SOLAR DRYING OF FRUITS AND VEGETABLES: DRYERS' THERMAL PERFORMANCE, QUALITY AND SHELF LIFE OF DRIED MANGO, BANANA, PINEAPPLE AND TOMATO

BY

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ABSTRACT

The thermal performance of solar drying methods (cabinet direct, cabinet mixed-mode and tunnel drying), biochemical, sensory, rehydration and shelf-life qualities of mango banana, pineapple and tomato varieties were investigated in this study. Collector efficiencies and drying rates were computed and compared to measure the performance of dryers. The results showed tunnel dryer had significantly ($p<0.05$) higher efficiency (57.5%) with drying rates of 1.36, 1.17, 1.35 and 1.57 kg/h for mango, banana, pineapple and tomato, respectively than cabinet dryers with efficiency of 32.4-34.2% and drying rates of 0.11-0.13, 0.09-0.11, 0.11-0.13 and 0.17-0.22 kg/h for mango, banana, pineapple and tomato, respectively. Biochemical values varied significantly ($p<0.05$) between fresh and dried samples and between drying methods with fresh samples in all fruit and vegetable having higher total phenols (139.3±2.3-538.9±1 mgGAE/100g DM), antioxidant capacity (10.8±0.1-46.8±0.5 µmol/100g DM), protein (2.8±1.3-16.5±1.1 g/100g DM) and vitamin C (28.3-126.8 mg Lasc/100g DM) than dried samples having total phenols, (81.2±0.5-675.5±1.5 mgGAE/100g DM), antioxidant capacity (6.0±0.2-43.0±0.4 µmol/100g DM), proteins (2.1±0.1-13.9±0.1 g/100g DM) and vitamin C (3.8-65.1 mg Lasc/100g DM). The sensory analysis findings showed that, all fresh samples had significantly higher colour intensity scores of 8.1 than dried counterparts, 6.3-7.8 points, which on the other hand had highest flavour scores. Fresh mango, banana and dried tomato were the most liked by consumers with colour and flavour attributes

being the main drivers for likeness. However, despite the loss, substantial amount of biochemical and sensory parameters were retained in concentrated dry forms except vitamin C. The shelf-life of six and above six months observed for dried vegetable and fruits respectively. Therefore, it can be concluded that tunnel dryer performs better than cabinet dryers. Solar drying has varied significant effects on some quality parameters of dried fruits and vegetables but retains substantial amounts and it has potential to extend shelf life of fruits and vegetables. Therefore, needs for solar drying technology advocacy in the country for reducing the alarming postharvest losses, more research and fabrication of affordable local tunnel dryer comparable to the industrial ones and further studies to ascertain shelf life above 6 months including more parameters are highly recommended.

DECLARATION

I, **RICHARD JOHN MONGI** do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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I dedicate this work to my beloved children Alex, Richard Junior Mongi and Mary Mongi so that they become greater scholars who will not only be able to understand different aspects of the world but also to change them in appropriate and positive ways. May Almighty God bless them all, Amen.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CDD	Cabinet Direct Dryer
CHO	Carbohydrate
CMD	Cabinet Mixed mode Dryer
CRD	Completely Randomized Design
CRBD	Complete Randomized Block Design
Cv	Cultivar
DM	Dry Matter
FAO	Food and Agriculture Organization of United Nation
FRAP	Ferric Reducing Antioxidant Power
FST	Food Science and Technology
FW	Fresh Weight
GTZ	Gesellschaft für Technische Zusammenarbeit
HDPE	High Density Polyethylene
HLSD	Honest Least Significant Difference
HPLC	High Performance Liquid Chromatography
IARC	International Agency for Research on Cancer
ISO	International Standard Organization
LDPE	Low Density Polyethylene
LSD-	Least Significant Difference
MAFC	Ministry of Agriculture, Food and Cooperatives
PCA	Principal Component Analysis
PCA	Plate Count Agar

PLSR	Partial Least Square Regression (PLSR)
SD	Standard Deviation
SPD	Split Plot Design
SEM	Standard Error of the Mean
SUA	Sokoine University of Agriculture
TaTEDO	Tanzania Traditional Energy Development Organization
TBS	Tanzania Bureau of Standards
TFNC	Tanzania Food and Nutrition Centre
TPC	Total Phenolic Compound
UMB	Universitet for Miljo and Bioventeskap
UNCTAD	United Nations Conference on Trade and Development
UNIDO	United Nations Industrial Organization
URT	United Republic of Tanzania
VRBA	Violet Red Bile Agar
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1. Background Information

Fruits and vegetables are both major food products in their own right and key ingredients in many processed foods (Jongen, 2007). They are of greater nutritional importance since they make a significant contribution in supplying wealth of essential vitamins, minerals, antioxidants, fibre and carbohydrate that improve the quality of the diet (Barrett, 2007). Fruits and vegetables are also important components of a healthy diet and their sufficient daily consumption has been strongly associated with reduced risk of some major diseases such as cardiovascular, diabetes, hypertension, and certain types of cancer (Bazzano *et al.*, 2002). According to FAO/WHO (2003), up to 2.7 million lives could potentially be saved each year with sufficient intake of fruits and vegetables.

However, despite their nutritional and health benefits, many fruits and vegetables are highly seasonal and perishable resulting into huge postharvest losses (Idah and Aderibigbe, 2007). According to Karim and Hawlader (2005), the post-harvest loss in fruits and vegetables is estimated to be 30-40% in developing countries. Some of the major contributing factors are poverty, inadequate postharvest handlings, lack of appropriate processing technology and storage facilities, poor infrastructure as well as poor marketing systems (Perumal, 2007). Reduction of the losses and improvement of the quality can only be

achieved by the introduction of suitable preservation technologies such as canning, freezing, and drying (Rolle, 2005).

Drying of fruits and vegetables is one of the oldest procedures for food preservation known to man (Sobukola *et al.*, 2007). It is a process that involves removal of biologically active water to a safe level that reduces deteriorative chemical reactions, provides microbiological stability and extends the shelf life of dried products (Perumal, 2007). Furthermore, it substantially reduces weight and volume; minimizes packaging, storage and transportation costs (Sagar and Suresh, 2010). Among all the drying methods, sun drying is a well-known method for drying agricultural commodities immediately after harvest, especially in developing countries. However, sun drying is plagued with in-built problems, since the product during drying is unprotected from rain, storm, windborne dirt, dust and infestation by insects, rodents, and other animals (Folaranmi, 2008). Consequently, the quality of dried products may be adversely affected, failing to meet the required local and international standards (Ivanova and Andonov, 2001). On the other hand, mechanical drying such as freeze, drum and cylone drying, which could otherwise be used is costly and hazardous to environment; hence more importance is given nowadays to use solar energy as an alternative in drying agricultural produces (Eltief *et al.,* 2007).

Solar drying technology seems to be one of the most promising alternatives to reduce the post-harvest losses (Wiriya *et al.*, 2009). The

solar dried products have much better colour and texture as compared to open sun dried products (Mulokozi and Svanberg, 2003). The attractiveness of solar dryers is further enhanced by its ability to dry the product rapidly, uniformly and hygienically to meet national and international standards with zero energy costs (Condori *et al.,* 2001). However, it has been noted that, drying at higher temperatures may cause damage to the flavour, colour and nutrients of the dehydrated products (Praveenkumar *et al.,* 2006). Despite adequate literature review, information on the nutritional, sensory and shelf life qualities of solar dried fruits and vegetables in Tanzania is limited.

This study therefore, assessed the solar dryer's performance, nutritional and sensory quality retention as well as shelf life of selected solar dried fruits and vegetable (banana, pineapple, mango and tomatoes) in Tanzania in order to establish their quality, processing and optimum storage conditions.

1.2 Problem Statement and Justification

Tanzania is richly endowed with a large variety of fruits and vegetables. However, postharvest losses are enormous (30-40%) resulting into nutritional and economic losses (Kimambo, 2007). The food processing industry in the country has not grown enough and only less than 10 % of the produced fruits and vegetables are being processed, resulting into large waste every year (MAFC, 2009). Various studies have shown that, solar drying is a simple inexpensive form of food processing that

has greater potential to reduce the post-harvest losses and ensure the availability of perishable products like fruits and vegetables all year round (Habou *et al.*, 2003; Mujumdar, 2004). Solar drying, however, exposes fruits and vegetables to solar radiation, which, in the presence of oxygen might result into loss of nutrients such as vitamins A and C (Kabasa *et al.*, 2004) as well as changes in sensory quality that might not be desirable (Barret, 2007). Despite several actors being involved in training, processing and marketing of solar dried fruit and vegetables in the country, the information on the performance of different dryers at different weather conditions, nutrient retention, sensory quality, shelf life qualities and local standards of these products is limited, which makes dried fruits and vegetables in Tanzania to be of varied qualities (Ringo, 2008). Consequently, product development and market opportunities of dried fruits and vegetable sub-sector in the country are adversely affected.

Considering the importance of fruits and vegetables in human health, food industry and national economy against the stated high post-harvest losses; it indicates a need for appropriate technology of fruit and vegetable processing and preservation to reduce the losses quantitatively and qualitatively (Kabasa *et al.,* 2004). The technology that will retain nutrients, improve quality and safety is critical in gaining access to markets as well as prolong the shelf-life of the fresh and processed fruits and vegetables (Temu *et al.,* 2008). It is therefore, important to carry out this study to evaluate the performance of solar

dryers at different weather conditions and document how nutritional and sensory qualities of the dried products relate to these parameters. Also, it is important to determine shelf life of solar dried products. The information and knowledge that will be generated from the study will serve as a guide for the establishment of quality and standards, optimum processing and storage conditions of dried fruits and vegetables that can penetrate both local and international markets. This can also serve as a guide for the development of appropriate but affordable technologies for processing value added fruits and vegetables products so as to enhance food security. In addition, it will provide a basis for establishment of an enterprise within the food processing industry for solar drying of fruits and vegetables and thus lay the foundation for youths and women to engage in small-scale processing enterprises for employment creation.

1.3 Objectives

1.3.1 Overall objective

The overall objective of the research was to determine thermal performance of solar dryers, quality and shelf life of dried fruits and vegetables in order to establish quality, processing and storage conditions which will support establishment of a viable enterprise in drying fruits and vegetables using solar dryers in Tanzania.

1.3.2 Specific objectives

The specific objectives were

i. To determine the performance (drying parameters, collector efficiency and drying rates) of cabinet direct, cabinet mixed-mode and tunnel dryers during dry and wet seasons.
ii. To determine biochemical, sensory, and rehydration qualities of solar dried fruits (mango, banana, pineapple) and vegetable (tomato) products.
iii. To determine shelf life of the solar dried products in different packaging materials and at storage times.

CHAPTER TWO

2.0 LITERATURE REVIEW

2. 1 Introduction to Fruits and Vegetables

Fruits are defined in several ways. Botanically, fruits are the mature ovaries of the plant with their seeds. Therefore, this definition included all grains, legume, nuts and seeds, and common vegetables-fruits such as cucumbers, olives, peppers, and tomatoes. When defined and considered in culinary role fruit refers to the flesh edible part of a plant, tree, bushy or vine that, usually eaten alone or served as a dessert and has sweet or tart taste. Fruits are high in organic acids and sugar, higher than vegetables (Vaclavik and Christian, 2008). They are used as breakfast beverage or side-dish (e.g., orange juice, berries, grape fruit, and melon), lunch side-dish or dessert, snack food between meals or dinner dessert. Raw and canned fruits are also used as appetizers, salads ingredients and side-dishes (IARC, 2003).

Vegetables are the edible usually succulent part(s) of plant or portion of it consumed raw or cooked, generally with a main dish, in a mixed dish, as appetizer or in a salad (Vaclavik and Christian, 2008). Vegetables include edible stems and stalks, roots, tubers, bulb, leaves, flowers, some fruits, pulses (mature beans and peas), fungi (mushrooms, tuffles), algae (sea-weeds) and sweet corn and horminy (cereal grains used as vegetables) (IARC, 2003). Since any definition of vegetable generally centers on its use, a plant may be a vegetable in one country but a fruit, weed, an ornamental or medicinal plant in another country,

depending on the crop. For example, tomato is a vegetable in Asia but a fruit in Europe (AVRDC, 1990). Vegetables may be processed into beverages or vegetable starches, eaten fresh or lightly processed, dried, pickled, or frozen. They impart their own characteristics flavour, colour, and texture to the diets and undergo changes during storage and cooking (Vaclavik and Christian, 2008).

Tanzania's climatic growing conditions can accommodate the production of a wide range of fruits and vegetables (Ngereza *et al.,* 2007). The most important fruits include pineapples, passion fruits, citrus fruits, mangoes, peaches, pears and bananas. Vegetables include tomatoes, spinach cabbages and okra (MAFC, 2009). This study however, concentrated on three selected fruits banana, mango and pineapple and one vegetable, tomato. Their detailed description has been discussed in the following sub sections.

2.1.1 Banana (*Musa acuminata and Musa balbisiana*)

Banana (*Musa sapientum L.*) is one of the important tropical fruit in the world. It belongs to genus *Musa* which include various species, the most important among which are *Musa acuminata* (A) and *Musa balbisiana* (B). Banana and plantains are the fourth most important food in the world today after rice, wheat, and maize (Nelson *et al.,* 2006). Bananas originated from the Indo-Malaysian region of south East Asia. They are now grown all over the tropical and subtropical continents of the world (Moser *et al*, 2008). China is the largest producer of the banana in the world with Tanzania ranked seventh and

second after Uganda in the world and Africa respectively (Maerere *et al.*, 2010). In Tanzania, bananas are grown in highlands of Kagera, Kilimanjaro, Mbeya, Arusha, Manyara, Tanga, Morogoro, and Pwani (MAFC, 2009). The total area under cultivation of this fruit is 31.9 thousands hectares with annual average production of 2.2 million metric tons per year (URT, 2006*).* They are grown at elevations of 1 800 m or more depending on latitude; mean annual temperatures of 26 - 30°C; annual rainfall of 2 000 mm (80 in) or higher and soil pH between 5-8 (Nelson *et al.,* 2006). Bananas are classified based on their usage as either dessert or green cooking bananas. The former are sweet and used raw when ripe and the major varieties in Tanzania are *Kisukari, Kimalindi, Mzungu* and *Mtwike* whereas the latter are unpalatable banana for eating raw thus roasted or cooked still green or after ripening. These include *Mzuzu*, *Mshare, Matoke, Bokoboko, Ndyali*, and *Mkono wa Tembo* (Maerere *et al.*, 2010; MAFC, 2009).

The ripe banana contains many of the necessary elements that are essential for a balanced diet. It contains fibre and sugars, Vitamins, A, B complex and C and minerals such as potassium, phosphorus, calcium, sodium and magnesium (Lukmanji *et al.*, 2008). Moreover, a ripe banana easily digests and it imparts quick energy. However, they are having low sodium and no fat and vitamin A (Anhwange, 2008). Banana can also be used as medicinal fruit. It is useful for the patients with blood pressure, constipation, peptic ulcers, for treatment of infant

diarrhoea, celiac disease and colitis (Kumar *et al.*, 2012). Its general composition on fresh weight basis per 100g is summarized in Table 1.

