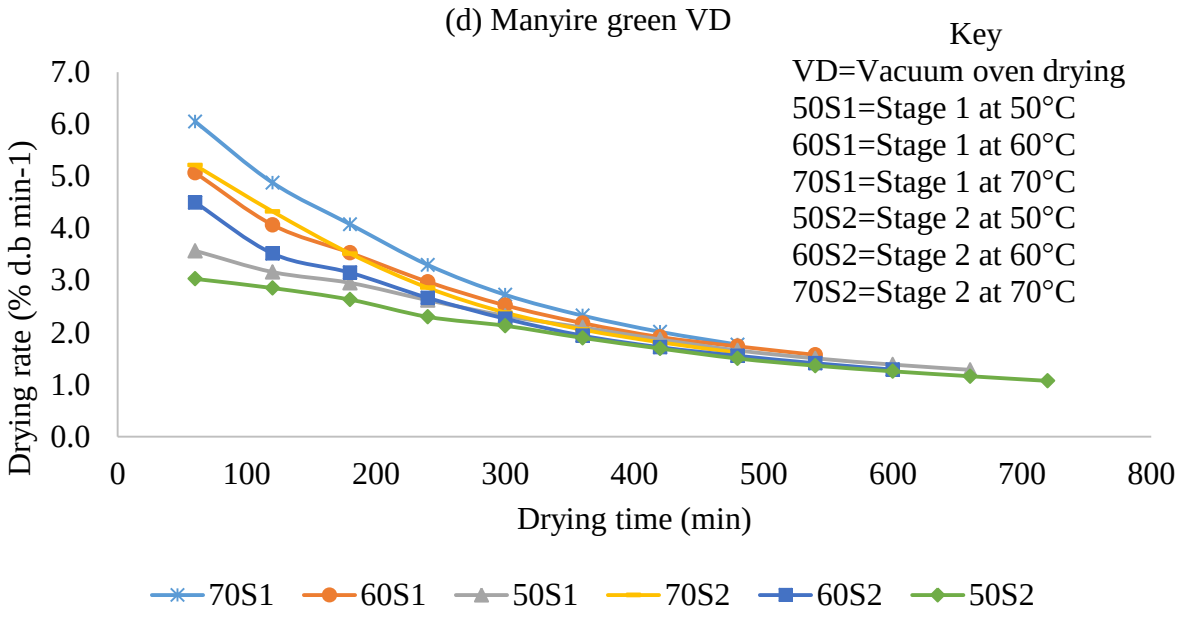


Figure 4.14: Variation of drying rates for the accession manyire green over drying time at different temperatures and maturities during vacuum oven drying

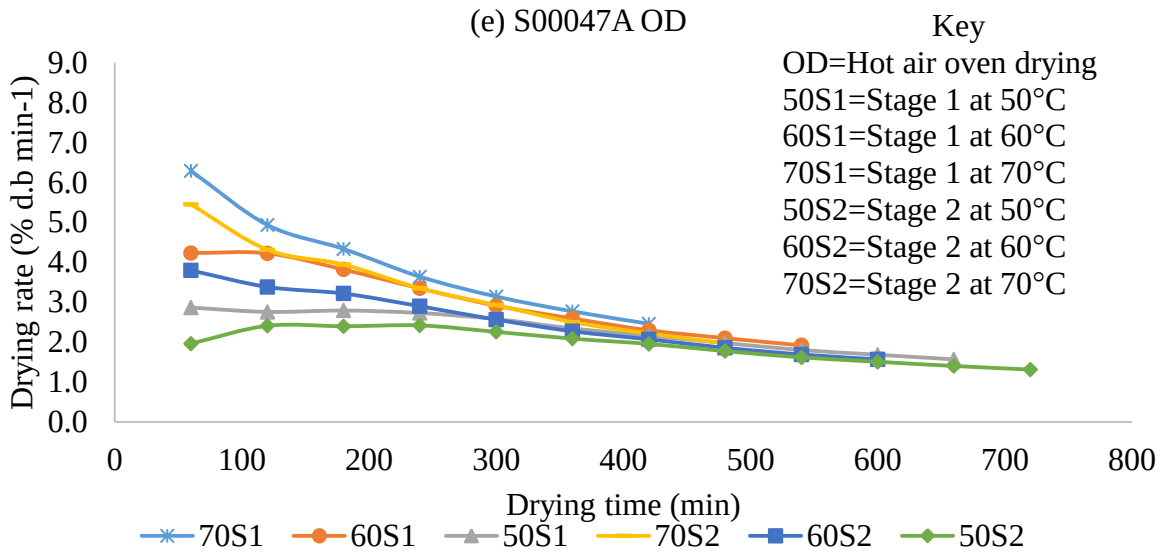


Figure 4.15: Variation of drying rates for the accession S00047A over drying time at different temperatures and maturities during hot air oven drying

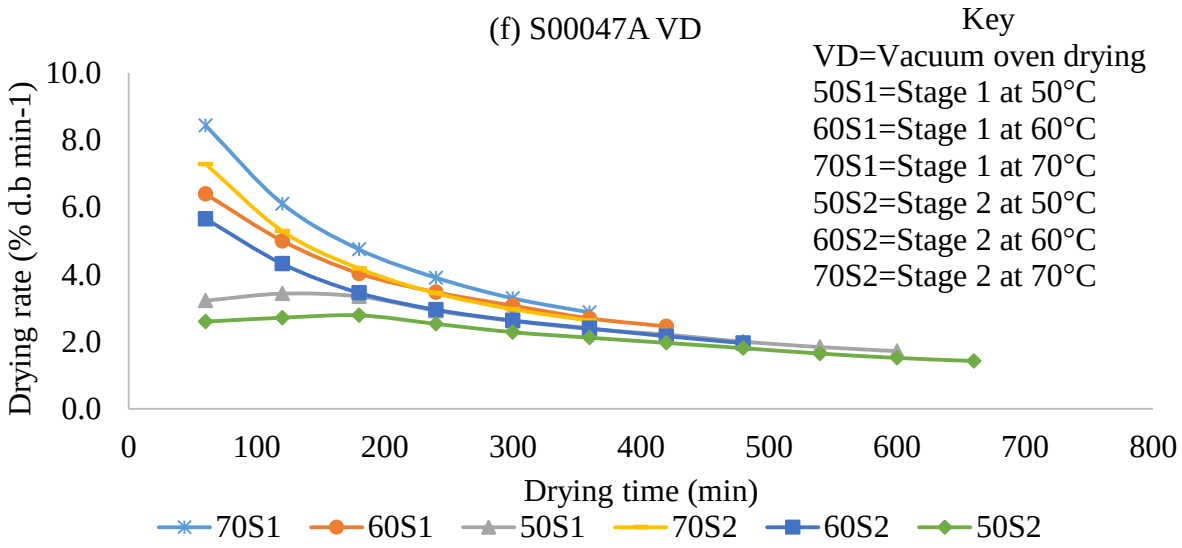


Figure 4.16: Variation of drying rates for the accession S00047A over drying time at different temperatures and maturities during vacuum oven drying

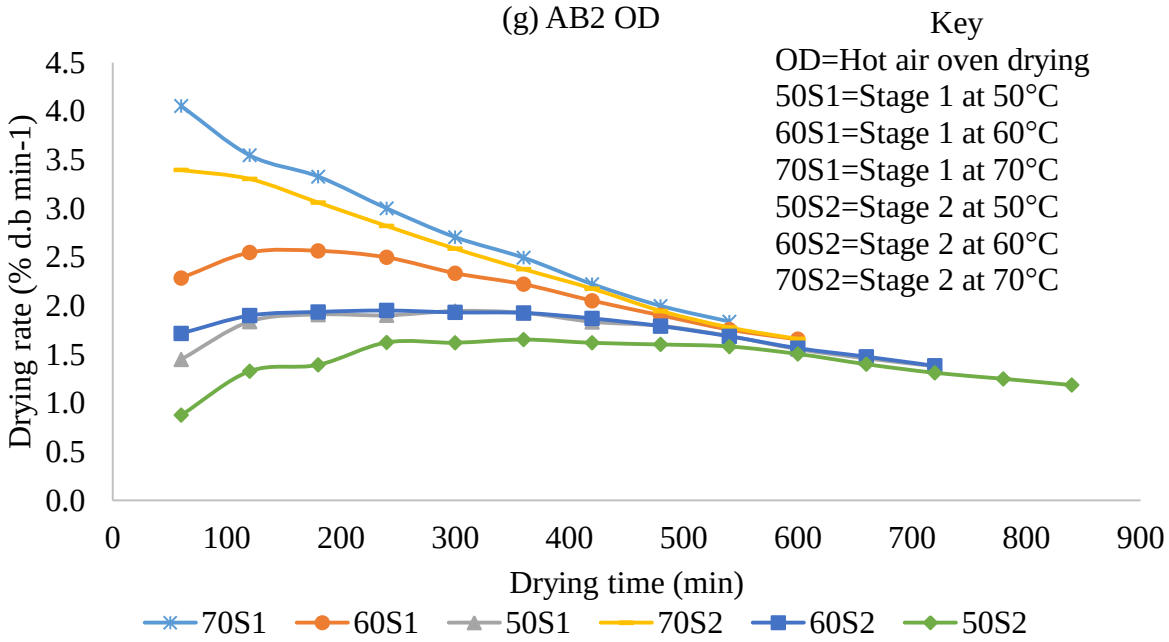


Figure 4.17: Variation of drying rates for the accession AB2 over drying time at different temperatures and maturities during hot air oven drying

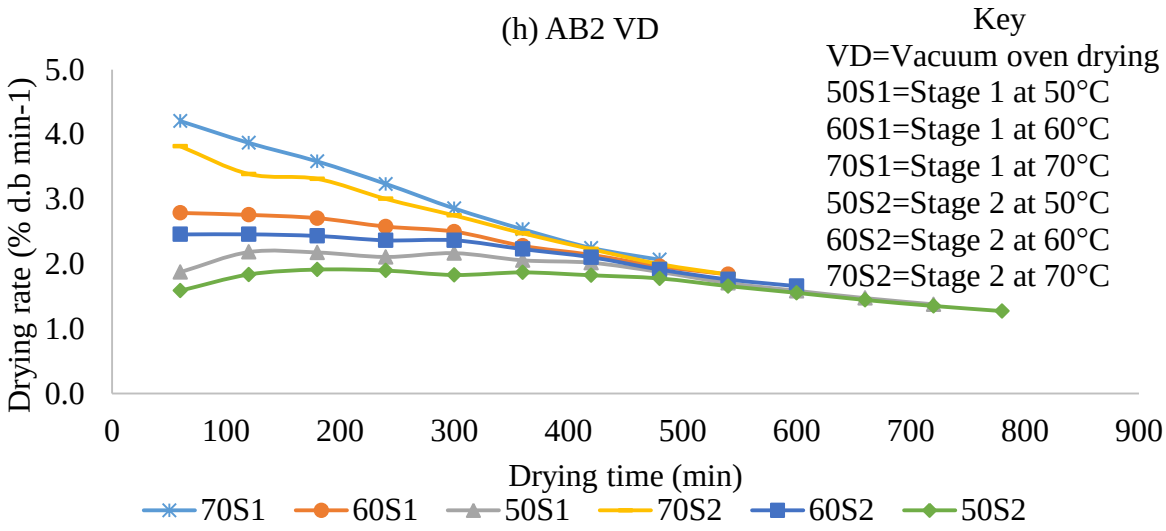


Figure 4.18: Variation of drying rates for the accession AB2 over drying time at different temperatures and maturities during vacuum oven drying.