Table : Chemical composition of raw banana (content per 100 g)

Proximate		Vitamins		Minerals		Energy	
Nutrient	**Proportion (g)**	**Nutrient**	**Quantity (mg)**	**Nutrient**	**Quantity (mg)**	**Kcal**	**J**
Water	70	Thiamine	0.0	Calcium	5	89.0	372.4
Protein	1.1	Riboflavin	0.1	Iron	0.3		
Fat	0.3	Niacin	0.7	Magnesium	27		
Carbohydrate	22.8	Pant. Acid	0.3	Phosphorous	22		
Dietary Fibre	2.6	Vitamin B6	0.4	Potassium	358		
Ash	3.2	Vitamin C	8.7	Zinc	0.2		
Ash		Vitamin A	3.0 µgRE				

Source: Lukmanji *et al.* (2008).

Bananas are among the most widely consumed foods in the world where it constitute a major staple food crop for millions of people in developing countries (Alkarkhi *et al.*, 2010). They are chiefly eaten raw as a dessert fruit, because in the ripe stage it is sweet and easily digestible (Robinson, 1996). They are also used as beverages, fermentable sugars and in human diet where they are often being sliced lengthwise, baked or boiled or cooked and served (FAO, 2004). Additionally, Bananas may also be dried and eaten as a type of chip or grounded into flour or powder by sun-drying slices of unripe or ripe fruits and pulverizing (Hassanain, 2009).

2.1.2 Mango (*Mangifera indica*)

Mango (*Mangifera indica)* belongs to the genus *Mangifera* of the family *Anacardiaceae* (Bally, 2006). It is popular due to its excellent flavour, delicious taste and high nutritive value (Shahnawz *et al*., 2012). The mango originated in Southeast Asia where it has been grown for over 4,000 years. It is now an important fruit of the tropical and sub-tropical part of the world like India, Pakistan, South China and Malaya (Hussain *et al.*, 2002). There are over 1,000 different varieties of mangos throughout the world (Bally, 2006). In Tanzania, mangoes are grown in all regions. The total area under cultivation of this fruit is 99176 hectares with annual average production of 342.5 thousands metric tons per year *(*URT, 2006). The mango tree will fruit 4 to 6 years after planting and require hot, dry periods to set and produce a good crop (Brown, 2013). The major varieties grown in Tanzania are *Boribo Muyini*, *Dodo*, *Mawazo*, *Sindano* (MAFC, 2009). Other varieties are *Tommy Artikins*, *Alphonso and Kent.*

Mango is a good source of dietary fibre, vitamin C, and provitamin A carotenoids (Ajila *et al.*, 2010). The general composition of ripe mango on fresh weight basis per 100g is summarized in Table 2. The mango fruit can be eaten as ripe or processed into a range of products such as achars, chutneys, jams, pulps, juices, and canned, frozen or dried products. The unripe green fruit is also eaten, processed into pickles, pulps, jams, and chutneys (Bally, 2006).

Table : Chemical composition of raw mango (content per 100 g).

Proximate		Vitamins		Minerals		Energy	
Nutrient	**Proportion (g)**	**Nutrient**	**Quantity (mg)**	**Nutrient**	**Quantity (mg)**	**Kcal**	**J**
Water		β-carotene	445µg	Calcium	10.0	65.0	272.4
Protein	0.5	Thiamine	0.1	Iron	0.1		
Fat	0.3	Riboflavin	0.1	Magnesium	9.0		
Carbohydrate	17	Niacin	0.6	Phosphorous	11.0		
Dietary Fibre	1.8	Pant. acid	0.2	Potassium	156.0		
Ash	1.4	Vitamin B6	0.1	Zinc	0.0		
		Vitamin C	27.7				

Source: Lukmanji *et al*. (2008).

2.1.3 Pineapple (Ananas comosus)

Pineapple (*Ananas comosuss)* belongs to the family *Bromeliaceae*. It is grown mainly for fresh and canned fruit and juice and is the only source of bromelin, an enzyme used in pharmaceuticals and as meat-tenderizing agent. Pineapple originated in South America and is now grown in various parts of the world, including Tanzania. In terms of commercial production, pineapple is the third most important tropical fruit after banana and mango (Botella *et al*., 2005). In Tanzania, pineapples are mainly grown Pwani, Kigoma, Mwanza, Morogoro, Tanga and Dar-es-Salaam regions. By 2006, the the total area under cultivation of this fruit is 12870 hectares with annual average production of 214, 840 metric tonnes per year *(*URT, 2006), which is

17.9% of all fruits produced. Pineapple is a good source of vitamin C and vitamin B (Lukmanji *et al.,* 2008). The general composition of ripe pineapple on fresh weight basis per 100 g is summarized in Table 3.

Pineapples are eaten fresh or processed into dried fruits, juice and as canned fruits. They are used in desserts, salads, as a complement to meat dishes and in fruit cocktail (FAO, 2011). Pineapple has benefits for some intestinal disorders, serves as a pain reliever (Ketteler, 2009*).* Others claim that, pineapples to induce childbirth when a baby is overdue (Adaikan and Adebowale, 2004*).*

Table : Chemical composition of raw pineapple (content per 100 g)

Proximate		**Vitamins**		**Minerals**		**Energy**	
Nutrient	**Proportion (g)**	**Nutrient**	**Quantity (mg)**	**Nutrient**	**Quantity (mg)**	**Kcal**	**J**
Water	81.7	Thiamine	0.1	Calcium	7.1	48.0	200.8
Protein	0.5	Riboflavin	0.0	Iron	0.4		
Fat	0.1	Niacin	0.5	Magnesium	14.0		
Carbohydrate	12.6	Pant. acid	0.2	Phosphorous	7.0		
Dietary Fibre	1.4	Vitamin B6	0.1	Potassium	113.0		
Ash	3.7	Vitamin C	36.2	Zinc	0.1		

Source: Lukmanji *et al*. (2008).

2.1.4 Tomato (*Lycopersicum esculentum*)

Tomato is herbaceous, usually sprawling plant in the *Solanaceae* family. It originated in the highlands of the west coast of South America and is now grown worldwide including Tanzania (Smith, 1994). It is a commercially important crop both for fresh fruit market and for the food processing industries. The annual worldwide production of tomatoes has been estimated at 125 million tonnes in an area of about 4.2 million hectares. The global production of tomatoes (fresh and processed) has been increased by 300% in the last four decades (FAO, 2005) and the leading tomato producers are in both tropical and temperate regions. Tomato is one of the most cultivated vegetables in Tanzania where is mostly grown in Kilimanjaro (Hai, Rombo and Moshi), Mbeya, (Mbeya Rural), Iringa, Morogoro (Mgeta), Arusha (Arumeru), Tanga (Lushoto), Dar-es-Salaam and Dodoma (Nyambo, 2009; MAFC, 2009).

In 2006, the total area under cultivation of this vegetable is 31913 hectares with annual average production of 12.9 thousands metric tons per year (URT, 2006). There are two types of tomatoes grown in Tanzania. These are the tall or intermediate varieties (Nyambo, 2009). Regardless of the types, the most common varieties grown in Tanzania are Cal J, Moneymaker, Tanya and Roma VF, Marglobe, Onyx, Tengeru 97, Mshumaa, Rumeco, Israe, Kituruma-local and VF 311 (Shenge *et al.*, 2010; Mbega *et al.*, 2012).

Tomatoes are one of the important vegetables/fruits in our diet, since they are rich in health valued food components such as carotenoids (lycopene), ascorbic acid (vitamin C), vitamin E, folate and dietary fibre (Preedy and Watson, 2008). The general composition of ripe tomato on fresh weight basis per 100g is summarized in Table 4.

Tomato is a versatile commodity that can be eaten fresh or processed to use in a wide array of products to improve these flavour (Permul, 2007). Various foods prepared from tomatoes are: i) tomato preserves such as whole peeled tomatoes, tomato paste, tomato juice, tomato pulp, tomato puree and pickled tomatoes, ii) dried tomatoes such as tomato flakes and tomato powder and iii) tomato based foods such as tomato soup, tomato sauce and ketchup (Takeoka *et al.,* 2001).

Table : Chemical composition of raw tomato (content per 100g)

Proximate		Vitamins		Minerals		Energy	
Nutrient	**Proportion (g)**	**Nutrient**	**Quantity (mg)**	**Nutrient**	**Quantity (mg)**	**Kcal**	**J**
Water	93	Vitamin A	87.0 µgRE	Calcium	5	21.0	87.9
Protein	0.9	Thiamine	0.1	Iron	0.5		
Fat	0.3	Riboflavin	0.1	Magnesium	11.0		
Carbohydrate	4.6	Niacin	0.6	Phosphorous	24.0		
Dietary Fibre	1.1	Pant. acid	0.3	Potassium	222.0		
Ash	0.1	Vitamin C	19.0				

Source: Lukmanji *et al*. (2008).

2.2 Food Drying Technology

Drying has always been of great importance for conserving agricultural products in agricultural countries like Tanzania. The major objective of drying food products is the reduction of moisture content to a safe level at which microbial spoilage and deteriorative reactions are greatly minimized (Akpinar and Bicer, 2004) which allows increasing the shelf life of dried products (Gürlek *et al.,* 2009). Principally, due to minimal water activity in the dried foods, microorganisms cannot proliferate and most of the chemical reactions, which alter plant's chemistry, are stopped (Khattab and Barakat, 2002). Improvement of product quality and reduction of post-harvest losses can only be achieved by the introduction of suitable drying technologies (Bala and Janjai, 2009).

Modern industrial technologies such as freeze drying, drum drying, cyclone drying have been developed which dry foods in a number of different ways. However, most of them are expensive and not appropriate for a developing country like Tanzania, particularly in the areas where prerequisites for these, such as electricity are simply not adequate. A more amenable and feasible alternative becomes necessary, which can be practical and simple to operate, cheap, and accessible to the local individual and small and medium enterprise in developing countries. The introduction of solar drying system is considered to be a promising alternative option in reducing post-harvest losses and could be significant contribution to maintaining a continuous food supply in developing countries (Basunai and Abe, 2001).

2.2.1 Solar energy and drying

There are two methods of drying using solar energy: Sun drying and solar drying

2.2.1.1 Open sun drying

Sun drying is the traditional method of drying in developing countries and it denotes the spreading of foodstuff in the sun on a suitable surface such as mat, roof, or drying floors (Plate 1). Although it is the cheapest method, the dry products are of poor quality due the vulnerability to contamination by insects, birds and dust. Moreover, the direct exposure to sunlight, or more precisely ultra-violet radiation, can greatly reduce the level of nutrients such as vitamins in the dried

product (Tunde-Akitunde, 2011). The resulting loss of food quality in the dried products may have negative effect on trade potential and economical worth of the product (Gürlek *et al.,* 2009).

Plate : Open sun drying (Photo courtesy: Mongi, R. J).

2.2.1.2 Solar drying

(i) Overview

Solar drying technology is one of the renewable energy resources particularly for low temperature heating and is a very attractive option for the small scale and resource poor enterprise. Studies undertaken so far have clearly indicated that while the initial cost of solar dryers are high, the life time cost of drying is only a third of dryers based on conventional fuels (Chavda and Kumar, 2009). Using a solar dryer, the drying time can be shortened by about 65% compared to sun drying because, inside the dryer, it is warmer than outside; the quality of the

dried products can be improved in terms of hygiene, cleanliness, safe moisture content, colour and taste; the product is also completely protected from rain, dust, insects; and the payback period for such dryers ranges from 2 to 4 years depending on the rate of utilization (Sacilik *et al.*, 2006).

The attractiveness of solar drying is further enhanced by its low capital and drying energy cost (Tunde-Akintunde, 2011). Many tropical countries receive on average 325 days per year of bright sun light (Yansane, 2007). In Tanzania, solar energy resource is abundantly available almost throughout the year (GTZ, 2007). Being in a “solar belt”, Tanzania receives between 2800-3500 hours of sunshine per year and has a global solar radiation between 4-7 kWh/m^2/day. The average solar flux based on 24 hours can be as high as 300W/m^2 or more (Kimambo, 2007). With such a high level of solar energy resource, Tanzania is naturally suitable for application of solar energy as viable alternative sources of modern energy supply like mechanical dryer for drying agricultural produce especially in rural area (GTZ, 2007).

Solar drying technology produces better quality products and is considered to be an alternative for drying agricultural products in developing countries (Gürlek *et al.,* 2009). It is often differentiated from ‘‘sun drying’’ by having and using designed structure to collect and enhance the solar radiation in order to harness the radioactive energy for drying applications. The advantages of solar dryers over sun drying include; generation of higher air temperatures and consequently lower

relative humidities, which are, both conducive to improved drying rates and lower final moisture content of the drying crops, energy and labour saving and environmental protection. Other advantages are less spoilage and less microbiological infestation, thus leads to improved and more consistent product quality (Tunde-Akitunde, 2011). However, dependency on weather for drying operation is one of the setbacks in solar drying technology. Considerable efforts have been made to design and use hybrid dryers which can perform better under adverse weather conditions.

(ii) Solar dryers

(a) Essential components

A solar dryer is an enclosed unit, to keep the food safe from damage, birds, insects, dust and unexpected rainfall. The food is dried using solar thermal energy in a cleaner and healthier way (TaTEDO, 2007). A solar dryer has three main components: a drying chamber, solar collector and some type of airflow system. A drying chamber is an enclosed, insulated structure inside which both solar collection and drying takes place. It protects the food from animals, insects, dust, and rain. It is often insulated to increase efficiency (Chavda and Kumar, 2009). Trays carrying produce to be dried are placed inside the chamber and they should be safe for food contact; a plastic coating is best to avoid harmful residues in food (Harrison and Andreas, 2000).

The solar collector (or absorber) is often a dark coloured box with a transparent cover. It raises the air temperature between 10 and 30°C above ambient. Depending on the construction, both collector and drying chamber may be combined or (as with direct dryers). Often the bottom surface of the absorber is painted black to promote solar absorption (Berinyuy *et al.*, 2012). Glass is recommended for the absorber cover, although it is expensive and difficult to use. Plastic is acceptable if it is firm or supported by a rib such that it does not sag and collect water (Vanderhulst *et al.*, 1990). The solar collector can be of any size and should be tilted toward the sun to optimize collection. The size of solar collector required for a certain size of dryer depends on the ambient temperature, amount of sun, and humidity (Green and Shwartz, 2001). By increasing the collector size, more heat energy can be added to the air to improve overall efficiency. Larger collector areas are helpful in places with little solar energy, cool or cold climates, and humid regions. The size of solar collector required for a certain size of dryer depends on the ambient temperature, amount of sun, and humidity (Chavda and Kumar, 2009). Tilting the collectors is more effective than placing them horizontally, for two reasons. First, more solar energy can be collected when the collector surface is more nearly perpendicular to the sun's rays. Second, by tilting the collectors, the warmer, less dense air rises naturally into the drying chamber.

Work has been done to study the optimum angle for capturing sun’s energy. According to FAO (2008), the angle should be greater than 15

to allow rain water to run off and the collector should be angled at 90° to the mid-day sun facing south in the Northern hemisphere and north in the Southern. Also, the dryer should be sited away from shadows from trees or buildings. A 90 degree angle is the highest angle of incidence and represents the angle at which the most energy can be captured from the sun (Stadler, 2011). The sun penetrates equator at a 90 degree angle on average topographically, and it passes twice a year, making it an area that receives the most amount of light energy from the sun (Stadler, 2011).

Solar dryers use one of two types of airflow systems; natural and forced convection. The convection utilizes the natural principle that hot air rises, and forced convection dryers force air through the drying chamber with fans (Vargas *et al.,* 1996). The effects of natural convection may be enhanced by the addition of a chimney in which exiting air is heated even more. Additionally, prevailing winds may be taken advantage of (Green and Shwartz, 2001).

(b) Classification of solar dryers

Solar dryers may be classified into several categories, depending upon the mode of heating or the mode of their operation and airflow systems. Based on how heat is provided for drying, dryers can be broadly divided into four categories; direct, indirect, mixed and hybrid types (Fudholi *et al.*, 2010; El-Sebaii and Shalaby, 2012).

Direct type

In this dryer, solar radiation is directly incident on the material to be dried. The material to be dried is placed in an enclosure, with a transparent cover of glass or plastic on it (Plate 2A). The sun heat acts on the material and enclosure causes a heat build-up due to the “greenhouse effect. Thus the temperature above the product inside chamber becomes higher. The glass or plastic covers server one more purpose of reducing direct convective losses to the ambient, which further becomes beneficial for rise in product and chamber temperature, respectively (Sharma *et al.*, 2009). The collector and dryer chamber are usually painted black to absorb the maximum amount of heat. However, convective and evaporative losses occur inside the chamber from the heated material. Direct solar dryers are cheap to make and easy to use. However, it does not allow temperature control. It is hard to protect the product that is drying from external factors. Furthermore, many fruits and vegetables may change colour and many vitamins are lost if they are exposed to sunlight for too long (Al-Juamily *et al.,* 2007).

Plate : Dryer types: Direct (A), Indirect (B), Mixed (C) and part of hybrid dryer (D) (Photo courtesy: Mongi, R. J).

Indirect type

In indirect solar dryers, solar radiation is not directly incident on the material to be dried. Air is heated in a solar collector and then ducted to the drying chamber to dry the product (El-Sebaii and Shalaby 2012) (Plate 2B). As the hot dry air stream, passes through this unit removes moisture of the product. It is possible to control the temperature with this kind of dryer thus better quality of the product is obtained than in direct dryer. Moreover, since the product is not exposed to ultraviolet radiation, then the colour and texture remain unchanged (Al-Juamily *et al.,* 2007). The solar radiations produce heat within the bulk of the product upon penetration through its porous skin and change the colour and texture (Sreekumar *et al.*, 2008). However, indirect dryers are more expensive to make and harder to use.

Mixed type

In these dryers, the combined action of solar radiation incident on the material to be dried and the air preheated in a separate solar collector provide the heat required for the drying operation (Plate 2C). The product is dried simultaneously by both radiation with downward conduction of heat and the convection of a heat from the solar air heater (El-Sebaii and Shalaby, 2012).

Hybrid type

In this type (Plate 2D), other sources of heat energy such as fan powered by solar PV are used to supplement solar heat and allow for faster rate of drying (Sharma *et al.*, 2009). The combination of solar

energy with other technologies increases the system efficiency and provides the advantage of continuous drying even during nights or in cloudy days (Thanaraj *et al.*, 2004; Ferreira *et al.*, 2008). Even though an extra cost is involved with extra technology, hybrid dryers provide benefits of reducing drying time, labour cost and improving the final quality (Ferreira *et al.*, 2008).

Plate : Tunnel dryer (Photo courtesy: Mongi, R. J).

Based on the airflow systems, dryers can be further classified into two basic categories namely: natural convection (passive) and forced convection (active) dryers (Zomorodian *et al.,* 2007). The natural operation principle is based on the temperature difference and consequently the difference in the density of the air inside and outside the drying chamber. This difference provides driving force (buoyant force) for the air to flow through the drying bed. Passive drying system does not require any mechanical or electrical power to run a fan. In

general, the construction is simple, easy to maintain and inexpensive but working mechanism is strongly dependent on the temperature difference and pressure drop across the product bed (Miramare, 1997).

In order to have continuous and reliable ventilation, forced convection solar dryer have been introduced. This drying system requires a blower to force air through or over the product and in contrast to natural convection, dryers requires a careful use; stacking the product too high or a lack of sun can cause air to stagnate in the dryer and halt the drying process (Vanderhulst *et al.*, 1990). Furthermore, in contrast to natural convection dryers, forced convectional dryer are more expensive construct and are dependent on electrical or other source of energy which increase the cost of construction (Zomorodian *et al.,* 2007). Nevertheless, the energy costs have to be compensated with reduction in drying time, higher drying capacity, reduction of mass losses and better quality of the product (Ratti and Mujumdar, 1997). According to Green and Schwartz (2001), the use of forced convection can reduce drying time by three times and decrease the required collector area by 50%. The summarized classification of solar dryers and drying modes are indicated in Fig. 1:

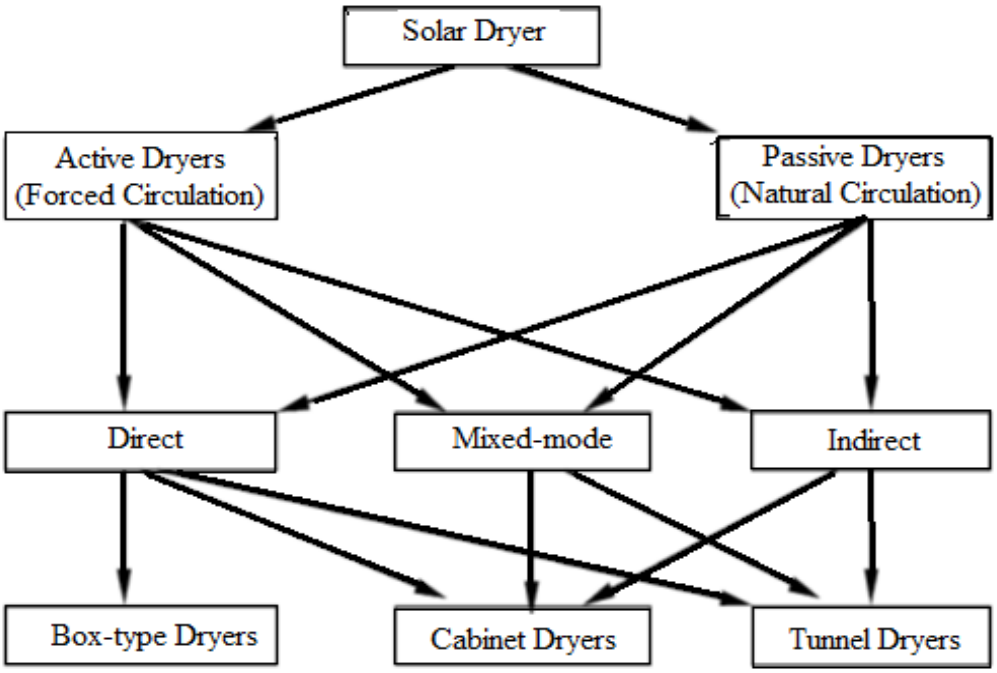


Figure : Classification of solar dryers and drying modes (Source: Leon *et al.*, 2002).

(C) Principles of the dryers

Direct solar drying

Drying (Fig. 2) involves simultaneous heat transfer to the product from the heating source and mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air heat. Incidence solar radiation acts on the glass/plastic cover, and a part of it is reflected back to atmosphere and the remaining is transmitted inside cabin dryer. Part of transmitted radiation is reflected back from the surface of the foodstuff and the remaining part is absorbed by the surface of the crop. Owing to the absorption of solar radiation, the foodstuff temperature increases and starts emitting long wavelength radiation that is not allowed to escape to atmosphere due

to presence of glass/plastic cover, unlike open sun drying. Thus, the temperature above the foodstuff inside the drying chamber becomes higher. The glass/plastic cover serves one more purpose of reducing direct convective losses to the ambient, which further becomes beneficial by a rising foodstuff and chamber temperature respectively. However, convective and evaporative losses occur inside the chamber from the heated foodstuff. The moisture is taken away by the air entering into the chamber from below and escaping through another opening provided at the top (Sharma *et al.*, 2009).

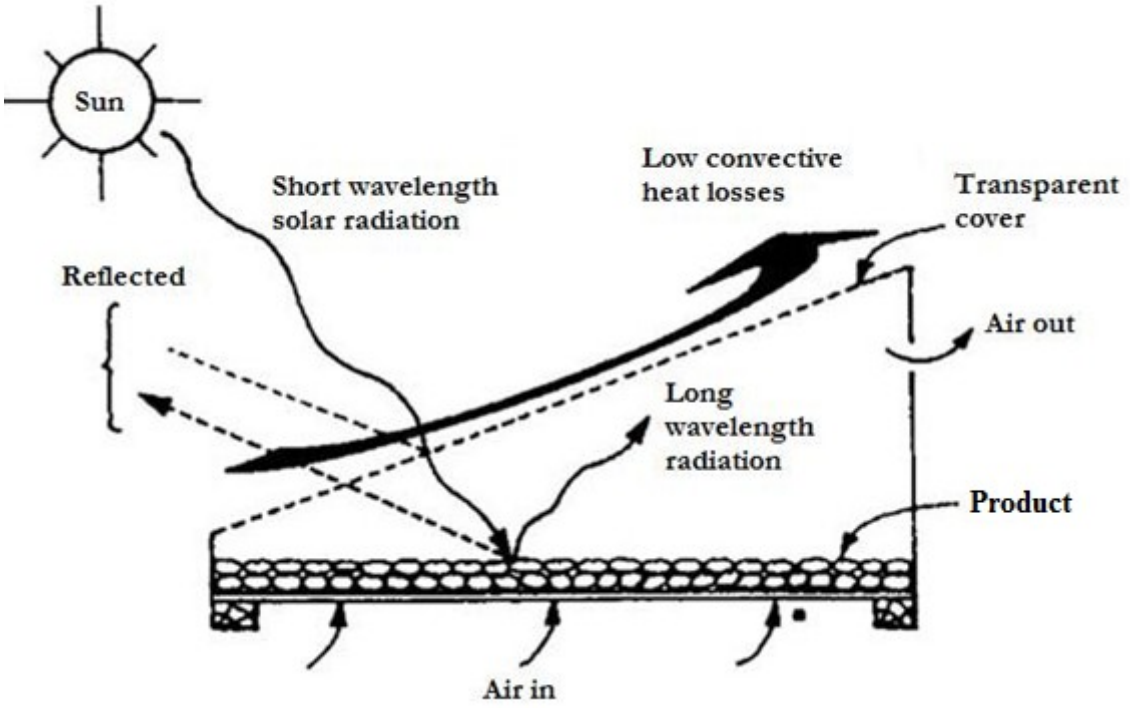


Figure : Working principles of direct solar drying (Sharma *et al.*, 2009).

Indirect solar drying

In this design (Fig. 3), a separate solar air heater is used to collect solar-energy for heating air entering into drying chamber. The air heater is connected to a separate drying chamber where the foodstuff

is kept. The heated air is allowed to flow through wet foodstuff, whereby the heat for moisture evaporation is provided by convective heat transfer between the hot air and the wet foodstuff. The drying is basically by the difference in moisture concentration between the drying air and the air in the vicinity of foodstuff surface (TaTEDO, 2007; Sharma *et al.*, 2009). A better control over drying is achieved in this type of dryer of solar drying systems and the product obtained is of good quality.

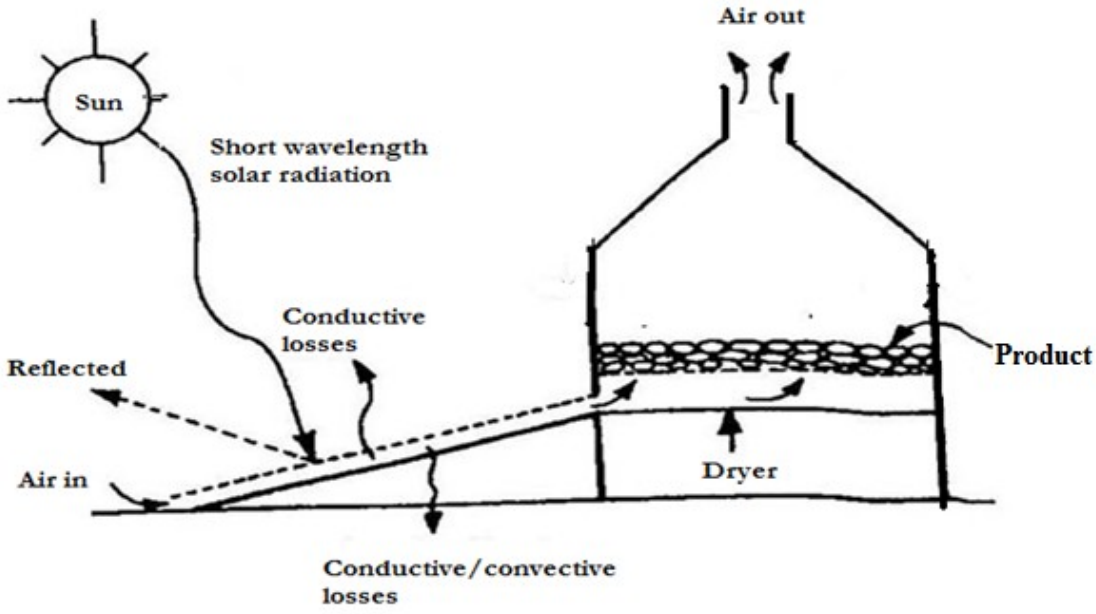


Figure : Working principles of indirect solar drying (Sharma *et al.*, 2009).

(d) Mechanisms of drying

Drying stages

Solar dryers use the energy of the sun to heat the air that flows over the food in the dryer. There are two basic mechanisms involved in the drying process (Fig. 4): the first stage being called the constant rate and the second being known as the falling rate period of drying (Alonge

and Adeboye, 2012). The constant rate period of drying is characterized by escape of water from the surface of the food into the drying air. As air is heated, its relative humidity decreases and it is able to hold more moisture. Warm, dry air flowing through the dryer carries away the moisture that evaporates from the surfaces of the food. In this case, the water content at the surface is considered constant, as water migration from the interior of the product is sufficiently rapid to maintain constant surface moisture (Heldman and Hapatel, 1999). The product temperature also, remains reasonably constant due to the effects of evaporative cooling (Traub, 2002).

The driving force for drying in constant rate period is the difference between the vapour pressure of water in the surface of foods (Pw) and that of the drying air. Other factors that influence the rate of drying in this period include air velocity, temperature, relative humidity, initial moisture contents and the surface area of the food exposed to the drying air (Heldman and Hapatel, 1999). The limiting factor during this step is the heat supply (Methakhup *et al.*, 2003). As drying proceeds, the actual amount of moisture evaporated per unit of time decreases.

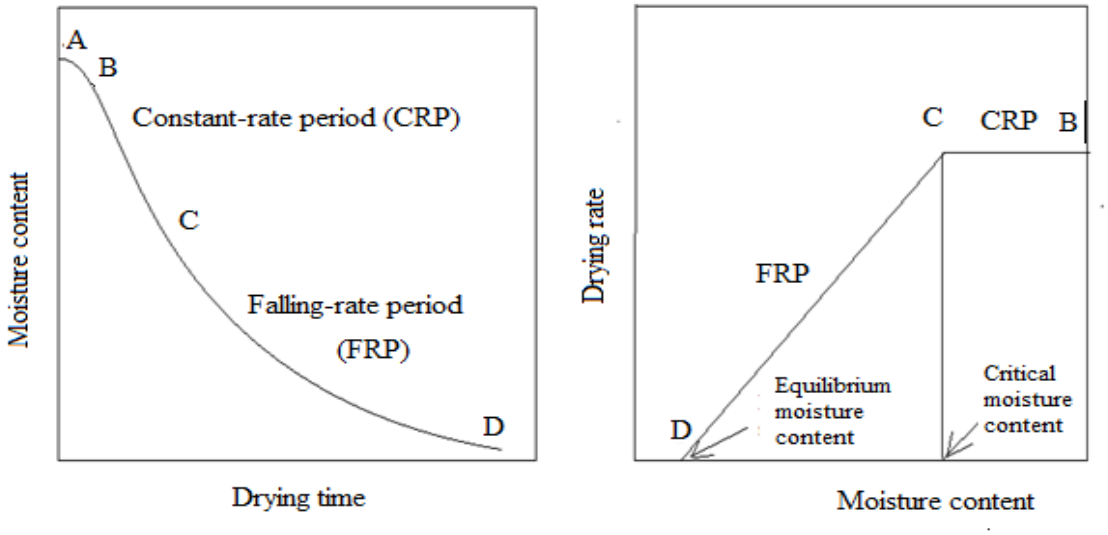


Figure : Drying rate curves for a food product (Source: Fellows, 2009).