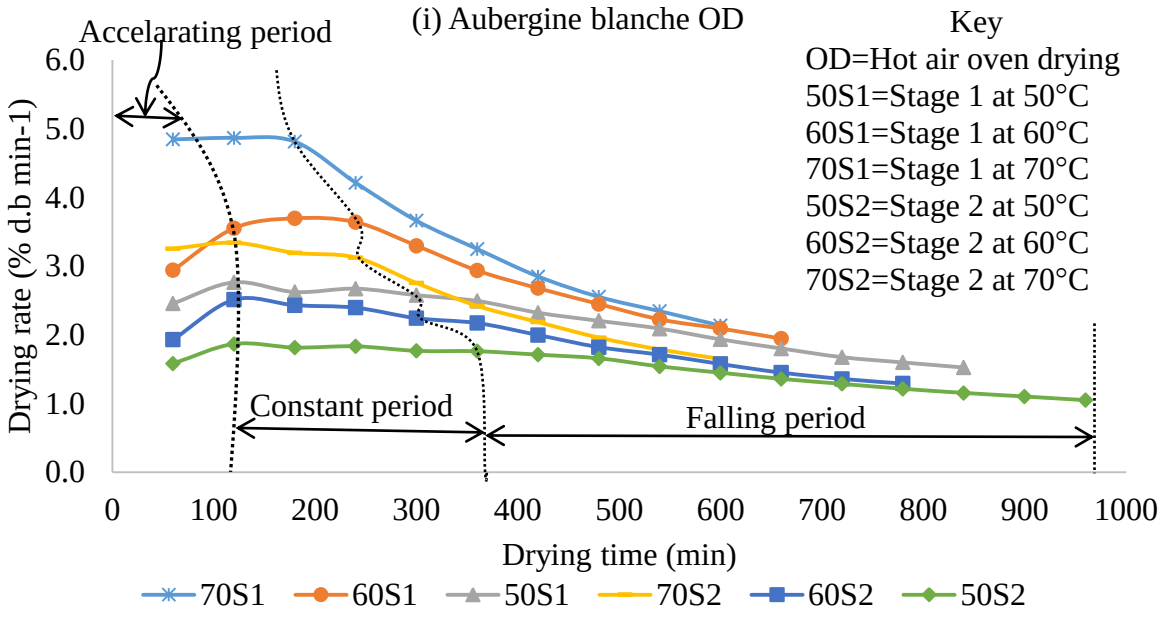


Figure 4.19: Variation of drying rates for the accession aubergine blanche over drying time at different temperatures and maturities during hot air oven drying

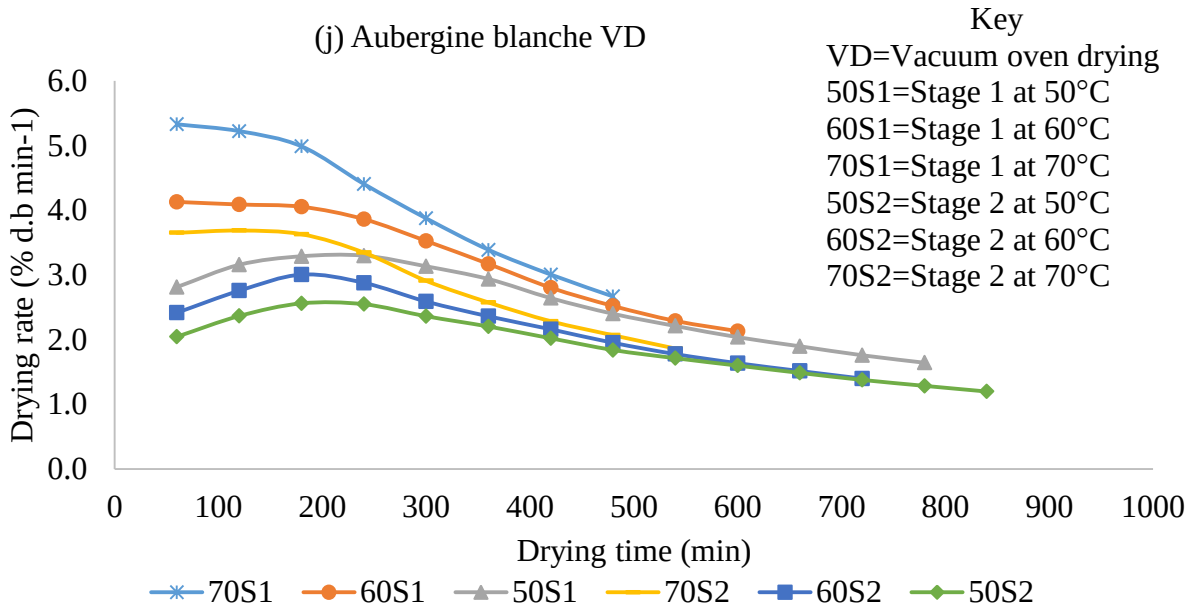


Figure 4.20: Variation of drying rates for the accession aubergine blanche over drying time at different temperatures and maturities during vacuum oven drying

4.3 Effect of harvest maturity on drying characteristics of five African eggplant accessions

Stage 1 maturity accessions dried faster in comparison to stage 2 maturity of the same accessions at both drying methods. As seen in Figure 4.19 and Figure 4.20, the drying rate was higher for stage 1 maturity fruits in comparison to stage 2 for aubergine blanche. As a result, there were significant differences in the drying times between stage 1 and stage 2 maturity. The drying times of aubergine blanche during hot air drying range was 600-840 minutes and 660-960 minutes for stage 1 and stage 2 fruits, respectively (Figure 4.9). On the other hand, the drying times of vacuum oven dried aubergine blanche range was 480-780 minutes and 540-840 minutes for stage 1 and stage 2 fruits, respectively (Figure 4.10). Similar effect of harvest maturity on the drying behavior in seen in the rest of the accessions (Figure 4.1 to Figure 4.8 and Figure 4.11 to Figure 4.18). This is

besides the stage 1 African eggplant accessions having higher moisture content (Table 4.1).

Overall, the drying time for stage 1 maturity fruits ranged between 420 and 840 minutes in S00047A (Figure 4.7) and aubergine blanche (Figure 4.9), respectively during hot air drying. In stage 2 maturity the range was between 480 and 960 minutes in S00047A (Figure 4.7) and aubergine blanche (Figure 4.9), respectively during hot air drying. With regard to vacuum oven drying, the drying time for stage 1 maturity ranged between 360 minutes (S00047A in Figure 4.8) and 720 minutes (aubergine blanche in Figure 4.10) in comparison to stage 2 maturity which ranged between 380 minutes (S00047A in Figure 4.8) and 840 minutes (aubergine blanchein Figure 4.10).

The shorter drying time for stage 1 accessions maybe associated with the smaller size of the vegetable fruit for all accessions as seen in Figure 3.1 in comparison to the relatively larger stage 2 fruits (Figure 3.2). Smaller sized fruits correspond to a larger surface area to volume ratio exposure to hot air and a shorter distance from the interior of the samples to the surface. This facilitates the heat and mass transfer to the surface for evaporation. Previous study by Correia *et al.,* (2015), showed that material thickness during drying played a significant role in the drying rate and drying time of tomatoes. In addition, other nutrient components such as carbohydrates, fiber and proteins have been shown to increase with maturity (Msogoya *et. al.,* 2014) thus increasing the dry matter of the commodity. Also, younger fruits and vegetables are fragile and easily bruised in comparison to more mature ones (Msogoya *et. al.,* 2014). This may be a contributing factor to easy, faster disruption and collapse of the cellular walls and tissues by heat energy during drying (Ramos, *et al.,* 2003). The drying time for the five accessions followed a decreasing order as follows; S00047A< Manyire green< AB2< Sangawili< Aubergine blanche at both maturity stages.

4.4 Total phenolics, beta carotene, vitamin C, antioxidant activity and lycopene content of fruit vegetables for five African eggplant accessions in fresh state

The total phenolic content (TPC), beta carotene content antioxidant activity and lycopene content for the five African eggplant accessions in fresh form are as shown in Table 4.2. The TPC of the five African eggplant accessions had significant differences (p<0.05) which ranged between 751.21 mg/100 g (manyire green) and 1363.95 mg/100 g (S00047A). Statistically, AB2 was found to be insignificantly different from sangawili (p=0.650). The beta carotene content for the fresh fruits had an average value of 20.55 mg/100 g db. Manyire green showed the highest beta carotene content (29.50 mg/100g db) (Table 4.2). On the other hand, beta carotene content in aubergine blanche was found not to be statistically different from sangawili (p=0.993). Antioxidant activity was determined in terms of IC_{50} value which means the concentration of a sample that induces 50% inhibition of DPPH free radicals (Karaman *et al.*, 2014). The IC_{50} values for all the five accessions showed variability ranging between 99.58 mg/ml db (S00047A) and 325.61 mg/ml db (sangawili) (Table 4.2). The percentage inhibition increased with increase in weight concentration for all the accessions, with S00047A having the highest rate of increase as shown in Figure 4.21. The weight concentration values at 50% inhibition in Figure 4.21 were used in equations to calculate the IC_{50} and ascorbic acid equivalent antioxidant capacity (AEAC). Notably, the accession S00047A which had the highest total phenolic content showed the lowest IC_{50} value. The AEAC was highest in S00047A (1004.21 mg/100g db) and lowest in sangawili (307.12 mg/100g db) (Table 4.2). Lycopene and vitamin C were not detected in the fresh fruits of all the accessions analyzed.

The results of this study indicate that the five African eggplant accessions are high in bioactive compounds as exhibited by high total phenolic content in particular. The significant differences in the total phenolic content between the five accessions as shown in Table 4.2 may be attributed to the differences in genetic make-up of the accessions, which is one of the influencing factors in the synthesis of phenolic compounds in plants

(Hanson *et al.,* 2004). The accession S00047A had the highest phenolic content in fresh samples. This may be attributed to its larger surface area due to its semi long shape. Studies have shown that most phenolic compounds are concentrated in the skin surface of fruits (Dadalı *et al.,* 2007). The total phenolic content of the five accessions in fresh samples was comparable to different Turkish eggplant *(S. melongena)* cultivars reported by Okmen *et al.,* (2009) and Hanson *et al*., (2006).

Significant differences in beta carotene content were observed between the five accessions. This may be similarly attributed to the differences in their genetic makeup (Rodriguez-Amaya & Kimura, 2004). Manyire green which had highest beta carotene content has a deep red color, different from the light red and purple color of the other accessions as shown in Chapter 3, Figure 3.2. Carotenoids are responsible for impacting fruits with a yellow to red color. In addition, manyire green plant is characterized by a short canopy which could mean greater exposure to sunlight and subsequent increase in carotenogenesis. Light exposure has been reported to influence carotenogenesis (Rodriguez-Amaya & Kimura, 2004). The beta carotene content of manyire green (29mg/100g db) is comparable to tomato as reported by Mwende *et al.,* (2018). On the other hand, the beta carotene contents reported in this study (Table 4.2) are higher compared to previous reports by Chepngeno *et al.,* (2016) and Msogoya *et al.,* (2014) on African eggplants. Plazas *et al.*, (2014) reported the existence of wide variability in the beta carotene and total phenolics content among African eggplant accessions.

With respect to the antioxidant capacity, the results showed a significant (p=0.001) positive correlation (r=0.822) between the total phenolic content and the AEAC. Interestingly, it was observed that the higher the total phenolic content, the lower the IC_{50} value and the higher the AEAC (Table 4.2). This is critical and may be attributed to the fact that the phenolic compounds are effective hydrogen donors and thus good antioxidants (Desai *et al.*, 2013). Similar positive correlations between phenolic content and antioxidant capacity have been reported by Hanson *et al.,* (2006) and Okmen *et al.,* (2009) in common eggplant (*S. melongena*). On the other hand, the correlation between

the beta carotene content and the AEAC was insignificant. Most studies on antioxidant capacity in eggplants used Trolox Equivalent Antioxidant Capacity (TEAC) Assay or Radical cation 2,2-Azinobis 3-ethylbenzothiazoline-6-sulfonate (ABTS) assay (Okmen *et al.*, 2009; Zaro *et al.*, 2015). However both the ABTS and DPPH assays are based on radical scavenging activity of antioxidants towards the two free radicals, and have been widely applied in fruits and vegetables since they are simple and quick to perform (Grigelmo-miguel *et al.*, 2010).

Table 4.2: Total phenolic content, beta carotene content, IC_{50} values, ascorbic equivalent antioxidant capacity (AEAC), lycopene content and vitamin C content in five African eggplant accessions in fresh state

Accession	TPC (mg/100g GAE db)	Beta carotene (mg/100g db)	IC_{50} value (mg/ml db)	AEAC mg/100g	Lycopene mg/100g	Vitamin C mg/100g
Sangawili	813.77±5.15^{b}	14.75±0.50^{a}	325.61	307.12	-	-
Manyire green	751.21±1.73^{a}	29.50±0.77^{d}	163.28	612.43	-	-
S00047A	1363.95±2.56^{d}	19.72±0.86^{b}	99.58	1004.21	-	-
AB2	823.01±3.20^{b}	23.77±1.32^{c}	283.32	352.96	-	-
Aubergine blanche	898.82±8.20^{c}	14.99±0.46^{a}	298.01	335.56	-	-
Total mean	930.17±59.33	20.55±1.52				
CV (%)	24.7	28.7				
p value	<0.0001	<0.0001				

- means not detected

Values represent mean ± SE of three replicates. Values with different letters within a column indicate significant differences based on a Tukey test at $p< 0.05$ (n = 3) level of significance.