The falling rate occurs when the food has lost most of the surface water and is typically longer than constant rate (Traub, 2002). It has been reported that, all the drying process of foods mostly occurs in falling rate (Gürlek *et al.,* 2009). The process begins once critical moisture content is reached, at later stages of drying, the rate at which moisture migrate to the surface limits drying. That, is the rate of moisture loss from surface to the drying air is faster than the rate at which that moisture is replenish at the surface (Heldman and Haptel, 1999). Moisture content is highest at the centre of the piece and lowest at the surface during this phase, thus care should be taken to prevent heat damage. Nevertheless, the evaporation of surface water during the constant rate period is usually sufficient to cool the product although the incoming air might be quite hot (Methakhup, *et al.*, 2003). Food dried too quickly initially become case hardened with the interior moisture unable to escape. Such foods spoils easily because of wet interior and will not rehydrate well because of the hardened exterior

(Katekawa and Silva, 2007a). To prevent overheating during this portion of the drying cycle increased airflows or less heat collection may be desirable.

Heat and mass transfer during drying

The energy required to cause water molecule to be released from the product surface into the drying air arises from heat transfer, according to the drying technology utilized. However, in the constant rate period of drying, the rate of heat input to the product just balancer the amount of water being evaporated. In the simplest case, all of the heat for drying comes from convective heat transfer between the drying air blowing across the food and the product surface (Fig. 5). However, there may be radiation heat transfer to the top surface, or even microwave radiation causing internal heat transfer into the product. If the food product sits on a solid tray, only the top surface is exposed to the drying air flow, and heat transfer into the bottom of the product occurs by a combination of convection and conduction heat transfer.

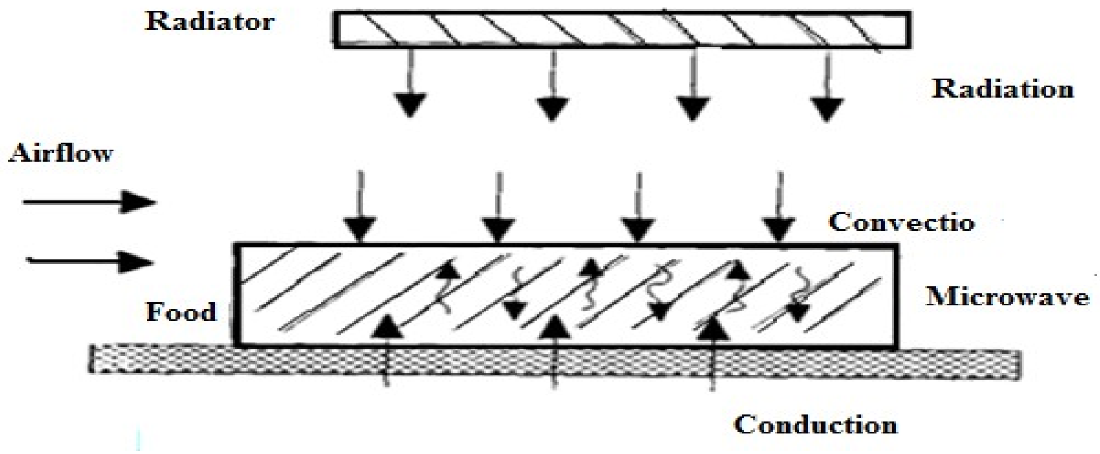


Figure : Potential heat transfer mechanism during drying (Source: Heldman and Hapatel, 1999).

(e) Performance of solar dryers

Collector efficiency

Collector efficiency is defined as the ratio of heat received by the drying air to the insolation upon the absorber surface (Sengar *et al.*, 2012). The efficiency of a solar collector is generally calculated using the subsequent Equation 1 (Chowdhury, *et al.*, 2011).

$$Collector\ efficiency\ \eta_c = \frac{\rho V C p \Delta T}{A I c} \ldots\ldots\ldots\ldots (1).$$

Where, where (ρ) is the density of air (kg/m^3), (I_c) is the insolation on the collector, (ΔT) is the temperature elevation, (cp) is the specific heat capacity of air at constant pressure (J/kg K), (V) is the volumetric flow rate (m^3/s), and (A) is the effective area of the collector facing the sun (m^3).

The performances of a solar collector, is represented by its outlet air temperature and its efficiency, depend on several parameters like

location where the collector is installed, and their internal parameters, such as its surface and the exterior conditions like the temperature and the velocity of the ambient air (Bennamoun, and Belhamri, 2011). These performances vary with time and have a general behaviour as the total received radiations. Moreover; the efficiency of a solar collector varies in time and depends strongly on the absorbed radiations and collector outlet temperature (Bennamoun, 2012).

Drying kinetics

Drying kinetics is the description of the changes of moisture content of material during drying period (Methakhup *et al.*, 2003). The drying rate is has been used to explain the drying kinetics and been defined as the amount of the evaporated moisture over time (Mohamadi *et al.,* 2008). It can be determined as the driving force for convective mass transfer of water molecules from the product surface into the drying air and may be given as in Equation 2 described by Itodo *et al. (*2002).

$$Drying\,rate = \frac{dM}{dt} = \frac{(Mi - Mf)}{t} \qquad (2)$$

Where, Mi and Mf are the initial and final moisture contents (kg moisture/kg dry matter), respectively, t is drying time.

The rate of drying is determined by moisture content of the crop, temperature of the crop, temperature of the air in contact with the crop, the relative humidity of the air contact with the crop, and the velocity of the air in contact with the crop (Alonge and Adeboye, 2012).

2.2.1.3 Pre-drying treatments

Although many fruits and vegetables may be dried and stores without pre-treatment, the pre-treatment generally improves quality and can make the food safe to eat. It preserves colour, minimizes nutrient loss, stop decomposition by enzyme action, ensure more even drying as well as extend storage life. Decomposition from enzyme action during storage is less a problem with fruits than it is with vegetables as they have higher sugar and acid, which counteract enzyme action (Harrison and Andress, 2000). Research shows that treating fruits and vegetables with an acidic solution (citric or ascorbic acid) or with a sodium metabisulphite solution helps destroy any harmful bacteria that may be present on produce during the dehydration process, including *E.coli0157;H7, Salmonella, and Listeria monocytogenes* (Swanson, 2009). Certain fruits, such as apricots, pears, peaches, and some varieties of apple, tend to discolour with drying, thus pre-treating those fruits with ascorbic acid/citric acid dip salt solution, syrup blanching or a sulphiting procedure can decrease the problem during processing and storage and lower losses of flavour and of vitamins A and C (Harrison, and Andress, 2000). The ascorbic acid, citric acid, and metabisulphite dips can also enhance the destruction of potentially hazardous bacteria during drying (Swanson, 2009).

Blanching (heating in boiling water or steam) is the pre-treatment method of choice for vegetables. Almost all vegetables should be blanched before drying to destroy the enzymes that make vegetables

deteriorate. Fruits, on the other hand, are usually not blanched prior to drying owing to their delicate nature and inherent acidity (Bruhn *et al.*, 2007). Some fruits and vegetables are blanched by immersion in hot water (95 to 100 °C) or exposure to steam. According to Fellows (2009) blanching at 88^0C stop all life process, inactivates enzymes, fixes green colour and removes certain harsh flavours common in vegetables. It also clean and soften vegetables and makes them easier to rehydrate later. Sulfuring dried fruits must be closely controlled so that enough sulphur is present to maintain the physical and nutritional properties of the product throughout its expected shelf life, but not so large that it adversely affects flavour (Harrison, and Andress, 2000).

2.3 Effects of Drying on Quality of Fruits and Vegetables

2.3.1 Overview

Food quality is a totality of features and characteristics of a product that bear on its ability to satisfy stated or implied needs (Center for Food Safety and Applied Nutrition, 2006). Drying, the added heat and exposure times at elevated temperatures affect a number of quality degradations of the food products (Jimoh *et al.*, 2008). The quality of the dried foods is greatly influenced by the drying operation and is judged by the amount of physical, chemical and biochemical changes occurring during the drying process (Jokić *et al.*, 2009). The quality degradations can be categorized as chemical quality such as browning reaction, lipid oxidation, change in pH, TTA and soluble sugars, and colour loss; physical quality such as shrinkage of cell, loss of rehydration, solubility and texture; and nutritional quality such as

nutrient losses and microbial survival (Methakhup *et al.*, 2003; Perera, 2005). The advancement of these changes depends also on the pre-treatment, which quite often precede drying in order to minimize the adverse changes occurring during drying and subsequent storage. Pre-treatments stop the metabolism of cut tissue either by killing cells or by injuring enzymatic routes (Lewicki, 2006).

2.3.2 Biochemical quality

2.3.2.1 Phytochemicals

Phytochemicals are bioactive non-nutrient plant compounds widely distributed in fruits, vegetables, grains, and other plant food (Liu, 2003). They are distributed in different type, at different plant parts and at varying levels. Under certain conditions, such as exposure to radiation sources, wounding, storage on low temperatures, and/or exposure to extreme temperatures the concentration of plant, phytochemicals may increase (Shahidi and Naczk, 2004). Chemically, phytochemicals are derived from phenylalanine and tyrosine and have a variety of functions such as pigmentation, antioxidation, protection against UV light (Shahidi and Naczk, 2004). Out of many identified phytochemical type, phenolic compounds are the most important ones.

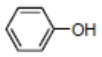
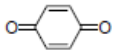
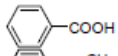
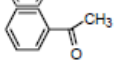
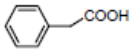
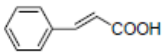
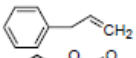
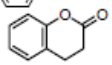
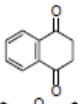
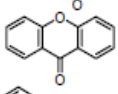
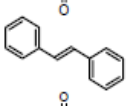
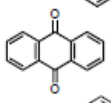
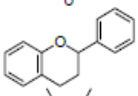
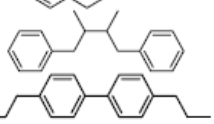
(i) Phenolic compounds

Phenolic compounds represent a large group of secondary metabolites that are produced and widely distributed in plants possessing one or more phenolic hydroxyl group attached to one or more aromatic ring (Escarpa and Gonzales, 2008). Phenolic compounds are abundantly

found in fruits and vegetables and are important compounds in protecting the cellular systems from oxidative damage induced by free radicals and to lower the risk of chronic diseases like CVDs, and cancers. The intake of these compounds is an important health-protecting factor (Segura-Carretero *et al*., 2010).

A structural diversity of phenolic compound constituents is large, ranging from small phenolic acids to polymers. The group includes simple phenols, flavonoids, lignin, lignans, stilbenes, and condensed tannins (Table 5). Of these, simple phenols and flavonoids are a large and diverse groups of important plant related phenolic compounds accounting for 30 and 60 % of total phenols, respectively (Escarpa and Gonzales, 2008). Owing to this, the level of total phenols can be used as an integrated measure of flavonoids, amongst other compounds. Their primary functions in plant are to act as antioxidant, phytolexin, UV-filter and attractants for insect and animals (Samanta *et al*., 2011).

Table : Classification of families of phenolic compounds

Carbon numbers	*Class*	*Basic structure*	*Sources*
C_6	Simple phenols		
	Benzoquinones		
C_6-C_1	Benzoic acid		Cranberry, cereals
C_6-C_2	Acetophenones		Apple, apricot, banana, cauliflower
	Phenylacetic acid		
C_6-C_3	Cinnamic acid		Carrot, citrus, tomato, spinach, peaches, cereal, pears, eggplant
	Phenylpropene		
	Coumarins		Carrot, celery, citrus, parsley
	Chromones		
C_6-C_4	Naphthoquinones		Nuts
C_6-C_1-C_6	Xanthones		Mango, Mangosteen
C_6-C_2-C_6	Stilbenes		Grapes
	Anthraquinones		
C_6-C_3-C_6	Flavonoids		Widely distributed
$(C_6$-$C_3)_2$	Lignans, neolignans		Sesame, rye, wheat, flax
$(C_6$-$C_1)_n$	Hydrolysable tannins	Heterogeneous polymer composed of phenolic acids and simple sugars	Pomegranate, raspberry
$(C_6$-$C_3)_n$	Lignins	Highly crosslinked aromatic polymer	

Source: Segura-Carretero *et al*. (2010).

(ii) Phenolic as antioxidants

Antioxidants in biological systems are any substance that when present at lower concentration than that of an oxidizable substrate significantly inhibits or delays the oxidative process while it being oxidized (Halliwel, 1990). They are important constituents in many areas like food industry for preventing oxidation, as ingredients in functional food and nutraceticals, pharmaceuticals and as active biological agents in functional food and nutraceticals (Becker *et al.*, 2004).

Cells in human body systems and other organisms are constantly exposed to a variety of oxidizing agents such as reactive oxygen species (ROS). The ROS such as peroxy radical, hydroxyl radical, singlet oxygen are an integral part of the aerobic life on earth as energy is extracted from food molecules by the oxidative metabolism in aerobic organism (Halliwel, 1990). The ROS and other free radicals can harm all kinds of biological materials such as proteins, carbohydrates, lipids, and nucleic acid. Furthermore, ROS can affect the formation of biological membranes, change enzyme activity, induce abnormal organ metabolism, and influence the generation of cataracts, atherosclerosis, and degenerative diseases (Fernández-Pachón *et al.*, 2004). If the rate of ROS production exceeds the antioxidant defence over a period, a state of oxidative stress may arise (Antolovich *et al.*, 2002).

Phenolic compounds are one of the important dietary antioxidants that can quench and neutralize free radicals in human body. Their

antioxidant capacity comes from their redox properties in acting as a reducing agents, hydrogen donator, metal chelator and singlet oxygen quencher (Pyo *et al*., 2004). The complex antioxidant systems in the human body rely on the dietary and endogenous antioxidants with three mechanisms of action, first, antioxidant enzymes which catalyses the breakdown of small radicals, second, chain breaking antioxidants like vitamins C and E) which denotes or receives an electron, thus terminating the chain reaction in for instance the lipid peroxidation reaction, and third, metal chelating polypeptide preventing initiation of free radical (Young and Woodside, 2001).

(iii) Effect of processing on phenolic compounds and antioxidant capacity

Antioxidants present in foods change during the processing, in a similar way to other food components. Naturally, the most pronounced changes result from oxidation reactions occurring rapidly on exposure of food components to temperatures above ambient conditions or slowly in storage (Pokorny *et al*., 2001). Antioxidants are oxidised either by lipid oxidation products (mainly hydroperoxides) or directly by oxygen, either dissolved in lipidic and aqueous phases or absorbed from the air. Chang *et al*. (2006), Bennet *et al*. (2011) and Caro *et al*. (2004) have reported a decrease in degrade during drying processing, which accompanied with diminished antioxidant activities. On the other hand, although natural antioxidants are partially lost during heating, the overall antioxidant properties of heated foods can be maintained or even enhanced by the development of new antioxidants, such as Maillard reaction products. Nicoli *et al*. (1997) found the antioxidant

activities of roasted coffee brews and tomato puree were enhanced as the roasting time and temperature increased due to development of new antioxidants from mallard reaction. Various studies (Nicoli *et al*., 1997; Marshall *et al*., 2000; Boetang *et al*., 2008) have similarly reported the increment in antioxidant activities of various fruits and vegetable on drying.