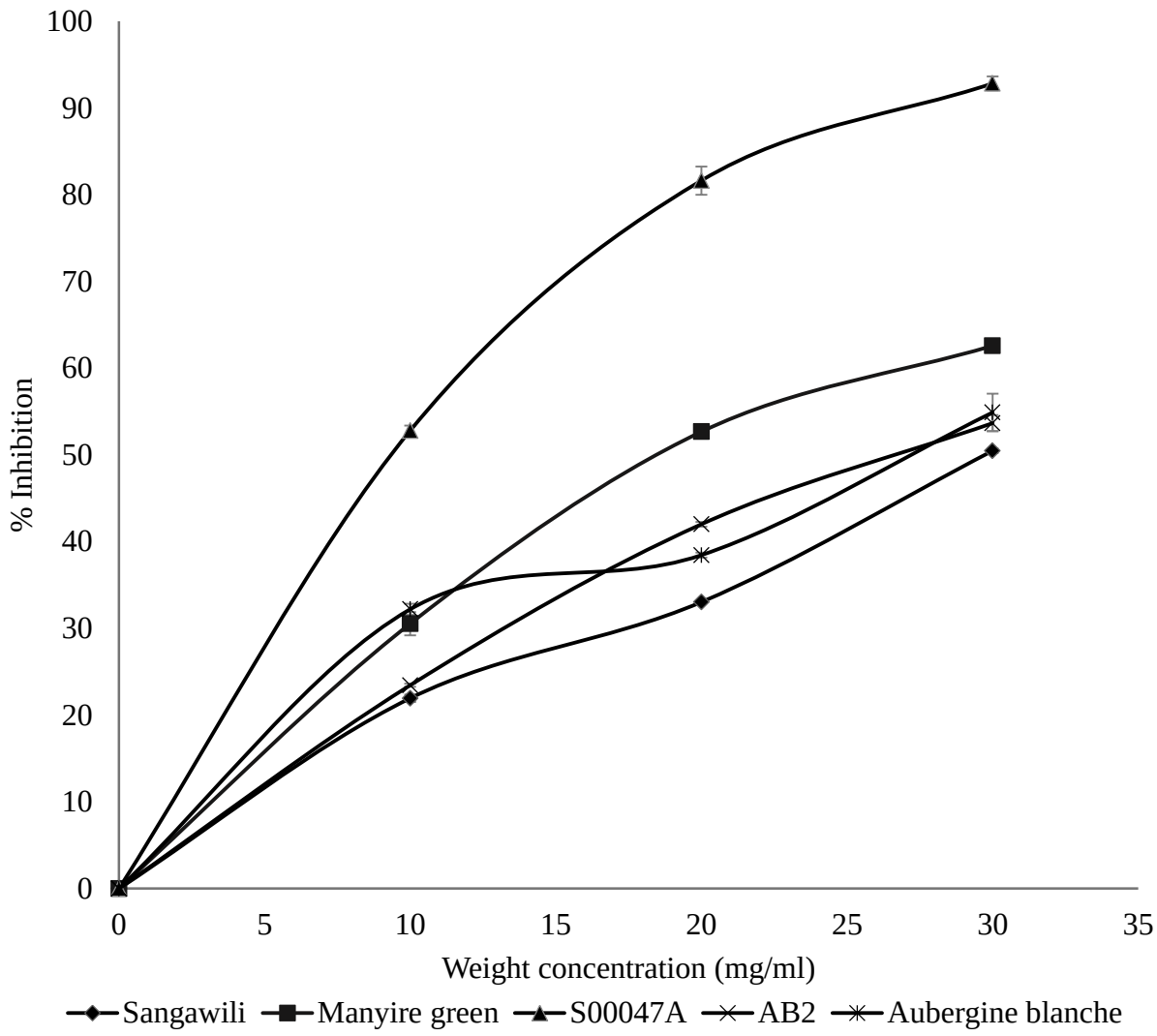


Figure 4.21: Percentage inhibition against weight concentration for fresh fruit vegetable samples of five African eggplant accessions

Each point is a representation of the mean of three replicates. Standard errors are represented in the figure by the error bars attached to each point.

4.5 Effect of drying method on the retention of total phenolics, beta carotene, antioxidant activity and lycopene

The results showing the effect of drying method on the retention of TPC, beta carotene, antioxidant capacity and lycopene are as shown in Table 4.3 and 4.4. Drying method resulted in significant changes (p<0.05) in total phenolics and beta carotene for all the five accessions. The effect of drying method was determined in each accession independently. The highest retention rate of total phenolics was observed in freeze dried samples (95.05%) followed by hot air oven drying at 70 ^{o}C (94.20%) and then vacuum oven drying at 70 ^{o}C (90.53%). The highest retention of total phenolics was observed in the manyire green accession. On the other hand, the lowest retention of total phenolics was observed in hot air oven dried samples at 60 $^{\circ}$C with 33.69% for AB2 accession (Table 4.3). Freeze drying and hot air oven drying at 70 $^{\circ}$C did not have a significant effect on the degradation of total phenolics in manyire green and aubergine blanche (Table 4.3). With regard to beta carotene, the highest retention rate was observed after freeze drying in manyire green (29.28 mg/100g db) where 99.27% of beta carotene was retained (Table 4.3). The free radical scavenging activity with respect to the IC_{50} values significantly declined in the four drying methods compared to the fresh state. This corresponded to a rise in the ascorbic acid equivalent antioxidant activity (AEAC) as shown in Table 4.4. Notably, lycopene was detected in low quantities in only one dried accession (manyire green) while absent in the rest (Table 4.3). There was no significant difference (p>0.05) between the effect of freeze drying and vacuum oven drying on the lycopene content. Vitamin C was not detected after drying in all the five accessions.

The effect of drying method as presented in Table 4.3 show that freeze drying was the most effective in retaining phenolic compounds and beta carotene content. This is in comparison with solar drying, vacuum oven drying and hot air oven drying and may be attributed to the gentle process of lyophilisation whereby enzymatic, bacterial and chemical changes are largely avoided. Despite the effectiveness of freeze drying, this

study showed slight degradation of total phenolics and beta carotene. Phenolic compounds decline after freeze drying may be associated with cellular decompartmentalization during pre-freezing step (Chang *et al.,* 2006) followed by the reaction of phenolics with proteins in the dehydration process, which could subsequently affect their extractability (Martín-Cabrejas *et al.,* 2009). Similar degradation of phenolic compounds have been reported by Zaro *et al.,* (2015), where a marked drop of antioxidants in common eggplant fruit was observed during freeze drying.

In contrast solar drying and hot air oven drying resulted in least retention of beta carotene (3.70%) and total phenolics (33.6%) respectively. Loss of total phenolics during solar drying and hot air oven drying (60 °C, 50 °C) may be attributed to enzymatic processes by polyphenol oxidases (Lim & Murtijaya, 2007). Optimum temperatures for specific enzymes have been shown to vary with type of commodity and variety. In *Solanum aethiopicum,* the optimum temperature for crude polyphenol oxidase was 50 °C (Bello & Sule, 2012). In addition, solar drying is dependent on the weather conditions which contribute to uneven losses due to non-constant drying temperature (Lim & Murtijaya, 2007). In this study, the drying temperature ranged between 50 and 60 °C and depending on weather conditions. Extended drying periods have also been shown in some cases to lead to higher losses in non-blanched tissues due to enzymatic browning (Kerkhofs, Lister, & Savage, 2005; McSweeney & Seetharaman, 2015). This may explain the low retention of bioactive compounds caused by solar drying where the period of drying is longer depending on the weather conditions. In this study, all the four drying methods used resulted in significant decline of the bioactive compounds. This is in agreement with Zaro *et al.,* (2015) who reported on chlorogenic acid retention in white and purple eggplant after processing and cooking where it was observed that high losses (80-98%) of TEAC (Trolox Equivalent Antioxidant Capacity) and CQA (5-O-caffeoyl-quinic acid) content occurred regardless of the drying method.

The detection of lycopene in the dried manyire green samples and its absence in the fresh samples may be associated with greater extractability of carotenoids from

processed samples (Rodriguez-Amaya & Kimura, 2004). In addition, lycopene bioavailability has been reported to exhibit an increase in heat-processed tomatoes compared with unprocessed tomatoes (van het Hof *et al*., 2000). Amongst the five accessions used in this study, only the dried samples of manyire green were found to contain lycopene. This may be of interest since the red colour of its peel is similar to that of tomato and as ripening progressed, the red colour deepened and developed into the pulp. In tomato berries, the lycopene concentration increases with maturation leading to the development of red color (Kirk, 1978).

Table 4.3: Total phenolics content (mg/100g GAE db), beta carotene content (mg/100g db) and lycopene content (mg/100g db) for five accessions of dried sangawili, manyire green, S00047A, AB2 and aubergine blanche.

Accession	**Sangawili**		**Manyire green**			**S00047A**		**AB2**		**Aubergine blanche**	
Drying method	**Total phenols**	**β carotene**	**Total phenols**	**β carotene**	**Lycopene**	**Total phenols**	**β carotene**	**Total phenols**	**β carotene**	**Total phenols**	**β carotene**
Fresh	813.77^{j}	14.75^{e}	751.21^{g}	29.50^{f}	-	1363.95^{h}	19.72^{d}	823.01^{i}	23.77^{f}	898.82^{g}	14.99^{g}
FD	595.80^{e}	14.61^{e}	714.01^{f}	29.28^{f}	0.17^{b}	494.60^{a}	6.20^{c}	657.27^{h}	13.98^{e}	574.31^{de}	14.88^{g}
SD	560.58^{d}	7.03^{cd}	422.57^{a}	10.91^{b}	0.15^{a}	547.08^{b}	0.73^{a}	628.32^{g}	12.08^{de}	447.32^{a}	12.58^{f}
OD70	761.05^{i}	1.53^{a}	707.66^{f}	3.63^{a}	0.16^{ab}	1024.60^{g}	3.68^{b}	587.53^{f}	11.42^{d}	585.21^{e}	2.10^{a}
OD60	467.73^{a}	2.58^{a}	487.86^{b}	2.25^{a}	0.16^{ab}	748.97^{e}	3.27^{b}	277.29^{a}	2.58^{a}	574.67^{de}	6.27^{bc}
OD50	670.38^{h}	5.55^{b}	574.27^{d}	9.76^{b}	0.17^{b}	682.44^{d}	5.40^{c}	362.70^{b}	5.31^{ab}	556.94^{d}	5.42^{b}
VD70	621.00^{g}	8.07^{d}	680.07^{e}	27.12^{e}	0.17^{b}	993.22^{f}	6.26^{c}	548.86^{e}	8.27^{c}	646.46^{f}	8.63^{e}
VD 60	529.55^{c}	$6.42b^{c}$	557.10^{c}	20.83^{d}	0.17^{b}	639.95^{c}	6.30^{c}	465.20^{c}	6.78^{bc}	533.85^{c}	7.12^{c}
VD50	493.09^{b}	5.50^{b}	564.83^{cd}	19.14^{c}	0.17^{b}	644.86^{c}	5.60^{c}	525.15^{d}	6.11^{bc}	481.30^{b}	6.15^{bc}
Mean	612.55	7.34	606.62	16.98	0.17	793.3	6.35	541.71	10.03	588.76	8.68
SE±	21.8	0.86	20.81	1.99	0.01	51.84	0.99	29.98	1.17	24.08	0.83
***p* value**	<0.0001	<0.0001	<0.0001	<0.0001	0.0017	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

FD=freeze drying, SD=solar dying, OD70=hot air oven drying at 70 °C, OD60=hot air oven drying at 60 °C, OD50=hot air oven drying ant 50 °C, VD70=vacuum oven drying at 70 °C, VD60=vacuum oven drying at 60 °C, VD50=vacuum oven drying at 50 °C. Values with different letters within a column indicate significant differences based on a Tukey test at $p < 0.05$ (n = 3) level of significance.

Table 4.4: IC_{50} Values (mg/ml) db and ascorbic equivalent antioxidant capacity (AEAC) (mg/100g) for five accessions of dried sangawili, manyire green, S00047A, AB2 and aubergine blanche.

Accession	**Sangawili**		**Manyire green**		**S00047A**		**AB2**		**Aubergine blanche**	
Drying method	**IC_{50} value**	**AEAC**	**IC_{50} value**	**AEAC**	**IC_{50} value**	**AEAC**	**IC_{50} value**	**AEAC**	**IC_{50} value**	**AEAC**
Fresh	325.61	307.12	163.28	612.44	99.58	1004.22	283.32	352.96	298.01	335.56
FD	5.70	17543.86	4.98	20080.32	4.25	23529.41	6.58	15197.57	6.37	15698.59
SD	5.47	18281.54	5.78	17301.04	4.80	20833.33	5.49	18214.94	5.16	19379.84
OD70	16.52	6053.27	6.76	14792.90	4.73	21141.65	15.19	6583.28	5.57	17953.32
OD60	18.89	5293.81	5.73	17452.01	4.72	21186.44	13.53	7390.98	5.27	18975.33
OD50	10.11	9891.20	5.62	17793.59	4.90	20408.16	10.31	9699.32	5.59	17889.09
VD70	4.85	20618.56	5.38	18587.36	4.79	20876.83	9.35	10695.19	5.99	16694.49
VD 60	5.86	17064.85	5.07	19723.87	5.08	19685.04	11.90	8403.36	11.08	9025.27
VD50	7.24	13812.15	8.97	11148.27	4.97	20120.72	11.73	8525.15	13.47	7423.90

FD=freeze drying, SD=solar dying, OD70=hot air oven drying at 70 $^{\circ}$C, OD60=hot air oven drying at 60 $^{\circ}$C, OD50=hot air oven drying ant 50 $^{\circ}$C, VD70=vacuum oven drying at 70 $^{\circ}$C, VD60=vacuum oven drying at 60 $^{\circ}$C, VD50=vacuum oven drying at 50 $^{\circ}$C. IC_{50} values derived from the dose inhibition curves whose each point is a representation of the mean of three replicates.

4.6 Effect of drying temperature on the retention of total phenolics, beta carotene, antioxidant activity and lycopene during hot air oven and vacuum oven drying

The results showing the effect of temperature conditions in hot air oven and vacuum oven drying on the retention of the bioactive compounds determined in the five accessions is as shown in Table 4.3 and 4.4. There was significant decline in the total phenolic content with decreasing drying temperature in hot air oven and vacuum oven drying. The highest retention of 94.20% was observed in hot air oven drying at 70 $^{\circ}$C of manyire green while lowest retention of 33.69% was observed at 60 $^{\circ}$C in AB2 accession (Table 4.3). The percentage retention of total phenolics ranged between 65.11% (Aubergine blanche) and 94.20% (manyire green); 33.69% (AB2) and 64.94% (manyire green); 44.07% (AB2) and 82.38% (sangawili) in hot air oven drying at 70 $^{\circ}$C, 60 $^{\circ}$C and 50 $^{\circ}$C, respectively (Table 4.3). On the other hand, the retention rate ranged between 66.69% (AB2) and 90.53% (manyire green); 46.92% (S00047A) and 74.16% (manyire green); 47.28% (S00047A) and 75.19% (manyire green) in vacuum oven drying at 70 $^{\circ}$C, 60 $^{\circ}$C and 50 $^{\circ}$C, respectively (Table 4.3). With respect to beta carotene, increase in temperature resulted to decrease in beta carotene content in hot air oven drying. The highest retention was observed in vacuum oven drying at 70 $^{\circ}$C where 91.93% (manyire green) of beta carotene was retained. In contrast, lowest retention was 7.63% in manyire green observed after hot air oven drying at 60 $^{\circ}$C (Table 4.3). The IC_{50} values increased with decrease in temperature from a low of 4.79 mg/ml db (S00047A) at 70 $^{\circ}$C vacuum drying to a high of 13.47 mg/ml db (aubergine blanche) at 50 $^{\circ}$C vacuum drying. An increase in IC_{50} value corresponded to a decrease in the AEAC content and vice versa (Table 4.4). The results showed no significant effect of temperature on the lycopene content in dried manyire green (Table 4.3).

The effect of drying temperature during hot air oven and vacuum oven drying as presented in Table 4.3 show that temperature had a significant effect on the retention of the total phenolics and beta carotene contents. The retention rate of total phenolics

decreased with decrease in temperature. This observation may be associated with the immediate inactivation of polyphenol oxidase enzymes at 70 °C and delayed inactivation at 60 °C and 50 °C. Higher drying temperatures inactivate or at least inhibits polyphenol oxidase (PPO) mediated oxidation of phenolics (Lim & Murtijaya, 2007). Zaro *et al.* (2015) reported that drying at 50 °C caused greater losses of phenolics antioxidants than at 70 °C. In addition, high thermal treatment and /or extended periods of drying may be responsible for a significant decline of natural antioxidants, since most of these compounds are relatively unstable. This study also showed that vacuum oven drying at 70 °C led to higher degradation of phenols as compared to hot air oven drying at 70 °C (Table 4.3). Similar results were reported in the drying of mandarin slices by Akdaş and Başlar, (2015). At 60 and 50 °C, the opposite was observed which could be associated with longer drying period for hot air oven drying in comparison to vacuum oven drying. The phenolic content degrades because of thermal degradation during the drying process while volatile and semi-volatile phenolic compounds can evaporate with water molecules in the samples during vacuum oven drying (Akdaş & Başlar, 2015). Antioxidant capacity degradation increased as the drying temperature decreased. This concurs with Karaman *et al.,* (2014) who reported that vacuum oven drying prevented antioxidant capacity degradation more than hot air oven drying.

Contrastingly, higher drying temperature resulted to significantly low retention of beta carotene while lower temperatures led to significantly higher retention during hot air oven drying (Table 4.3). This may be attributed to higher rate of isomerization and oxidation at 70 °C as compared to 60 °C and 50 °C (Eldahshan & Singab, 2013). Similar observation was reported by Mwende *et al.,* (2018) and Demiray, Tulek and Yilmaz (2013) in the drying of tomatoes. On the other hand, carotenoid retention has been shown to decrease with longer processing time, higher processing temperature, and cutting or puréeing of the food regardless of the processing method. Retention is significantly improved by reducing the processing time, lowering the temperature, and shortening the time lag between peeling, cutting or puréeing and processing (Rodriguez-

Amaya & Kimura, 2004). In some cases however, processing leads to little or no change to the content and activity of naturally occurring antioxidants, such as lycopene which has been found to be very heat stable (Nicoli, Anese, & Parpinel, 1999). This may support the results of this study whereby, there was insignificant difference in the lycopene content regardless of the drying method or temperature in manyire green (Table 4.3).

4.7 Degradation kinetics of total phenolic content (TPC) during hot air oven and vacuum oven drying

The initial TPC in the five African eggplant accessions ranged between 751.21 mg/100 g GAE (manyire green) and 1363.95 mg/100 g GAE (S00047A) on dry basis. The degradation kinetic data is as shown in Table 4.5. Reaction rate constants (*k*) increased with increase in drying temperature for all the accessions in both hot air oven and vacuum oven drying. The *k* values ranged between 0.018 h^{-1} (manyire green) and 0.067 h^{-1} (AB2) during hot air oven drying and between 0.020 h^{-1} (aubergine blanche) and 0.067 h^{-1} (S00047A) during vacuum oven drying. While the Q_{10} values were variable, the half-life values decreased with increasing drying temperature. Overall, the degradation rate of TPC in at least half of the accessions was affected most when the temperatures changed from 60 to 70 $^{\circ}$C as marked by the highest Q_{10} values. The kinetics of degradation of TPC followed a first-order reaction for both hot air oven and vacuum oven drying as shown in Figures: 4.22 (sangawili), 4.23 (manyire green), 4.24 (S00047A), 4.25 (AB2), and 4.26 (aubergine blanche). All the plots were approximately linear with R^2 values > 0.980. Total phenolics degradation ranged between 19.88% (manyire green) and 50.49% (AB2) for hot air oven drying and between 20.68% (manyire green) and 43.615% (AB2) for vacuum oven drying as calculated from Section 4.5, Table 4.3 of this chapter.

Although the degradation rate increased with increase in drying temperature, remaining TPC at the end of 70 $^{\circ}$C drying was higher than at 50 and 60 $^{\circ}$C. This can be attributed to long term heat treatment at lower temperatures and some detrimental factors such as

oxidation. In addition, there is immediate inactivation of polyphenol oxidase enzymes at 70 °C and delayed inactivation at 60 °C and 50 °C. Higher drying temperatures inactivate or at least inhibits polyphenol oxidase (PPO) mediated oxidation of phenolics according to Lim and Murtijaya, (2007). Madrau *et al.* also reported that a longer drying time caused a greater loss of TPC at a lower drying temperature in the presence of air. Similar observations were reported by Zaro *et al.* (2015) in the drying of eggplants (*S. melongena*). Experimental data was fitted into the Arrhenius model to predict TPC degradation dependence on temperature. As shown in Table 4.5, the E_a values ranged between 8.246 kJ/mol (sangawili) and 15.944 kJ/mol (AB2) for hot air oven drying and between 13.402 kJ/mol (AB2) and 23.548 kJ/mol for vacuum oven drying. Activation energy increased with decreasing reaction rate constant and vice versa thus confirming its dependence on drying temperature.

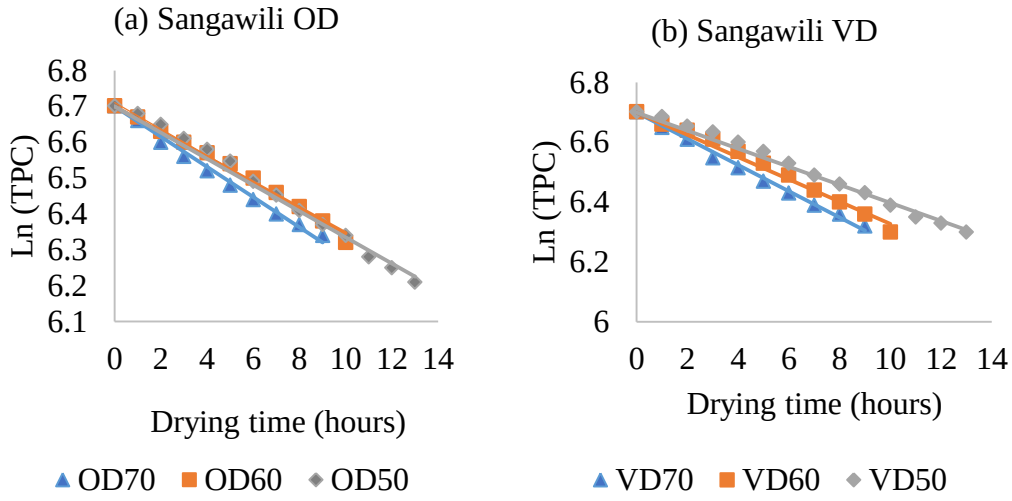


Figure 4.22: The degradation kinetics of TPC in the accession sangawili dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

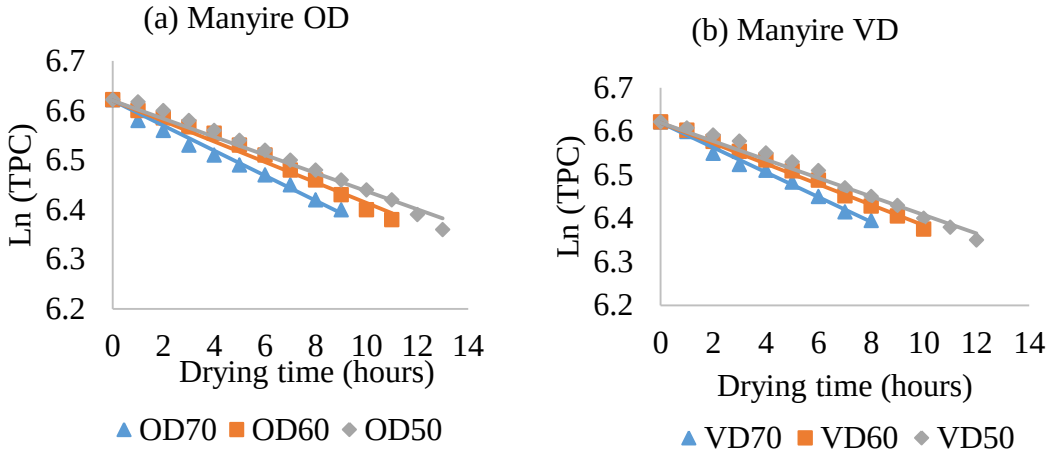


Figure 4.23: The degradation kinetics of TPC in the accession manyire green dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point is a mean of triplicates.