2.3.2.2 Colour

Color is one of the most relevant attributes with respect to the quality of dried foods (Bonazzi and Dumoulin, 2011). It is an index of the inherent good quality of foods and the association of colour with the acceptability of food is universal (Methakhup *et al*., 2003). Usually during drying, colour may change due to a number of chemical and biochemical reactions (Maskan *et al.,* 2002). It has been reported that, one colour-related problem that is always encountered during drying and long-term storage of dried fruits and vegetables is discoloration due to browning (Methakhup *et al*., 2003). Browning in foods is of two types: enzymatic and non-enzymatic. Enzymatic browning is one of the most important reactions that occur in fruits and vegetables, usually resulting in negative effects on color, taste, flavor, and nutritional value. It is is a consequence of oxidation reaction of polyphenols catalysed by polyphenol oxidase enzyme, which facilitate the conversion of phenols to the brown pigment melanin in an oxidation reaction (Guerra *et al*., 2010).

Fruit and vegetable products often contain phenolic compounds, which are oxidized and polymerized to form brown pigments, melanin during drying and storage (Perera, 2005), This type of browning occurs in many fruits and vegetables, such as potatoes, apples, and bananas, upon tissue bruising, cutting, peeling, diseased, and exposed to any number of abnormal conditions (UNIDO, 2001a). The injured tissue rapidly darkens on exposure to air, due to the conversion of phenolic compounds to brown melanins (Manzocco, *et al.,* 2001). Phenolase is extensively distributed in plants such as roots, citrus fruits, plums, bananas, peaches, pears, melons, olives, tea, mushrooms, and others. It includes such enzymes as phenoloxidase, catecholase, tyrosinase and ascorbinase (Wiriya *et al*., 2009). It is estimated that over 50 percent losses in fruit occur as a result of enzymatic browning (Whitaker and Lee, 1995) and which shows the need for understanding and controlling diphenolase enzymes in foods.

Projected increases in the fruit and vegetable market for the future will however not occur if enzymatic browning is not well understood and controlled (Marshall *et al.,* 2000). Researchers (Gupta *et al*., 2002; Hossain and Bala, 2002) reports that, enzymatic browning reaction can be prevented by pre-treatment methods, such as blanching and chemical treatment, that inactivates enzyme activity. In fruits and vegetables, enzyme polyphenoloxidase (PPO) can be inactivated at temperatures above 60^{o}C. Wakayama (1995) studied the effect of temperature on PPO activity in Japanese apple. It was found that for Fuji apple, the relative PPO activity decreased from 49% to 13% as the

temperatures increased from 50°C to 60°C and the enzyme was reduced to an undetectable level at temperature above 70°C. Moreover, in citrus fruits, the ascorbic acid and its isomers and derivatives act as inhibitors of enzymatic browning (Roig *et al.*, 1999).

Non enzymatic browning consists of three types; Maillard reaction, caramelization and ascorbic acid degradation (Klieber, 2000; Perera and Baldwin, 2001 Methakhup *et al.*, 2003). It has been reported that Maillard condensation and oxidation of ascorbic acid are the causes of browning in fruits and their derivatives (Barreiro *et al.,* 1997; Maskan, 2001). Maillard reaction is a diffusion-controlled binary reaction between amino acid and reducing sugar; it is critical in the production of off colour and flavour compounds, which are features of quality change in a food product (Miao and Roos, 2006). Wedzicha (1984) defined ascorbic acid browning as a spontaneous thermal decomposition of ascorbic acid under both aerobic and anaerobic conditions and either in the presence or absence of amino-compound.
The rate of non-enzymatic reactions is affected by number of factors such as temperatures, time of heat treatment, pH, the concentration and nature of the reactants as well as moisture content in the fruit and vegetable (Manzocco *et al.*, 2001; Belitz *et al.*, 2004). In Maillard reaction for example, the rate increases with increasing temperature, and the increase is faster in systems high in sugar content (Chua *et al.*, 2002).

Other than browning, many reactions can affect colour during thermal processing of fruits and vegetables. Among them, the most common is pigment degradation, especially carotenoids and chlorophyll (Barreiro *et al*. 1997; Maskan, 2001, Maskan *et al.,* 2002) and chemical oxidation of phenols and ascorbic acid (Manzocco *et al.*, 2001). Chemical changes to carotenoids and chlorophyll pigments are caused by heat and oxidation during drying. In general, longer drying times and higher drying temperatures produce greater pigment losses (UNIDO, 2004). Other factors affecting colour include fruit pH, acidity, fruit cultivar and heavy metal contamination (Maskan, 2001).

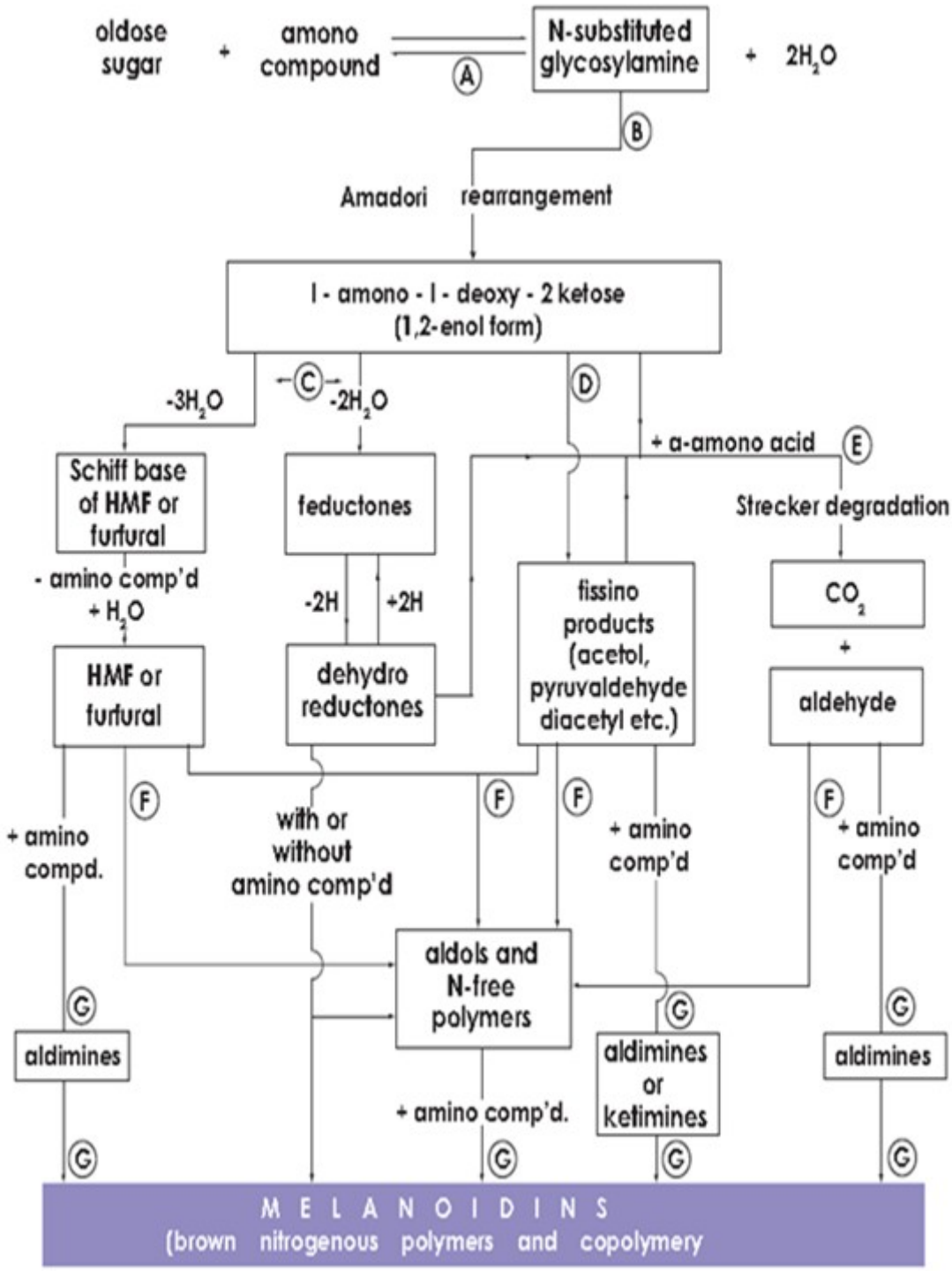


Figure : Maillard browning pathway (Source: Davies and Labuza, 2003).

2.3.2.3 Flavour

Fruits and vegetables flavour depends upon taste (balance between sweetness and sourness or acidity, and low or no astringency) and aroma (concentrations of odour-active volatile compounds) (Kader, 2008). Although taste and aroma are well integrated in their contribution to the overall flavour, aroma is often considered to play a dominant role in flavour (Goff and Klee, 2006). Thus, future research on flavour quality must include both non-volatile and volatile constituents that contribute to taste and aroma of fruits and vegetables (Perkins-Veazie and Collins, 2001). Volatile compounds are largely esters, alcohols, aldehydes, and ketones (low-molecular-weight compounds) (Kader, 2008). Sweetness is determined by the concentrations of the predominant sugars, which are ranked relative to sucrose in the following order of sweetness: fructose (1.2) > sucrose (1.0) > glucose (0.64). Sourness or acidity is determined by the concentrations of the predominant organic acids, which are ranked relative to citric acid in the following order of sourness: citric (1.0) > malic (0.9) > tartaric (0.8); some amino acids, such as aspartic and glutamic, may also contribute to sourness (Kader, 2008).

In drying, food loses its moisture content, which results in increasing the concentration of flavour compounds in the remaining mass. Sugars in fruits, for example are concentrated during drying and the products become sweeter than their fresh counterpart (UNIDO, 2001b). However, it has been reported that, drying often reduces the number of original volatile flavour compounds, while introducing additional volatile

flavour compounds through the autoxidation of unsaturated fatty acids and thermal decomposition, and/or initiation of Maillard reactions (Goff and Klee, 2006). Volatile organic compounds responsible for aroma and flavour have boiling points at temperatures lower than water and those which have a higher relative volatility and diffusivity, are lost earlier during drying (UNIDO, 2001c). Fewer volatile components are lost at later stages. Another important cause of aroma loss is oxidation of pigments, vitamins and lipids during storage. The storage temperature and water activity of the food determine the rate of deterioration. Control of drying conditions during each stage of drying minimizes losses.

2.3.3 Nutritional quality

2.3.3.1 Overview

Drying, like all methods of preservation, can result in loss of some nutrients (Kendall *et al.*, 2004). Nevertheless, studies have demonstrated that, the nutritional value of food is only minimally affected by solar drying. Large differences in reported data on the nutritive value of dried foods are due to wide variations in the preparation procedures, the drying temperature and time, and the storage conditions (Morris *et al.,* 2004). In fruits and vegetables, losses during preparation are reported to be high, which may sometimes exceed those caused by the drying operation (Morris *et al.,* 2004; Karim *et al.,* 2008). Washing, peeling and blanching steps prior to processing are responsible for some loss of water-soluble nutrients (Bruhn *et al.*, 2007). Mason *et al.* (2001), reported that, some of the sugars, salts

and water-soluble vitamins are lost during preparation and according to Mepba *et al.* (2007), blanching causes up to 47.1% loss of vitamin C as well as significant reduction in K, Na, Ca, Mg, Zn, Fe, and P contents of the vegetables. The detail of the effects of drying on macronutrients and micronutrients are described in the following sub-section. Macronutrients are essential nutrient required in relatively large amounts and they include carbohydrates, fats, and proteins. They provide energy and chemical building-blocks for tissues (McKinley, 2008).

2.3.3.2 Macronutrients

(i) Carbohydrates

Carbohydrates are the main component of fruit and vegetables and represent more than 90% of their dry matter (FAO, 1995). The total carbohydrate content of fruits and vegetables has been reported to vary widely from as little as 2% in cucumber and squashes to over 30% of fresh weight in sweet potatoes (Khan, 1989). Fruit vary widely in their carbohydrate content (between 1.5 and 2.6 %). Ripe fruit contain no starch; sucrose is the most dominating sugars followed by fructose and glucose which are often present in equal proportions (Lintas, 1992; Lester *et al.*, 2001; Cordain, 2012). Like vegetables, fruits also contain dietary fibre (FAO, 2001). Vegetables are composed chiefly of carbohydrates, mainly simple sugars and complex carbohydrates

(starch and dietary fibre). The content ranges from 1-2% in the leaf and stem vegetables to 27% in sweet potato. Root vegetables have the highest carbohydrate content. Dietary fibre content ranges from 0.8% in cucumber to 8.0% in artichoke (Lintas, 1992).

Changes in carbohydrates are a prominent chemical transformation occurring during drying of fruits and vegetables (Perera, 2005). Carbohydrate together with other macronutrients (proteins and fats), are present in larger amounts per unit weight in dried foods than in their fresh counterpart (UNIDO, 2001a). However, high heat treatments cause interaction between reducing sugars and amino group to give Maillard browning and the associated with flavour change. Hassan *et al.* (2007) compared carbohydrate content in fresh and dried fruits and vegetables, and found out that, carbohydrate contents were significantly lower in all drying methods compared to fresh samples. Other studies have shown no change in fibre and energy content of fruits and vegetables (Kendall, *et al.,* 2004; Perera, 2005). This is due to the fact that, fibre is relatively insensitive to thermal processing, so its contents are very similar in fresh and processed fruits and vegetables (Barret, 2007).

(ii) Proteins

Fruits and vegetables are not good sources of protein in human nutrition. Most of them have amino acid imbalance and many lack the essential amino acid in required quantities, as a results their protein

efficiency ratio value is low (Spiller, 2001). They are generally considered as “incomplete proteins” or sources of low biological value protein and diets based only on these foods would have a good chance of being too low in protein (Mahan and Escott-Stump, 2000). While nearly all fruits are characteristically low in protein of less than 1%, some vegetables contain some, and often much, protein. Legume vegetables contribute about 5% of the per capita availability of proteins in the diet as their proteins are of high quality due to their content of essential amino acids **(**Khetarpal and Kochar, 2011).

(iii) Fats

Most fruits and vegetables contain only small quantities of lipid, but oxidation of unsaturated fatty acids, produces hydroperoxides, ketones and acids, causes rancid and objectionable odours (Perera, 2005). Rancidity is an important problem in dried foods. The oxidation of fats is greater at higher temperatures than at low temperatures of dehydration. Protection of fats with antioxidants is an effective control.

2.3.3.3 Micronutrients

Micronutrients are vitamins and minerals. They are not usually synthesized in the human body and are therefore essential in diet (Berdanier and Zempleni, 2009). They are known as micronutrients because the body only requires them in very small amounts i.e. micrograms or milligrams a day.

(i) Vitamins

The vitamins constitute a group of organic compounds which are essential in small quantities for the normal metabolism of other nutrients and maintenance of physiological well-being (Anderson and Young, 2008). They cannot be synthesized by the body and must be obtained from the diet (Yeung and Laquatra, 2003). The primary role of vitamins is catalytic and therefore they are required in small amounts in the body (FAO/WHO, 2003). Based on their solubility; vitamins are categorized into two main groups; fat soluble vitamins (vitamin A, D, E, K) and water soluble vitamins (vitamin B and C). Excesses of fat soluble vitamins are stored in the liver and thus they are not needed every day in the diet. By contrast, water-soluble vitamins dissolve in water and are not stored; they are eliminated in urine. Therefore a continuous supply of water soluble vitamin in daily diets is highly required (Berdanier and Zempleni, 2009). Both fresh and dried fruits and vegetables are good sources of vitamins. However, some vitamin potency, especially the heat sensitive vitamins, may be lost during drying (UNIDO, 2001a). It is therefore quite understandable to determine the effect of drying techniques have on these important nutrients.

(a) Ascorbic acid

Ascorbic acid or vitamin C (Fig. 7) is the water-soluble vitamin and is sensitive to heat (Lisiewska *et al.,* 2002). It is available in a wide variety of natural products but is present in significant quantities in vegetables and fruits (Methakhup, 2003). Citrus fruits and juices are particularly rich sources of vitamin C, but other fruits including

cantaloupe, black currants honeydew melon, cherries, kiwi fruits, mangoes, papaya, strawberries, tangelo, watermelon, and tomatoes also contain variable amounts of vitamin C. Vegetables such as cabbage, broccoli, Brussels sprouts, bean sprouts, cauliflower, kale, mustard greens, red and green peppers, peas, tomatoes, and potatoes may be more important sources of vitamin C than fruits (FAO/WHO, 2002; Yeung and Laquatra, 2003). This is particularly true because the vegetable supply often extends for longer periods during the year than does the fruit supply. Vitamin C is essential for connective tissue formation and maintenance, immune system stimulation, works as anti-oxidant, and enhances iron utilization among other roles (Shrimpton, 1993).

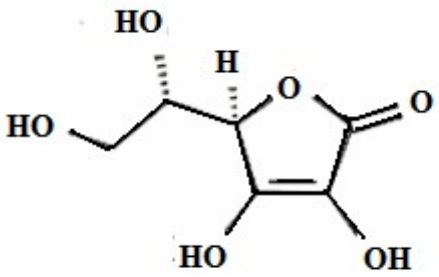


Figure : Structure of L-Ascorbic acids (Source: Moser and Bendich, 1991).

Ascorbic acid is one of the most thermolabile components of food products and is by far the least stable nutrient during processing (Cernîşev and Sleagun, 2007). It is susceptible to heat, highly sensitive to oxidation and leaching into water-soluble media during processing,

storage and cooking of fresh, frozen and canned fruits and vegetables (Franke *et al.*, 2004). It is the most difficult vitamin to retain during the dehydration of foods and thus its retention is often used as an estimate for the overall nutrient retention of food products (Murcia *et al.*, 2000). The loss of ascorbic acid is dependent on many factors including the presence and type of heavy metals, such as copper and iron, exposure to direct sun light, pH, water activity level in the product, dissolved oxygen, and the drying temperature (Uddin *et al.*, 2002; Bulent-Koc *et al.*, 2007). The degradation of ascorbic acid can cause the quality loss and colour formation of product. Therefore, ascorbic acid content and colour are important factors for fruit and vegetable products and are both subjected to appreciable change during the drying process (Giovanelli *et al.,* 2002).

A number of studies have been conducted to investigate ascorbic acid loss during drying. Lavelli *et al*. (1999) studied the effect of drying on ascorbic acid using tomatoes and the results showed that, the content of ascorbic acid decreased from 3300 mg/kg DM in fresh tomatoes to 400 mg/kg DM in dried tomatoes at temperature of 80^{o}C. The results of other researchers (Toor and Savage, 2006) have shown that, drying tomatoes in quarters at 42^{o}C for 18 hours, lead to ascorbic acid losses between 17-27%, according to tomato varieties. Open sun drying has been reported to have more significant effect on ascorbic acid during drying. Researchers (Permul, 2007) and Kabasa *et al. (*2004) have reported a significant reduction in ascorbic acid content in dried tomato

samples and mango fruits (*Mangifera indica*), respectively, with open sun drying causes the most and the solar dryer the least. Similar reduction has also been reported by Oboh and Akindahunsi, (2004) for dried leafy vegetables and Srzednicki *et al*. (2009) in dried Indian gooseberry powder. From the data, it is observed that, the ascorbic acid was very sensitive to oxidative heat damages as the reduction was significant in both the solar and open sun drying methods.

The breakdown of ascorbic acid (Fig. 8) includes two major steps. The first is the oxidation of ascorbic acids to dehydroascorbic acid, a reversible reaction occurs under an aerobic condition. The vitamin C activity of ascorbic acid and its oxidized form, dehydroascorbic acid, is the same (Ottaway, 1993). The second step is conversion of dehydroascorbic acid to diketogluonic acid, an irreversible reaction and occurs both aerobically and anaerobically, particularly during heating. One water molecule is removed from diketogulonic acid and opening of the ring structure to form diketogluconic acid. The oxidation of reduced ascorbic acid may result in the formation of furfural, which is reactive aldehyde, by decarboxylation and dehydration. When furfural passes through polymerization, the formations of dark-colored pigments are resulted. These dark-colored compounds affect the colour and flavour of certain foods, such as citrus juices, and decrease their nutritive values.

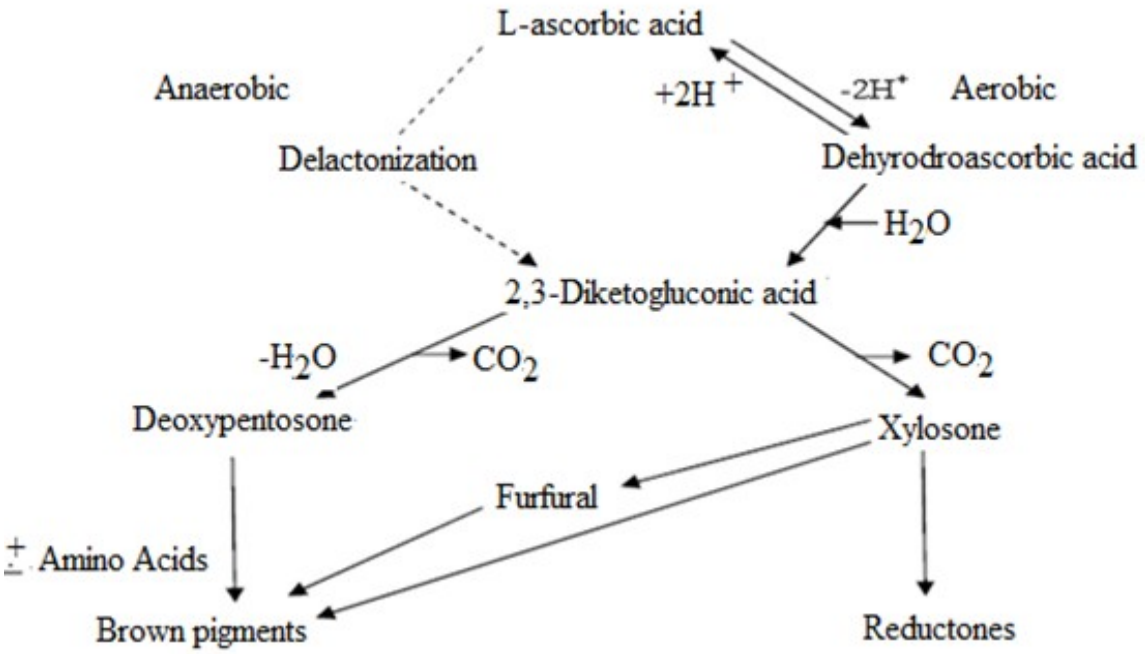


Figure : Degradation of ascorbic acid (Source: Erdman and Klein, 1982).

(ii) Minerals

Minerals are very important and essential ingredients of diet required for normal metabolic activities of body tissues (Sonni, 2002). They are classified as macro minerals or micro minerals (trace elements) depending on their dietary requirement (Yeung and Laquatra, 2003). The macro minerals include calcium, phosphorus, potassium, sodium, chloride, sulphur and magnesium. The trace elements include copper, cobalt, chromium, fluorine, iodine, iron, manganese, molybdenum, nickel, selenium, silicon, tin, vanadium and zinc. Other minerals such as lead, arsenic and cadmium are toxic and their consumption through contaminated plants or animals has been known to result in biochemical disorders (Duruibe *et al.*, 2007). Minerals may function as cofactors of enzymes, as components of organic compounds and as

structural components of bones and teeth and are catalysts for many biological processes (Sonni, 2002). Minerals may also participate in contraction and conduction of nerve impulses (Anhwange *et al*., 2005).

Fruits and vegetables are important sources of minerals which are essential for body functions (Barrett, 2007). Drying has been reported to have insignificant effect on the mineral contents of food products (Kresic, 2004). A study by Aliero and Abdullahi, (2009), suggests that, drying improve the concentration of both organic and mineral constituents. In the same line, Hassan *et al*. (2007) has shown, mineral elements with exception of sodium are significantly increased upon drying. Solar drying method retains more minerals than sun drying as observed in studies by Babarinde *et al. (*2009) in tomatoes and Aliero and Abdullahi, (2009) in *Vernonia amygdalina* (bitter leaf).

2.3.4 Physical quality

2.3.4.1 Shrinkage

During the drying process, deformable materials such as fruits, vegetables and other foodstuffs undergo volume deformations, usually referred to as shrinkage (Katekawa and Silva, 2007a). The shrinkage phenomenon affects in particular the diffusion coefficient of the material, which is one of the main parameters governing the drying process; it also has an influence on the drying rate (Lima *et al*., 2002). If the shrinking during the drying were ideal, the volume reduction would be equivalent to the volume of the removed liquid water (Waje *et al*., 2005). There is experimental evidence that shrinkage extent

during drying is strongly related to drying conditions (Mayor and Sereno, 2004). These relations are expressed in the forms of the glass transition temperature theory (Rahman, 2001, Katekawa and Silva, 2007b) and crust formation, also referred to as the case-hardening phenomenon (Ratti, 1994). The formation of the crust can occur during drying due to the formation of high moisture content gradients within the dried material. The dried surface reaches the glassy state first while the interior of the material still is moist and rubbery. This hard surface hinders not only volume reduction but also moisture removal (Talla *et al.,* 2004). As drying progresses, material shrinking is restricted and the liquid water removed is replaced by air (pores), provided that the crust does not crack (Katekawa and Silva, 2007b). Shrinkage influences textural properties of the dried fruits and vegetables. A study conducted by Funebo *et al.* (2000), confirms that the degree of shrinkage in a food is correlated with the firmness of the product, a vital textural attribute an important quality parameter for the consumers.

2.3.4.2 Texture and porosity

The textural properties play an important role in the overall quality of fruits and vegetables (Banjongsinsiri *et al.,* 2004). Their changes in solid foods are an important cause of quality deterioration during drying (Fellows, 2009). Texture includes tenderness, firmness, crispness, crunchiness, chewiness, fibrousness which is measured by applying force to the produce (UNCTAD, 2007). Fruits and vegetables undergo collapse of structure during drying, leading to firmer textures

and increased chewiness (Gabas *et al.,* 2007). According to Fellows (2009), the loss of texture is explained to be caused by gelatinization of starch, crystallization of cellulose, degradation of pectin, and localized variation in the moisture content during dehydration which set up internal stress. These rupture compress and permanently distort the relatively rigid cells, to give the food a shrunken shrivel appearance. This may be responsible for the variation in the quality of texture of the dried samples and the rehydration index as explained by Maskan (2001).

Past research has proven that the texture of fruits and vegetables is greatly influenced by the rate and temperature of drying of the product (Quintero-Ramos *et al.*, 1992). In general, rapid drying and high temperatures may possibly cause heat damage or injury to the vegetable tissue which may affect texture and structure of the food material cause greater changes than do moderate rates of drying and lower temperatures. Structure and composition of cellular tissues mainly determine the texture of vegetables (Bhale, 2004).

The texture of the dried food products has direct correlation with porosity (Aguilera and Stanley, 1999). Porosity is a measure of the volume of pore or empty spaces of a material to that of the total volume (Rahman, 1995). It also gives an indication about the extent of shrinkage a food material undergoes during drying, which in turn determines the size and shape of the finished product (Ayrosa, and

Nogueira, 2003). The size, shape, and colour could contribute to the quality of some dried products (Perera, 2005).

2.4 Storage and Shelf life of Dried Fruits and Vegetables

2.4.1 Storage conditions

It is noted that a good drying method must be followed by a good storage method if the quality attributes are to be maintained (Anon, 1997). Storage temperature is of vital importance in relation to maintenance of quality. Storage at higher temperatures, the rate of change in flavour and sulphur dioxide loss increases. It is therefore recommended that, the storage of dried fruits and vegetables be at relatively low temperatures to maximize storage life and maintain longer optimal quality. For every -7.8 °C drop in temperature, the shelf life increases 2-3 times (Deni, 2001). Light, during storage, has also been reported to have detrimental effect on the quality and nutritive value of stored fruits and vegetables (Michael and Robinson, 2000). It causes a reduction in carotene and riboflavin contents, increases the rate and amount of sulphur dioxide loss, and thereby increases the rate of darkening. It is therefore recommended to keep dried foods in the dark or in opaque containers (Deni, 2001).

2.4.2 Shelf life

Shelf life is defined as the period in which a product should maintain a predetermined level of quality under specified storage conditions (Michael and Robinson, 2000). It is a measure of microbiological safety and stability of a food product, which in turn determined both food

quality and food safety of a product (Man, 2004). Many fresh fruits and vegetables have a shorter shelf life of only days before they are unsafe or undesirable for consumption (Bruhn *et al.*, 2007). It ranges from 1-2 days in banana, asparagus, and mushroom; 2-4 days in avocados, cucumbers, eggplant, grapes, lettuce and pineapple; 4-6 days in apricots, grapefruit, lemons, oranges, pears, peppers, Spinach, tomatoes and watermelon; and more than 7 days in apples, beets, cabbage carrots, onions and potatoes (Romine, 2009).

Fruits have a naturally high sugar and acid content, which will allow them to dry well and store for longer periods of time than vegetables. When properly packaged and stored at room temperature or below (70°F or less), most fruits will maintain a high quality and nutritional value for up to a year. Most dried vegetables are best when consumed within six months (Harrison and Andress, 2000). It was also reported by Kenneth (2006) that, dried vegetables have shelf life of approximately six to twelve months.

2.4.3 Factors affecting storage stability

Some of the major factors affecting storage stability and shelf life of raw and processed foods include; moisture contents and water activity, storage temperature, time, light, and packaging material (Harrison and Andress, 2000; Swanson, 2009). Moisture loss or uptake is one of the most important factors that control shelf life of foods. As water activity in a foodstuff decreases, the number and growth rate of microbial species able to grow in that environment also decreases (Idah and

Aderibigbe, 2007). Below the limit of 0.60, no microbial proliferation occurs, browning is minimized and the product becomes fully stable in that respect. However, very few specialized yeasts and moulds are able to grow below a_w 0.70, the limit that is usually regarded as safe for prolonged storage. Dried foods have moisture content below 20 % and a water activity 0.7 or below and thus resistant to microbial deterioration (UNIDO, 2001a).