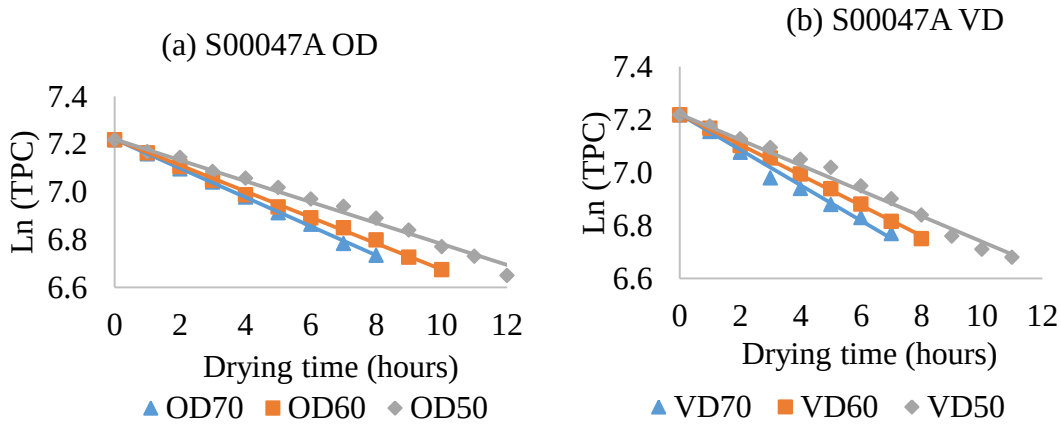


Figure 4.24: The degradation kinetics of TPC in the accession S00047A dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

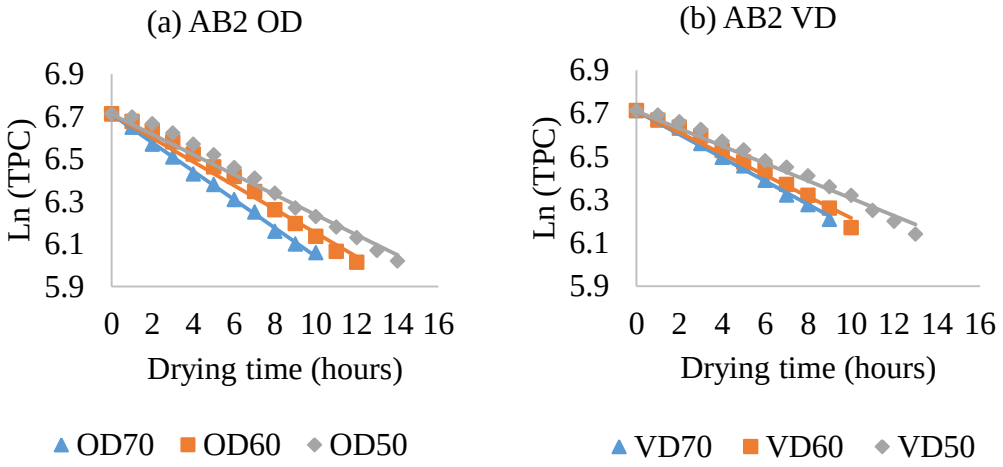


Figure 4.25: The degradation kinetics of TPC in the accession AB2 dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point is a mean of triplicates.

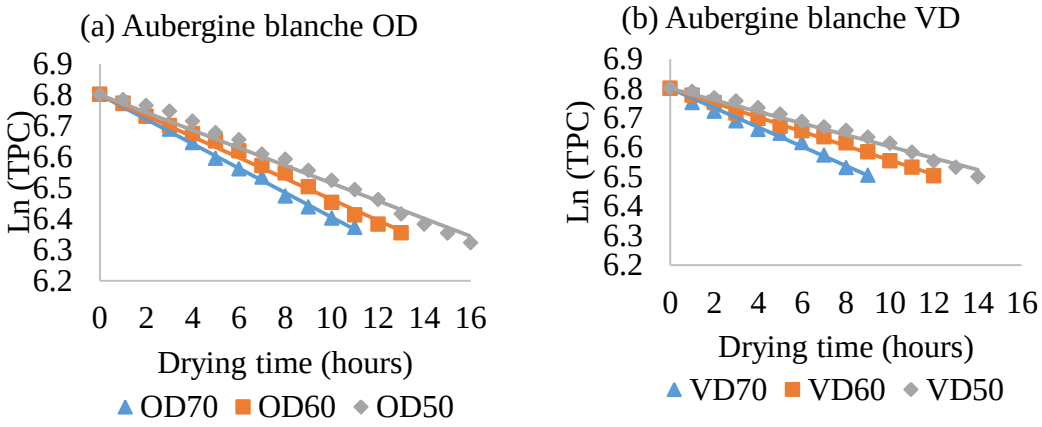


Figure 4.26: The degradation kinetics of TPC in the accession aubergine blanche dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each temperature. Each point is average of triplicates.

Table 4.5: Degradation kinetic parameters (Q_{10}, k, $t_{1/2}$ and E_a) for total phenolics content of the five African eggplant accessions during hot air oven and vacuum oven drying

Drying method	Accession	Temperature	Q_{10} value	$k(h^{-1})$	$t_{1/2}$ (h)	R^2	E_a (kJ/mol)
Hot air oven drying	Sangawili	50		0.035	19.64	0.991	
		60	1.034	0.037	18.99	0.990	8.246
		70	1.156	0.042	16.43	0.992	
	Manyire green	50		0.018	38.09	0.980	
		60	1.132	0.021	33.65	0.983	15.031
		70	1.223	0.025	27.51	0.984	
	S00047A	50		0.044	15.79	0.989	
		60	1.241	0.055	12.72	0.997	15.118
		70	1.117	0.061	11.38	0.999	
	AB2	50		0.047	14.65	0.980	
		60	1.180	0.056	12.42	0.985	15.944
		70	1.197	0.067	10.38	0.998	
	Aubergine blanche	50		0.029	23.90	0.986	
		60	1.172	0.034	20.39	0.993	14.854
		70	1.176	0.040	17.33	0.997	
Vacuum oven drying	Sangawili	50		0.030	22.95	0.989	
		60	1.232	0.037	18.63	0.987	17.278
		70	1.180	0.044	15.79	0.993	
	Manyire green	50		0.021	32.70	0.981	
		60	1.113	0.024	29.37	0.994	13.667
		70	1.208	0.029	24.32	0.991	
	S00047A	50		0.048	14.41	0.987	
		60	1.193	0.057	12.08	0.999	15.307
		70	1.167	0.067	10.35	0.987	
	AB2	50		0.040	17.16	0.982	
		60	1.223	0.049	14.03	0.984	13.402
		70	1.093	0.054	12.84	0.993	
	Aubergine blanche	50		0.020	35.19	0.984	
		60	1.239	0.024	28.41	0.996	23.548
		70	1.344	0.033	21.13	0.989	

Q_{10}, k, $t_{1/2}$, E_a represent temperature coefficient, reaction rate constant, half life time and activation energy, respectively.

4.8 Degradation kinetics of beta carotene content during hot air oven and vacuum oven drying

The initial beta carotene content for the five accessions ranged between 14.75mg/100g db (sangawili) and 29.50mg/100g db (manyire green). The kinetics of degradation data is as shown in Table 4.6. The results show that the *k* values increased with increasing drying temperature for both hot air oven and vacuum oven drying. This means that the rate of beta carotene degradation increased with increase in drying temperature. The *k* values ranged between 0.057 h^{-1} (aubergine blanche) and 0.226 h^{-1} (manyire green) for hot air oven drying and between 0.016 h^{-1} (manyire green) and 0.164 h^{-1} (S00047A) for vacuum oven drying. Consequently, the half-life declined with increase in drying temperature. The temperature range that had significantly highest effect on degradation of beta carotene was from 50 to 60 $^{\circ}$C as represented by the highest Q_{10} value (Table 4.6). The degradation of beta carotene ranged between 51.96% (AB2) and 92.37% (manyire green) for hot air oven drying while ranging between 8.07% (manyire green) and 74.30% (AB2) for vacuum oven drying. Increasing the drying temperature caused more degradation of beta carotene during hot air oven drying in comparison to vacuum oven drying.

The degradation kinetics of beta carotene followed a first order reaction for the accession sangawili as shown in Figure 4.27. Similar reaction order was noted in manyire green (Figure 4.28), S00047A (4.29), AB2 (Figure 4.30) and aubergine blanche (Figure 4.31). The increased degradation of beta carotene with increasing temperature during hot air oven drying may be attributed to higher rate of isomerization and oxidation at 70 $^{\circ}$C in comparison to 60 $^{\circ}$C and 50 $^{\circ}$C (Eldahshan & Singab, 2013). Similar observation was reported by Mwende *et al.,* (2018) and Demiray *et al.,* (2013) in the drying of tomatoes. The E_a values ranged between 30.822 kJ/mol (AB2) and 60.845 kJ/mol (sangawili) for hot air oven drying and between 15.994 kJ/mol (S00047A) and 43.554 kJ/mol (Aubergine blanche) for vacuum oven drying. The E_a values for beta carotene were higher in comparison to E_a values for TPC and antioxidant activity. This

indicates that the heat stability for beta carotene is lower compared to that of TPC and antioxidant activity (Başlar *et al.*, 2014).

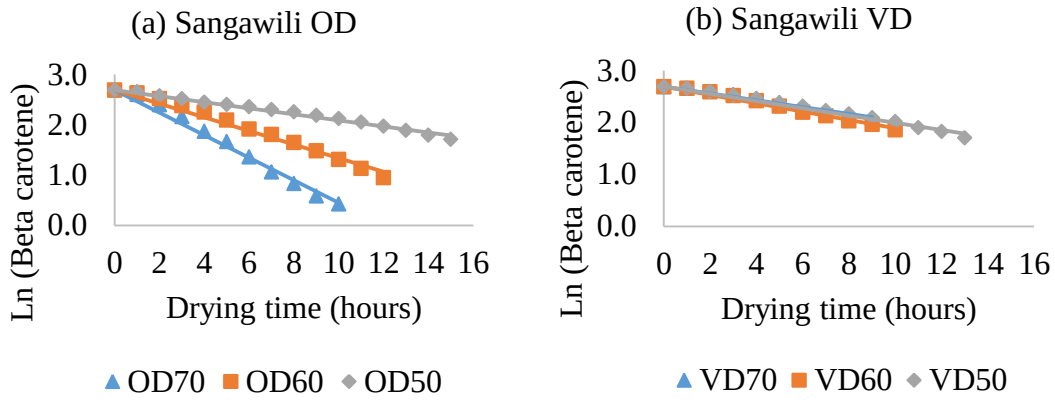


Figure 4.27: The degradation kinetics of beta carotene in the accession sangawili dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

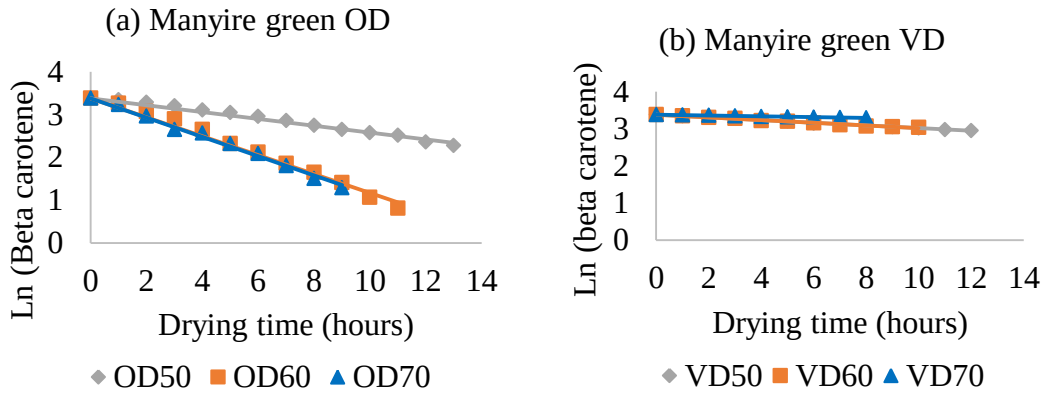


Figure 4.28: The degradation kinetics of beta carotene in the accession manyire green dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

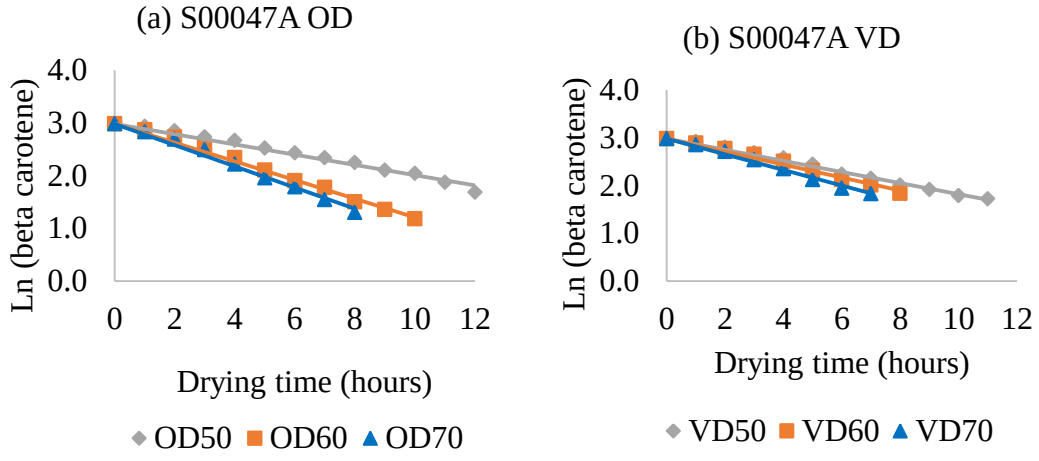


Figure 4.29: The degradation kinetics of beta carotene in the accession S00047A dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