2.4.4 Packaging materials

Packaging has a great deal of influence on the shelf life of the dried product (Hii and Law, 2010). The packaging of dehydrated fruits and vegetables must protect the product against moisture, light, air, dust, micro flora, foreign odour, insects, and rodents (Robertson, 2010). It should also provide strength and stability to maintain original product size, shape, and appearance throughout storage, handling, and marketing. Such material must not contain toxic substances that make the food unsafe (FAO, 1995). Rozis (1997) noted that the choice of packaging material depends on several factors such as the kind of foodstuff, the storage conditions, the material's protective qualities and the materials availability and cost. To extend the shelf life, it is recommended to pack dried foods in freezer plastic bags, squeezing out as much air as possible and store the plastic bags inside of airtight metal, plastic or glass containers. Storing foods in rigid containers without first putting them into freezer bags exposes the dried foods to air and moisture which are among the major deteriorative factors. It is

suggested that using vacuum sealing will greatly extend shelf life 2-3 times longer than conventional methods (Deni, 2001).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Study Area

This study was carried out at Sokoine University of Agriculture (SUA), Tanzania and Norwegian University of Life Sciences (UMB), Norway. Dryers' performance, processing of fruits and vegetables and sensory analyses were conducted at SUA while chemical and microbiological analyses were carried out at Norwegian University of Life Sciences (UMB).

3.2 Materials

3.2.1 Raw materials

Selected varieties of mango (*Mangifera indica* cv. *Dodo, Viringe* and *Kent*), banana (*Musa acuminata* cv*. Kisukari*, *Kimalindi* and *Mtwike*), pineapples (*Ananas comosus* cv*. Smooth cayenne*) and tomato (*Lycopersicum esculentum* cv*. Tanya, Cal J* and *Onyx*) were procured at physiological maturity and ripeness from selected farmers in Morogoro and Pwani regions, Tanzania. The samples were collected from farmers in order to ensure freshness of the produce and for proper post-harvest handling prior to preparation, drying and chemical analysis. A total of 960 mangoes, 480 pineapples, 1440 bananas and 5880 tomatoes, equal number from each variety were sampled for the study. The indicated numbers of fruit and vegetable had been predetermined to give one kilogram of dried product from each variety in each dryer as elaborated in Appendix 1.

3.2.2 Drying equipment and their descriptions

Two solar cabinet dryers: Cabinet direct dryer (CDD) and cabinet mixed modes dryer (CMD) were locally fabricated and one solar tunnel dryer (TD) (Innotech, German) was imported and installed in the study area. The dryers consisted of two parts namely collector and a drying unit/tunnel. In addition, the tunnel dryers consist of small fans to provide the required air flow over the products to be dried. The dimensions for collector and drying section of CDD were (1.17 x 2.35 m) and (0.67 x 1.44 x 2.29 m), respectively while for CMD were [(1.03 x 1.16) + (90 x1.16 m) for extension] and [(1.13 x 1.19 x 1.23+ 0.99 x 1.23 m) for extension]. The tunnel dryer had dimension of 7.1 x 2 m and 10 x 2 m for collector and drying chamber, respectively. Both collector and the drying units were covered with UV stabilized visqueen sheets and food grade black paint was used as an absorber in the collectors. The products to be dried were placed in trays in cabinet dryers and a single layer on a wire mesh in the tunnel dryer.

3.2.3 Chemicals

Methanol, acetonitrile, acetic acids, $FeCl_3.6H_2O$, $FeSO_4.7H_2O$, anhydrous sodium carbonate, were obtained from Merck KGaA (Darmstadt, Germany), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,4,6-tri (2pyridyl)-s-triazine (TPTZ) were obtained from Fluka Chemie GmbH (Buchs, Switzeland). Folin-Ciocalteu phenol reagent (2.0, N), 3, 4, 5,-Trihydroxybenzoic acid (Gallic acid) were bought from Sigma-Aldrich (St Louis, MO, USA). Liquid nitrogen was supplied by

Hydro Gas and Chemicals AS (Oslo, Norway). All chemicals and gases were of analytical grade.

3.3 Methods

3.3.1 Research designs

A purposive sampling procedure was used to collect three varieties of mango (cv. *Dodo, Viringe and Kent*), banana (cv. *Kisukari, Kimalindi and Mtwike*) and tomato (cv*. Tanya, Cal J and Onyx*) from selected farmers in selected regions. Only one variety of pineapple (cv. *Smooth cayenne*) was collected. Each variety was further divided into four equal groups: one group served as a control while the other three groups were subjected to three solar drying methods; cabinet direct, cabinet mixed mode and tunnel dryers.

Completely randomized design (CRD) was used to study the performance of the dryers, nutritional retention and rehydration capacity between the solar drying methods. The effect of dryer types on these parameters were assessed and compared. The mathematical expression is shown in Equation 1.

$$y_{ij} = \mu i + \tau_i + \varepsilon_{ij} \quad \text{.....(1)}$$

$$i=1,2,..., t, j=1,2,...,ni$$

Where μ is the overall mean, τi is the ith treatment effect and ε_{ij} is the random effect due to jth replication receiving ith treatment.

Complete randomized block design (CRBD) was used in the sensory analysis of fresh and dried products and principal factors were drying methods (fresh, direct and mixed dryers) and assessors. The effects of these factors on sensory attributes during drying were determined. The mathematical expression is depicted in Equation 2.

$$yij = \mu + \tau_i + \beta_j + ij\,\varepsilon \quad \text{.....(2)}$$

Where μ is the overall mean, $i\,\tau$ is the ith treatment effect, $j\,\beta$ is the jth block effect and $ij\,\varepsilon$ is the random effect.

Split plot design was used to study the shelf life of the dried products and the principal factors were drying methods, packaging materials and storage time. Drying methods were set as block, storage times were set as main plot and packaging materials were set as sub plots. The effect of these factors on microbial load and their interaction were determined. The mathematical expression is shown in Equation 3.

$$yijk = \mu + \rho i + \alpha j + \gamma ij + \beta k + (\alpha\beta)jk + \varepsilon ijk \quad \text{..... (3)}$$

$$i = 1, 2, \ldots, r;\ j = 1, 2, \ldots, a;\ k = 1, 2, \ldots, b.$$

Where μ is overall mean, ρi is the ith block effect, αj is the jth factor A effect, γij is the ijth random effect associated with whole-plot factor, βk is the kth factor B effect, (αβ)jk is the jkth interaction effect and εijk is the random effect associated with sub-plot factor.

3.3.2 Drying procedures

Solar drying of fresh fruits and vegetable followed procedure explained by (King'ori *et al.*, 1999). Fresh mature ripe fruits and vegetable samples were washed, peeled and sliced to 5 mm thick and each sample divided into 3 portions that were subjected in equal loading density of 2.91 kg of fresh produce/m^2 of solar aperture to either cabinet direct dryer with temperature ranging from 30-55ºC for about 3 days, cabinet mixed dryer with temperature ranging from 25-49ºC for about 3 days and tunnel dryer with temperature ranging from 30-73ºC, for about 2 days. These temperatures were not preset but obtained during drying process and samples were offloaded from dryers after predetermined moisture levels were obtained after the stated duration. The dried products were packed in polyethylene bags and stored at -4º C prior to laboratory analysis. The procedure was similar for vegetables except that, they had to be pre-treated by blanching or sulphiting prior to drying as indicated in Fig. 9:

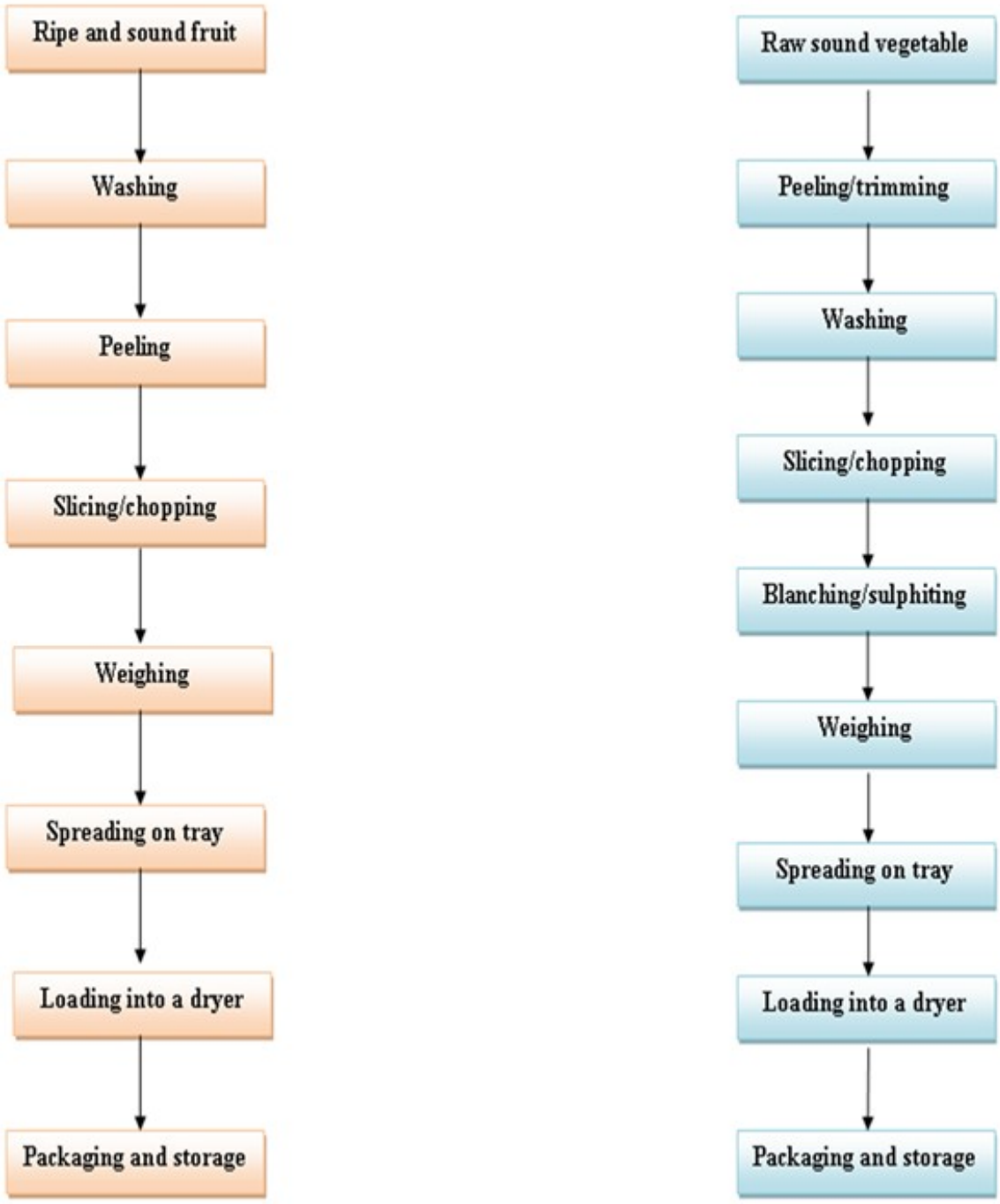


Figure : General flow sheet for fruit (Left) and Vegetable (Right) drying (Modified from Kingori *et al*., 1999).

3.3.3 Evaluation of dryers' thermal performance

The performance of the dryers was evaluated by the collector efficiency and drying time/rates in two different seasons; dry and rainy seasons. A number of dry season tests were conducted between September and November, 2010 and 2011 while the wet season tests were conducted between December 2010 and 2011. Both tests were done without loading with products (no load tests) and started at 8:00 am and stopped at 6:00 pm. The drying time/ rate were determined by loading dryers with mango, banana, pineapple and tomato (load test) during the same seasons, periods and times. The important parameters affecting performance of the dryers were measured as follows:

3.3.3.1 Solar radiation intensity measurement

The incident solar radiation was measured by solarimeter (Model SL 200, Romania). The solarimeter was placed in a fixed position between dryers and the readings were taken continuous from 8.00 am to 6.00 pm on every experimental day.

3.3.3.2 Temperature measurement

The temperatures at different points of collector and drying chamber were measured with thermocouples (Model HI 98704 K, J and T types) via a data logger, Hanna Instrument Inc, Romania), every 15 minutes. The ambient air temperature, temperature at the entrance of the solar collector, at the exit air from the collector and the drying chamber were determined and averaged.

3.3.3.3 Air velocity measurement

The air velocity at the entrance of dryer was measured using Anenometer (Model EA 3000, Technoline Ltd, Romania) and the readings were taken at 15 minute intervals.

3.3.3.4 Relative humidity measurement

Relative humidity for the inlet ambient air and the outlet air from the drying chamber were determined using thermohygrometer (Model HI 8564, Hanna Instrument Inc, Romania) and readings were taken at 15 minutes intervals.

3.3.3.5 Determination of collector efficiency

Collector efficiency of the dryers was determined by using the Equation 1 in chapter 2 as explained by Chowdhury *et al*. (2011).

3.3.3.6 Determination of drying rate

The drying rate was computed using Equation 2 in chapter 2 as described by Itodo *et al. (*2002).

3.3.4 Biochemical analysis

Chemical analyses were done on both fresh and dried samples to allow comparisons.

3.3.4.1 Total acidity

Total acidity was determined by potentiometric titration. Twenty-five grams of sample was homogenized in a blender and diluted with distilled water to 250 cm^3 in a volumetric flask. The samples were then

cooked for 30 minutes in a water bath, diluted with distilled water to 250 cm^3 and filtered through filter paper. A 25 ml of filtrate was titrated with 0.1M NaOH to pH 8.1 using a glass electrode pH-meter (Model HI 9124, Hanna Instrument Inc, Romania) at 25°C. The results were expressed as mmols of acid per 100 g of the sample.

3.3.4.2 pH

A 20 g sample was dissolved in 100mL of distilled water and filtered. The pH of the extract was measured using a glass electrode laboratory pH-meter (Model HI 9124, Hanna Instrument Inc., Romania). Readings were taken in triplicate and averaged.

3.3.4.3 Total phenols and antioxidant activity assay

(i) Extraction of the plant materials

The edible parts of the fruits/vegetables were analysed. The procedure was performed as described in Remberg *et al*. (2003). Triplicate samples of 3 g each, were diluted in 30 ml of methanol and flushed with nitrogen in order to prevent oxidation. The bottles were exposed to sonication at 0° C for 15 min in an ultrasonic bath and then stored frozen at -20° C until analysed. The extract was centrifuged at 31 000 G for 10 minutes at 4 ° C using a Beckman J2-21M/E centrifuge (GMI Inc., Ramsey, MIN, USA). The supernatant was decanted and tightly capped in 5 ml plastic tubes especially designed for low temperature use and stored at -80° C prior to analysis of total phenol and antioxidant power.

(ii) Total phenols (TP)

Total phenol was determined by using the Folin-Ciocalteu reagent (FCR) as described by singleton *et al*. (1999). A triplicate of each sample was analysed using the KoneLab 30i (Kone Instruments Corp, Espoo, Finland) spectrophotometer where 20 µl for each sample was added to 100 µl FCR (diluted 1:10 with distilled water), mixed and incubated at 37ºC for 60 seconds prior to addition of 80 µl 7.5% (w/v) sodium bicarbonate solution. The samples were again mixed and incubated at 37ºC for 15 minutes prior to absorbance reading at 765 nm. TP were assessed against a calibrated standard curve of gallic acid, and the results presented as mg gallic acid equivalents (GAE) per 100 g 100 g fresh weight (FW).