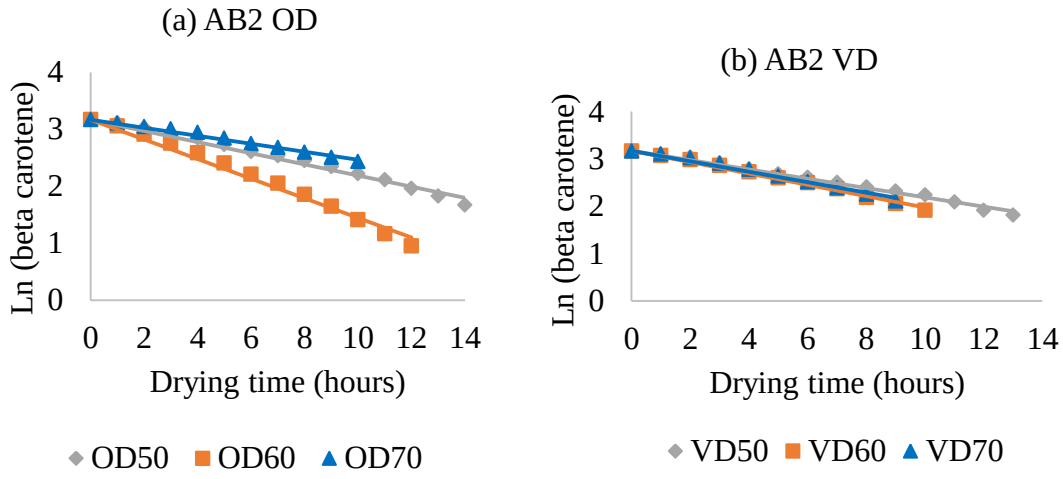


Figure 4.30: The degradation kinetics of beta carotene in the accession AB2 dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

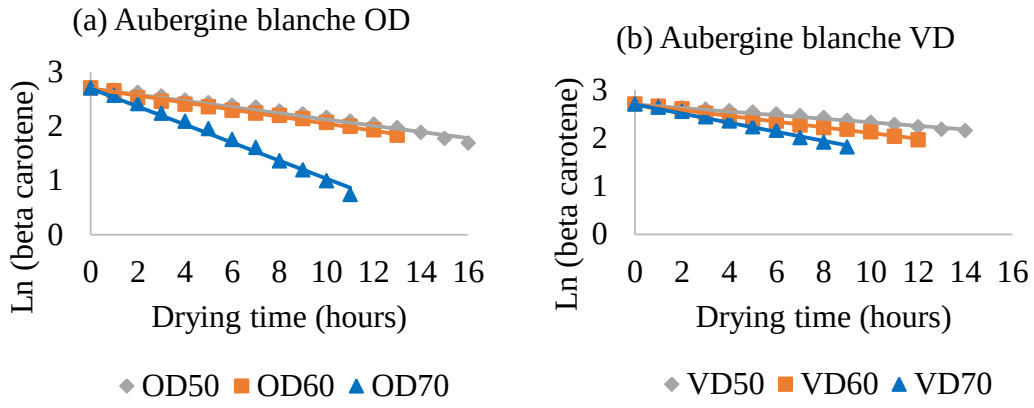


Figure 4.31: The degradation kinetics of beta carotene in the accession aubergine blanche dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

Table 4.6: Degradation kinetic parameters (Q_{10}, k, $t_{1/2}$ and E_a) for beta carotene content of five African eggplant accessions during hot air oven and vacuum oven drying

Drying method	Accession	Temperature	Q_{10} value	k(h^{-1})	$t_{1/2}$ (h)	R^2	E_a (kJ/mol)
Hot air oven drying	Sangawili	50		0.060	11.55	0.986	
		60	2.250	0.135	5.13	0.983	60.845
		70	1.659	0.224	3.09	0.986	
	Manyire green	50		0.080	8.66	0.983	
		60	2.763	0.221	3.14	0.985	47.968
		70	1.023	0.226	3.07	0.992	
	S00047A	50		0.097	7.15	0.981	
		60	1.825	0.177	3.92	0.990	33.653
		70	1.136	0.201	3.45	0.987	
	AB2	50		0.098	7.07	0.985	
		60	1.765	0.173	4.01	0.985	30.822
		70	1.104	0.191	3.63	0.986	
	Aubergine blanche	50		0.057	12.16	0.983	
		60	1.140	0.065	10.66	0.991	49.650
		70	2.569	0.167	4.15	0.990	
Vacuum oven drying	Sangawili	50		0.056	12.38	0.984	
		60	1.232	0.069	10.05	0.983	16.474
		70	1.159	0.080	8.66	0.985	
	Manyire green	50		0.016	43.32	0.996	
		60	1.188	0.019	36.48	0.992	38.721
		70	1.947	0.037	18.73	0.986	
	S00047A	50		0.116	5.98	0.990	
		60	1.172	0.136	5.10	0.982	15.994
		70	1.206	0.164	4.23	0.990	
	AB2	50		0.099	7.00	0.990	
		60	1.212	0.120	5.78	0.991	16.334
		70	1.175	0.141	4.92	0.983	
	Aubergine blanche	50		0.037	18.73	0.987	
		60	1.622	0.060	11.55	0.995	43.554
		70	1.583	0.095	7.30	0.989	

Q_{10}, k, $t_{1/2}$, E_a represent temperature coefficient, reaction rate constant, half life time and activation energy, respectively.

4.9 Degradation kinetics of antioxidant capacity during hot air oven and vacuum oven drying

Antioxidant activity is a culmination of various bioactive compounds such as flavonoids, carotenoids, vitamins and other phenolic compounds in a commodity (Minussi *et al.*, 2003: Zhang & Hamauzu, 2004). Its measurement is expressed as IC_{50} value or the AEAC. IC_{50} is the concentration that is required to cause 50% inhibition of DPPH free radicals (Karaman *et al.*, 2014). The initial IC_{50} values for the fresh five African eggplant accessions ranged between 99.58mg/ml db (S00047A) and 325.61mg/ml db (sangawili). The reaction order for antioxidant activity degradation of the dried African eggplant accessions was determined by plotting the natural logarithm of antioxidants concentration (mg/ml db) against time for each temperature as shown in Figures; 4.32 (sangawili), 4.33 (manyire green), 4.34 (S00047A), 4.35 (AB2) and 4.36 (aubergine blanche). The kinetics of degradation followed a first-order reaction for hot air oven and vaccum oven drying in the five accessions. The kinetics of degradation parameters for antioxidant capacity is as shown in Table 4.7. The reaction rate constant (*k*) ranged between 0.239 h^{-1} (sangawili) and 0.376 h^{-1} (S00047A) during hot air oven drying and between 0.237 h^{-1} (aubergine blanche) and 0.453 h^{-1} (sangawili) during vacuum oven drying. As shown in Table 4.7, the *k* values increased with increase in drying temperature. This indicates that the IC_{50} values were significantly reduced by thermal processing. The results show slight changes in the half-life values while increasing temperature from 50 to 60 $^{\circ}$C had the highest degradation effect on antioxidant activity. Also, slight differences between drying temperature conditions in terms of the antioxidant capacity change were observed. This indicate the importance of an optimal drying time and drying temperature in order to decrease the degradation of bioactive components which result into antioxidant activity decrease (Başlar *et al.*, 2014).

Generally, degradation of the antioxidants ranged between 93.24% (S00047A) and 98.23% (aubergine blanche) for hot air oven drying and between 94.51% (manyire green) and 98.51% (sangawili) for vacuum oven drying. On the other hand, degradation

of the IC_{50} values implies that lesser concentrations of the dried samples would be required to induce 50% inhibition. Similar results of antioxidant activity degradation with thermal processing have been reported by Jiménez *et al.*, (2009), Jaiswal *et al.*, (2012), Papetti *et al.*, (2002) and Podse¸dek (2007) in various vegetables.

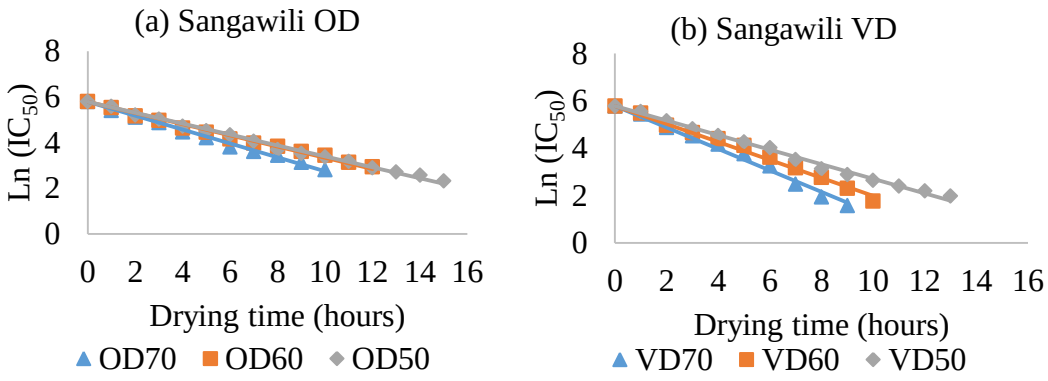


Figure 4.32: The degradation kinetics of IC_{50} value in the accession sangawili dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD).

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

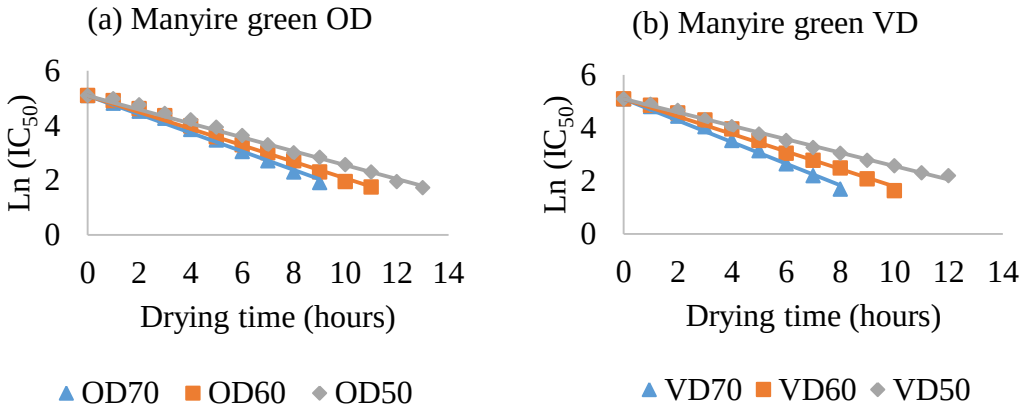


Figure 4.33: The degradation kinetics of IC_{50} value in the accession manyire green dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

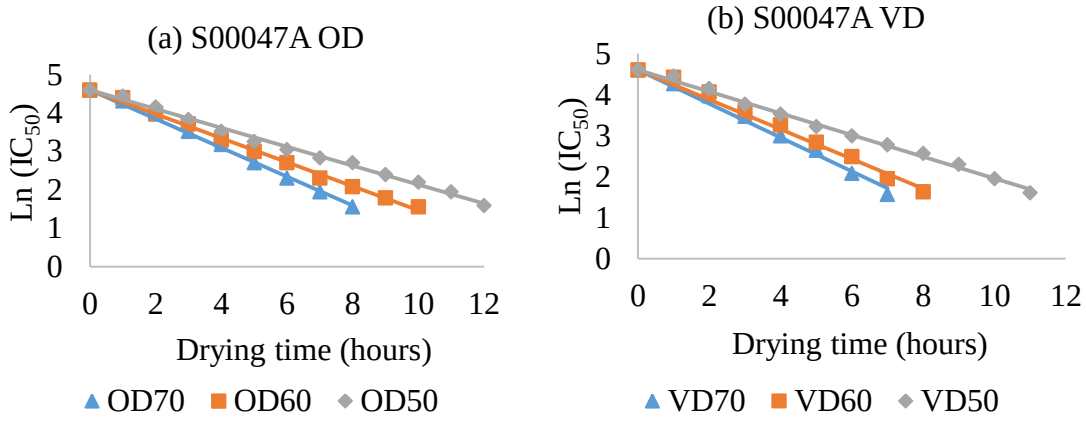


Figure 4.34: The degradation kinetics of IC_{50} value in the accession S00047A dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

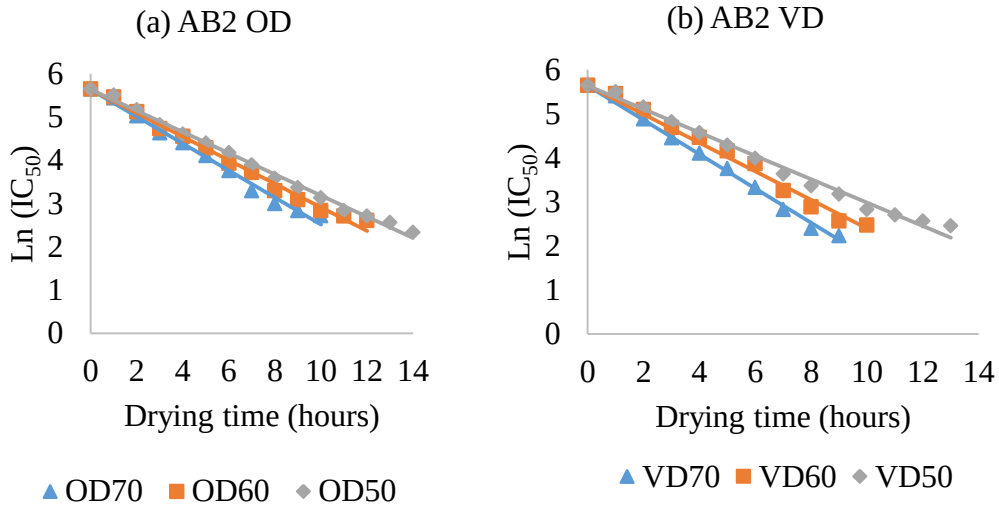


Figure 4.35: The degradation kinetics of IC_{50} value in the accession AB2 dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

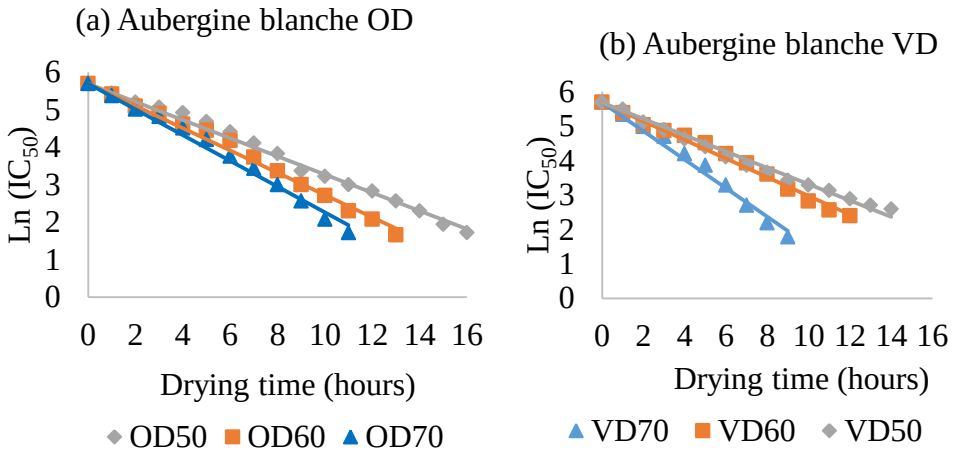


Figure 4.36: The degradation kinetics of IC_{50} value in the accession aubergine blanche dried at 50, 60 and 70°C using; (a) Hot air oven drying (OD) and (b) Vacuum oven drying (VD)

Lines indicate linear regression for each drying temperature. Each point reflects the average of triplicates.

Table 4.7: Degradation kinetic parameters (Q_{10}, k, $t_{1/2}$ and E_a) for antioxidant activity of the five African eggplant accessions during hot air oven and vacuum oven drying

Drying method	Accession	Temperature	Q_{10} value	$k(h^{-1})$	$t_{1/2}$ (h)	R^2	E_a (kJ/mol)
Hot air oven drying	Sangawili	50		0.239	2.90	0.994	
		60	1.025	0.245	2.83	0.987	11.111
		70	1.241	0.304	2.28	0.993	
	Manyire green	50		0.254	2.73	0.993	
		60	1.193	0.303	2.29	0.993	13.469
		70	1.122	0.340	2.04	0.991	
	S00047A	50		0.247	2.81	0.995	
		60	1.271	0.314	2.21	0.997	19.409
		70	1.197	0.376	1.84	0.996	
	AB2	50		0.246	2.82	0.995	
		60	1.110	0.273	2.54	0.991	11.126
		70	1.147	0.313	2.21	0.990	
	Aubergine blanche	50		0.242	2.86	0.993	
		60	1.223	0.296	2.34	0.990	15.975
		70	1.155	0.342	2.03	0.988	
Vacuum oven drying	Sangawili	50		0.307	2.26	0.994	
		60	1.235	0.379	1.83	0.991	17.970
		70	1.195	0.453	1.53	0.987	
	Manyire green	50		0.253	2.74	0.997	
		60	1.304	0.330	2.10	0.990	21.959
		70	1.233	0.407	1.70	0.991	
	S00047A	50		0.264	2.63	0.996	
		60	1.367	0.361	1.92	0.988	20.445
		70	1.139	0.411	1.69	0.989	
	AB2	50		0.265	2.62	0.989	
		60	1.223	0.324	2.14	0.987	17.730
		70	1.201	0.389	1.78	0.995	
	Aubergine blanche	50		0.237	2.92	0.987	
		60	1.148	0.272	2.55	0.989	25.764
		70	1.522	0.414	1.67	0.984	

Q_{10}, k, $t_{1/2}$, E_a represent temperature coefficient, reaction rate constant, half life time and activation energy, respectively.

4.10 Sensory evaluation for five dried African eggplant accessions

The results for sensory analysis of the five African eggplant accessions in the dried state on four attributes (appearance, colour, texture and overall score) are as shown in Table 4.8. There was no significant difference in the appearance and texture amongst the five samples at p=0.0846 and p=0.8703, respectively. However, S00047A scored lowest in appearance and texture in comparison to the rest of the accessions. With respect to colour, S00047A was notably significantly different from manyire green with the latter's colour rating highest and the former lowest in terms of likability score. Overall the panel preferred manyire green (5.87) the most and S00047A (3.87) the least. The overall best score by manyire green may be attributed to its deep red colour. It has been reported that appearance and colour are the most critical quality attributes that determine acceptance or rejection of fruits and vegetables (Barrett *et al.,* 2010) Accession maybe considered a factor in colour and overall likability of African eggplants.

Table 4.8: Sensory evaluation outcome for five dried African eggplant accessions on the attributes of appearance, colour, texture and overall score.

Sample	Appearance	Colour	Texture	Overall score
Sangawili	5.60 ± 0.45^{a}	5.73 ± 0.38^{ab}	4.93 ± 0.47^{a}	5.47 ± 0.36^{ab}
Manyire green	5.60 ± 0.43^{a}	6.20 ± 0.34^{b}	4.40 ± 0.52^{a}	5.87 ± 0.38^{b}
S00047A	4.00 ± 0.55^{a}	4.07 ± 0.51^{a}	4.20 ± 0.54^{a}	3.87 ± 0.48^{a}
AB2	5.47 ± 0.46^{a}	5.53 ± 0.45^{ab}	4.60 ± 0.42^{a}	5.07 ± 0.45^{ab}
Aubergine blanche	4.87 ± 0.46^{a}	5.00 ± 0.40^{ab}	4.53 ± 0.47^{a}	4.87 ± 0.45^{ab}
p value	0.0846	0.0079	0.8703	0.0196
CV (%)	36.79	32.93	40.76	34.61

Values represent mean ± SE of 80 replicates. Values with different letters within a column indicate significant differences based on Tukey test at $p< 0.05$ level of significance.

4.11 Sensory evaluation for reconstituted African eggplant accessions

The results of sensory analysis for five African eggplant accessions in the fresh and reconstituted forms on five attributes (appearance, aroma, taste, texture and overall score) are as shown in Table 4.9. There was no significant difference between the two forms of the five accessions in most attributes (aroma, taste and texture) with the exception of appearance and overall score. The dried manyire green and fresh AB2 scored significantly different from the dried S00047A in appearance. In addition, fresh AB2 was most preferred for its appearance as well as aroma. Overall, the fresh AB2 scored highest in comparison to the rest of the accessions. On the other hand, dried aubergine scored the least followed by the dried S00047A. Furthermore, there was higher preference for at least four out of five attributes for the fresh states of all accessions with the exception of dried manyire green which was most preferred in its dried state than fresh state. The insignificant differences in the attributes of aroma, taste and texture may be attributed to maturity stage uniformity. Gajewski, and Arasimowicz (2004) reported cultivar and harvest maturity stage as main factors influencing sensory analysis in *S. melongena* cultivars. In contrast, this study showed insignificant effect of the accession for all attributes except appearance. Similar results were observed in the sensorial evaluation of common eggplant (*S. melongena*) dried under different temperatures using convective air drier (Guiné *et al.,* 2018).

Table 4.9: Sensory evaluation outcome for five African eggplant accessions on the attributes of appearance, aroma, taste, texture and overall score in the fresh and reconstituted form.

Sample	Appearance	Aroma	Taste	Texture	Overall score
Fresh sangawili	5.53±0.48^{ab}	4.73±0.41^{a}	4.47±0.52^{a}	4.67±0.46^{a}	5.13±0.41^{ab}
Dried sangawili	5.13±0.53^{ab}	4.20±0.44^{a}	3.93±0.41^{a}	4.33±0.43^{a}	4.13±0.47^{a}
Fresh manyire green	4.67±0.57^{ab}	4.40±0.36^{a}	4.33±0.46^{a}	4.27±0.42^{a}	4.33±0.42^{a}
Dried manyire green	5.93±0.30^{b}	4.60±0.38^{a}	4.60±0.41^{a}	4.87±0.52^{a}	5.13±0.31^{ab}
Fresh S00047A	4.88±0.55^{ab}	5.06±0.32^{a}	4.06±0.46^{a}	5.12±0.44^{a}	4.81±0.40^{ab}
Dried S00047A	3.67±0.61^{a}	4.73±0.43^{a}	4.27±0.41^{a}	4.20±0.35^{a}	4.07±0.41^{a}
Fresh AB2	6.40±0.16^{b}	5.33±0.27^{a}	4.00±0.46^{a}	5.13±0.31^{a}	5.33±0.27^{ab}
Dried AB2	5.20±0.46^{ab}	4.73±0.32^{a}	3.73±0.46^{a}	4.93±0.41^{a}	5.07±0.25^{ab}
Fresh aubergine blanche	5.80±0.57^{ab}	4.40±0.50^{a}	4.60±0.47^{a}	4.87±0.50^{a}	5.00±0.56^{ab}
Dried aubergine blanche	4.73±0.48^{ab}	4.53±0.42^{a}	3.47±0.43^{a}	3.53±0.48^{a}	3.67±0.41^{a}
p value	0.0116	0.6768	0.7157	0.2174	0.0417
CV (%)	38.31	32.06	41.82	37.20	34.33

Values represent mean ± SE of 80 replicates. Values with different letters within a column indicate significant differences based on a Tukey test at $p < 0.05$ level of significance.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From this study, the effect of harvest maturity stage prior to drying proved to significantly affect the drying characteristics. Despite stage 1 maturity having slightly higher moisture content, it significantly showed higher drying rates and subsequent shorter drying times in comparison to stage 2 maturity. In addition, drying rate was influenced by drying temperature, drying method and accession. The drying rate curves were characterized by a characteristic constant rate period and a falling rate period for some accessions while others showed an accelerating period and falling rate period only.

The fresh African eggplant accessions proved to be high in TPC, beta-carotene and antioxidant activity. However, the four drying methods that were employed proved to cause drastic weight losses, shrinkage and significant decline of TPC, beta carotene and antioxidant activity. Highest retention was observed in freeze drying and thus can be concluded to be the optimum drying method in comparison to vacuum oven, hot air oven and solar drying. In addition, drying proved to improve the extractability of lycopene in manyire green.

The kinetics of degradation of TPC, beta carotene and antioxidant activity proved to follow first order reaction for both vacuum oven and hot air oven drying. The degradation rates increased with increase in drying temperature. TPC degradation proved to be significantly affected by the length of exposure to heat treatment as well as the drying temperature. Also the activation energy proved an inverse proportional relationship with the reaction rate constant.

Also, this study indicated some apparent differences in sensorial evaluation; however, the results were not statistically significant for most attributes. Therefore, it was not possible to assess the panel's favorite accession. Considering that choice of drying method depends on various factors such as the type of product, availability of dryer,

energy consumption, cost of dehydration and quality of dehydrated product; these results maybe a demonstration of the potentiality of optimizing drying technology to reduce postharvest losses in African eggplants and thus combat the problem of hunger during the drought periods when fresh fruits and vegetables are scarce.

5.2 Recommendations

Farmers and industrialists may apply the drying characteristics and degradation kinetics results from this study in conceptualizing and setting control plans for hot air oven and vacuum oven drying process. Despite being the most costly drying method, freeze drying is the best in retaining phytonutrients in African eggplant. Other studies are needed to establish by how long the shelf life is extended and the microbial stability during storage. Also, there is need to investigate how the sensorial quality of African eggplant accessions can be improved to promote consumer acceptability. The feasibility of developing new products through incorporating dried eggplant powder or pieces in other foods such as baby cereals, porridge flour and bakery products may be considered. This will improve the utilization of African eggplants. A study on the feasibility of inclusion of various accessions into the fresh cut industry should be considered to further improve its utilization. There are up to 72 known accessions of African eggplants whose research information in the areas of nutritional, medicinal and economic benefits is inadequate and or lacking. Research on other accessions is recommended.

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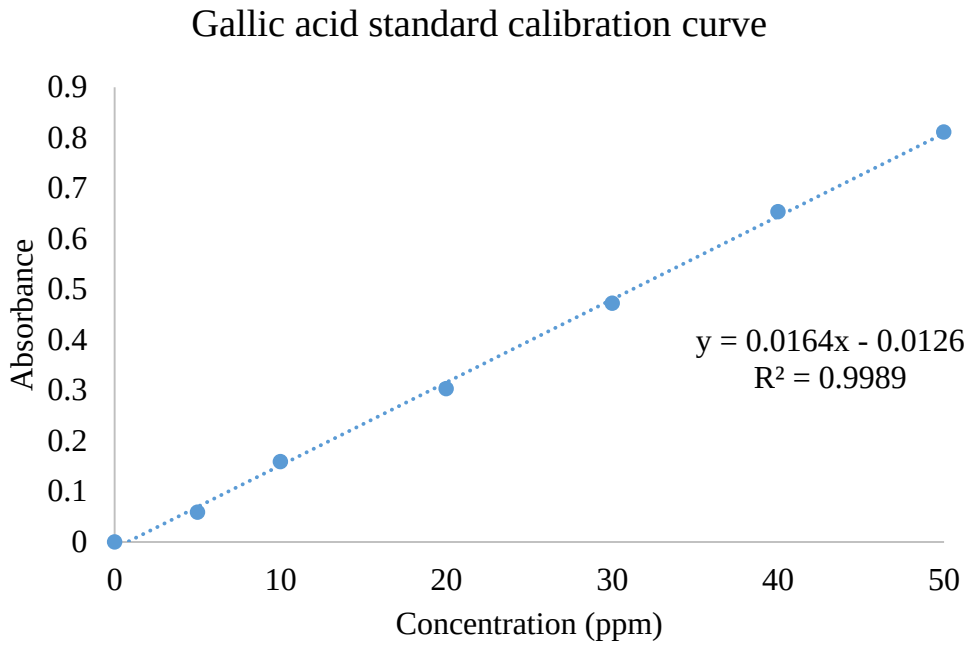
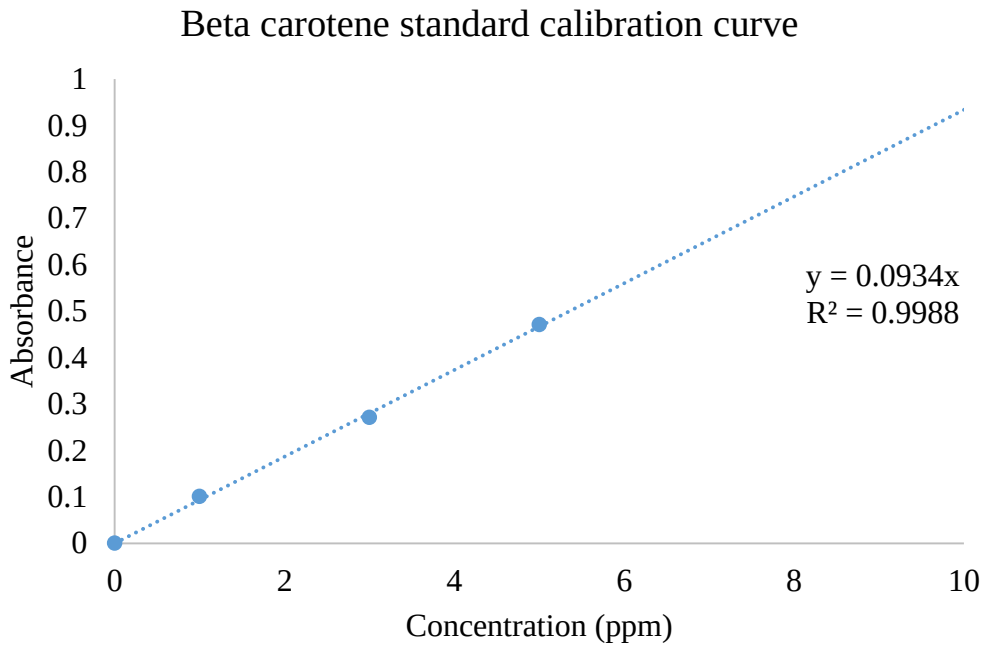
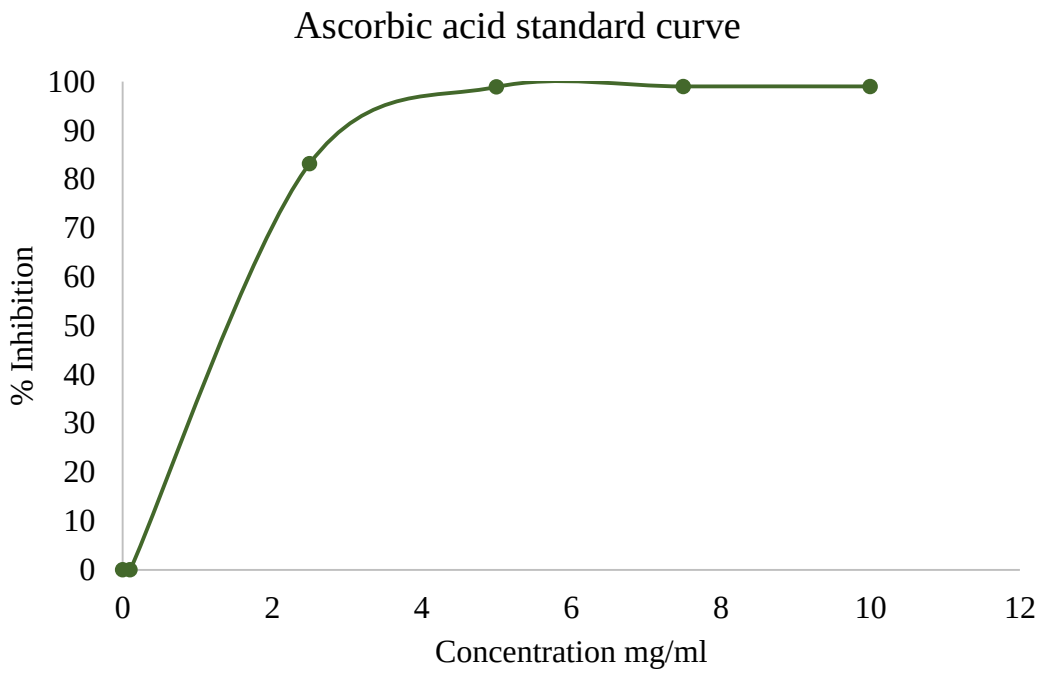
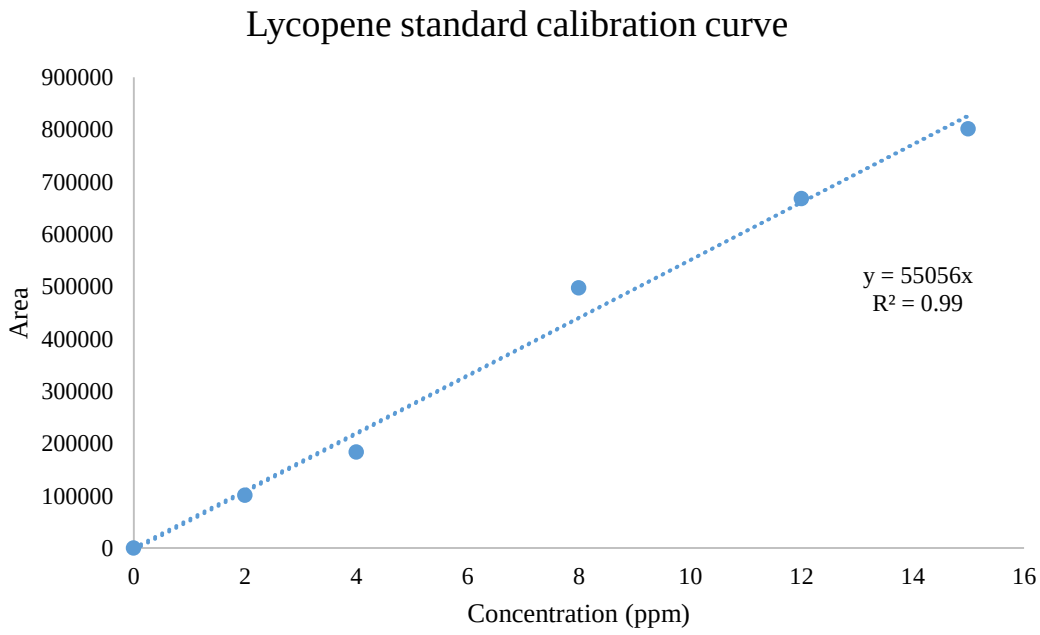
APPENDICES

Appendix I: Standard curves






Ascorbic acid standard curve
% Inhibition
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
Concentration mg/ml


Lycopene standard calibration curve
Area
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
0
2
4
6
8
10
12
14
16
Concentration (ppm)
y = 55056x
R² = 0.99

Appendix II: Consent form and sensory evaluation questionnaires

CONSENT FORM

Sensory evaluation of Dried African eggplants

You are invited to participate in a research study of perception of dried African eggplants. Kindly read this form and ask any questions that you may have before agreeing to be in the study.

This is a voluntary exercise to determine acceptability of dried African eggplants.
The results of your performance as a panelist will be kept strictly confidential.
Kindly fill in your details in the section below

Gender

Male ☐ Female ☐

AGE:

Less or equal to 20; ☐ 21-25; ☐ 26-30; ☐ 31-35; ☐

36-40; ☐ 41 and above; ☐

How often do you consume African eggplants?

Daily; ☐ Weekly; ☐ Fortnightly; ☐ Monthly; ☐ Never; ☐

STATEMENT OF CONSENT

I have read the information about the conditions of this sensory evaluation and all my concerns about the study have been addressed. I hereby give my voluntary consent for participation in this study.

Name: _____ Date: __ __ 2017

Signature: _____

Sensory evaluation questionnaire for dried African eggplant using 7 point hedonic scale

Instruction: You are provided with five coded samples of dried African eggplants. Please assess each in terms of appearance, color, texture and overall score by giving the appropriate score to each sample and attribute in the table below. Use the score card provided.

Description	**Score**
Like extremely	7
Like moderately	6
Like slightly	5
Neither like nor dislike	4
Dislike slightly	3
Dislike moderately	2
Dislike extremely	1

Sample code	Appearance	Colour	Texture	Overall score
720				
138				
430				
996				
269				

Sensory evaluation questionnaire for fresh and reconstituted African eggplant using 7 point hedonic scale

Instruction: You are provided with ten coded samples of African eggplants. Please assess each in terms of appearance, aroma, taste, texture and overall score by giving the appropriate score to each sample and attribute in the table below. Use the score card provided.

Description	**Score**
Like extremely	7
Like moderately	6
Like slightly	5
Neither like nor dislike	4
Dislike slightly	3
Dislike moderately	2
Dislike extremely	1

Sample code	**Appearance**	**Aroma**	**Taste**	**Texture**	**Overall score**
113					
850					
102					
910					
680					
740					
520					
111					
124					
410					