(iii) Ferric reducing activity power (FRAP) assay

Antioxidant activity in the samples was measured using the ferric reducing ability of plasma (FRAP) assay (Benzie and Strain, 1996), following the modification by Halvorsen *et al*. (2002) in which the samples were diluted in methanol instead of water. A triplicate of each sample was analysed using the KoneLab 30i (Kone Instruments Corp, Espoo, Finland) spectrophotometer where 200 µl of the FRAP reagents (3.0mM acetate buffer, 10mM TPTZ in 40 mM HCl, 20 mM $FeCl_3.H_2O$, ratio 10:1:1) were automatically pipette separately and mixed in the cuvettes, 8 µl of sample were added and mixed and incubated at 37ºC for 10 minutes and the absorbance measurement at 595 nm. Trolox (Vitamin E analogue)) were used as control. The antioxidant activity in the samples was calculated as mmol Fe^{2+} per 100 g fresh weight (mmol/100 g fresh weight of sample.

3.3.4.4 Proximate analysis

Proximate analysis of the fresh and dried products was determined according to the official methods of analysis of the Association of Analytical Chemists (AOAC, 1995). The samples were analysed, in triplicate, for estimation of the following constituents; moisture, ash, crude fat, crude protein and carbohydrate (by difference).

3.3.4.5 Mineral analysis

The ash content was used for analysis of the minerals according to the AOAC (1990) procedures.

3.3.4.6 Vitamin C (L-ascorbic acid) analysis

Samples for the Vitamin C determination was performed as described by Wold *et* al. (2004) using HPLC. Fifty grams of samples were added to 100 ml 1.0% (w/v) oxalic acids and homogenized for 1 minute using a Braun MR 400 hand processor, then filtered through a Whatman 113 V folded filter (Whatman International Ltd., Brentford, UK) then applied onto a activated (5 ml methanol + 5 ml water) Sep-Pak C18 from Waters Corp. (Milford, MA, USA). The three ml was discarded and the eluent to be analysed by HPLC was filtered through a 0.45 µm (VWR) prior to injection. All samples were analysed in duplicate and injected in triplicate. Isocratic HPLC separation and detection were performed according to Williams *et al*. (1973) using an Angilent 1100 Series LC system (Angilent Technologies, Waldbronn, Germany) equipped with a quaternary pump, an inline degasser, an auto sampler, a column oven

and a UV detector. The separation was conducted with a Zorbax SB-C18 (250 X 4.6 mm, 5 µm) column with a complementary Zorbax XDB C18 (4 x 4 mm, 5 µm) guard column, Agilent Technologies (Waldbronn, Germany). Injection volume was 5 µl, the flow was 1 ml min^{-1} of 0.05 M KH_2PO_4 at 25 ºC and detection was performed at 254 nm. Vitamin C was quantified by external calibration and results were reported as mg L-AA acid per 100 g DM.

3.3.4.7 Sugar profile analysis

Sugar profile (Glucose, sucrose and fructose) were determined according to a slightly modified method described by Sharma *et al*. (1988). Triplicate samples of 2 g of each sample were diluted in 700 µl deionized water. 5 ml of 0.5 M H_2SO4 and 20 ml Acetonitrile (CH_3CN) of methanol were added and mixed in the Multifix mixing machine for 1 hour. The mixture was centrifuged at 3 500 rpm for 15 minutes, supernatant drawn using a 10 ml plastic syringe with 0.2 um filter and 1 ml was further filtered directly into the HPLC vial, sealed with a septum and plastic cap prior to analysis. Normal phase separation and detection were performed using a Perking 410 Series LC (Perking Elmar) HPLC with main column Aminex HPX-87H, (300 X 7.8 mm id) and a guard column: Cation-H refill (30 x 4.6 mm id) (Bio Rad). The mobile phase was 5 mM H_2SO_4 and separation operated at 32°C at a flow of 0.4 mL/min. A Perkin 200 RI (Perking Elmar) was used for sugar analysis. Quantification was based on external standards and quates as g sugars per 100 g fresh weight.

3.3.5 Sensory evaluation

3.3.5.1 Quantitative descriptive analysis (QDA)

A descriptive sensory profiling was conducted at the Department of Food Science and Technology, SUA by trained sensory panel of 15 assessors, comprising of 8 males and 7 female with age ranging from 23 to 28 years according to method described in Lawless and Heyman (2010). The assessors were selected and trained according to ISO Standard (1993). In a pre-testing session the assessors were trained in developing sensory descriptors and the definition of the sensory attributes. The assessors developed a test vocabulary describing differences between samples and they agreed upon to a total number of attributes on whiteness, colour, aroma, sweetness, hardness and acidity (Table 6).

An unstructured line scale was used for rating the intensity of each attribute. The left side of the scale corresponded to the lowest intensity of each attribute (value 1) and the right side corresponded to the highest intensity (value 9) (Appendix 6). Descriptive analyses of 16 fresh and dried samples were carried out in two sessions and each assessor was evaluating eight samples per session. The samples were coded with 3-digit random numbers and served to each panellist in a randomized order and instructed to rate the whiteness, colour, aroma, hardness and sweetness attributes. Water was served alongside samples for rinsing mouth before evaluating other samples during the test. The average response was used in the univariate and multivariate analyses.

Table : Definitions of sensory attributes used in descriptive sensory analysis

Parameter	Attribute	Definition
Colour	Colour hue	Yellow/red to red/blue
	Whiteness	Degree of white/black in the colour
	Colour intensity	Clear, strong colour
Aroma	Fruity	Aromatics associated with fresh fruit
Taste	Sweetness	The taste associated with sucrose solution
Texture	Hardness	The force to compress a sample via first compression (The force required to bite through the sample)

Source: Trained panelists in the study (2011)

3.3.5.2 Consumer test

The test was carried out in the Department of Food Science and Technology laboratory, SUA by 78 untrained consumers aged 18 years and above who arrived in groups of 10, using a 9 point hedonic scale (where 1 = dislike extremely and 9 = like extremely) as described by Lawless and Heyman (2010). The samples were sliced into pieces of uniform thickness (2 cm), coded with 3-digit random number using statistical random tables and served to the panelists at around 10.15 a.m. with distilled water in a randomized order. The judges were instructed to rate the colour, aroma, taste, texture, mouth feel and overall acceptability of each sample indicating their degree of liking or

disliking by putting a number as provided in the hedonic scale according to their preference. Testing was complete in one session and each consumer evaluated all 12 samples with a 10-minute break after four samples were tasted. This evaluation was conducted under the same conditions as for the sensory descriptive test.

3.3.6 Rehydration capacity

Rehydration experiments were performed following a procedure described by (Maskan, 2001). About five grams of dried samples were immersed into hot water at 50°C for 50 min. At 10 min intervals the samples were drained over a mesh for 30 s and quickly blotted with the paper towels 4±5 times gently in order to eliminate the surface water and then reweighed. The rehydration ratio (RR) was calculated using Equation 4 described by Singh *et al. (*2010).

$$Rehydration\,ratio = \frac{W_r}{W_d} \quad \text{..... (4)}$$

Where W_r is drained weight (g) of the rehydrated sample and W_d is weight of the dry sample used for rehydration.

3.3.7 Determination of shelf life

Shelf life was determined by periodic assessments of microbial loads of dried samples from three drying methods, packed in different polythene bags and stored at room temperature (28°C) for six months. The effect of these factors on microbial load were assessed and

compared. Triplicate samples were taken after every three months for evaluation**.**

3.3.7.1 Microbiological analysis

The microbial quality of the dried fruits and vegetables was assessed by using total number of bacteria, coliform, mold and yeast analyses (AOAC, 1995). Plate Count Agar (PCA) (Casein-peptone glucose yeast extract, from Merck KGaA, Germany), Violet Red Bile Agar (VRBA) (OXOID LTD) and Rose Bengal (RB) (OXOID LTD) added Chloramphenicol selective supplement, for the total amount of bacteria, coliforms counts and fungi enumeration respectively were used in this study. The agars, dissolving and diluting media were prepared as described by the manufacturer.

1 g of dry sample was put in a test tube with 9 ml peptone water. This gives a 10^{-1} dilution. The test tubes were placed on a wending table for 30 minutes, before the samples were diluted to 10^{-2} and 10^{-3}, and spread in the petri-dishes. The PCA was incubated at 30 °C for three days, VRBA at 37 °C for 24 hours, and RB at 22 °C for five days. For PCA, all the colonies were counted, for VRBA only the colonies showing growth as described for coli were counted. For RB all the colonies were counted, and registered if it was mold, yeast or both, growing on the agar. The numbers of microorganisms found in the samples were presented as the colony forming unit per g sample (cfu/g).

3.3.8 Statistical data analysis

The data were analysed by using R statistical package (R Development Core Team, Version 3.0.0, Vienna, Austria) for one-way and two way analysis of variances to determine the significant differences and interaction between the factors means at ($p<0.05$). Means were separated by Turkey's Honest Significant Difference at $p<0.05$. Results were presented in Tables, bar charts and spider plots as mean±SD. Principal component analysis (PCA) and partial least squares regression (PLSR) were performed using the Unscrambler statistical package (Camo, version 8.0, Oslo, Norway). PCA was used to study the main sources of systematic variation in the average sensory descriptive data while PLSR were conducted to study the relationship between descriptive data and hedonic liking from the consumers. The variables were standardized and full cross-validation was applied. Correlation loading plots were applied with circles indicating 50 and 100% explained variance, respectively. In the correlation loadings plots products were included as dummy variables (passified in the data matrix) to improve the visual interpretation as described by Martens and Martens (2001).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Dryers' Thermal Performance

4.1.1 Drying parameters under no load test

4.1.1.1 Solar radiation intensity and temperature profile

Fig. 10-12: show the variation of solar radiation intensity and temperature profile inside the dryers with the time of the day during solar drying under no load condition during the season. The findings showed that, temperature rises and falls with increasing and decreasing of solar radiation intensity which varies in a day. The maximum average solar radiation intensity and ambient temperature were 1166 W/m^2 and 36.8°C, respectively at 1:00 pm while minimum values were observed in the morning and end of day at 7:00 am and 5:00 pm respectively during the experimental days. The temperature inside the drying chamber and solar collector were much higher than ambient temperature during most hours of the day. The maximum collector and drying air temperatures of 60°C and 55°C, were respectively inside the cabinet direct dryer (CDD) (Fig. 10) recorded at1.00 pm while maximum collector and drying air temperatures of 55.5°C and 55°C respectively were recorded inside the cabinet mixed-mode dryer (CMD) (Fig. 11).

Higher temperature values were observed in tunnel dryer (TD) than in cabinet dryers. Eighty three degree centigrade (83°C) and 73°C were, respectively observed for collector and drying air temperature at 1:00 pm (Fig. 12).

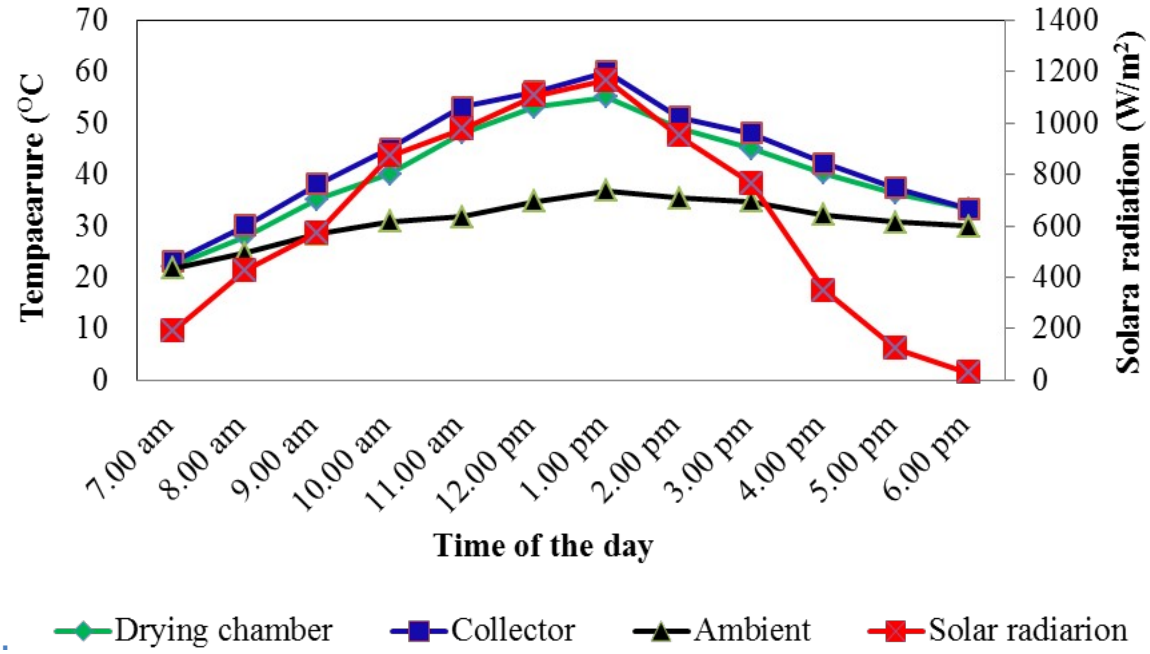


Figure : Solar radiation and thermal profile inside the direct dryer (CDD) under no load condition during experimental days (n=3).

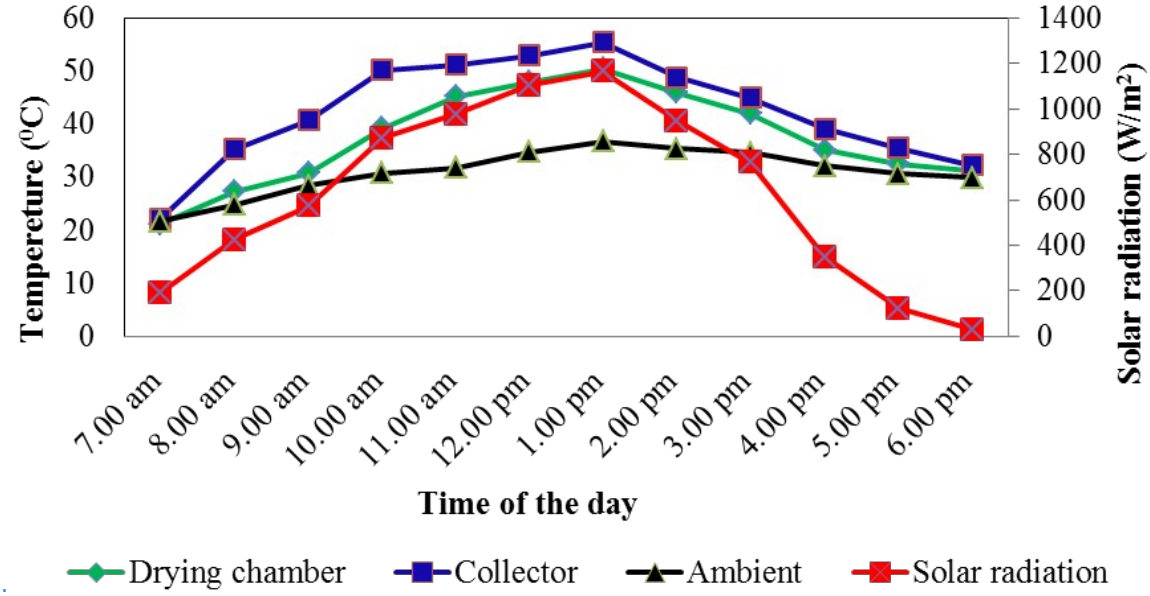


Figure : Solar radiation and thermal profile inside the cabinet mixed mode dryer (CMD) under no load condition during experimental days (n=3).

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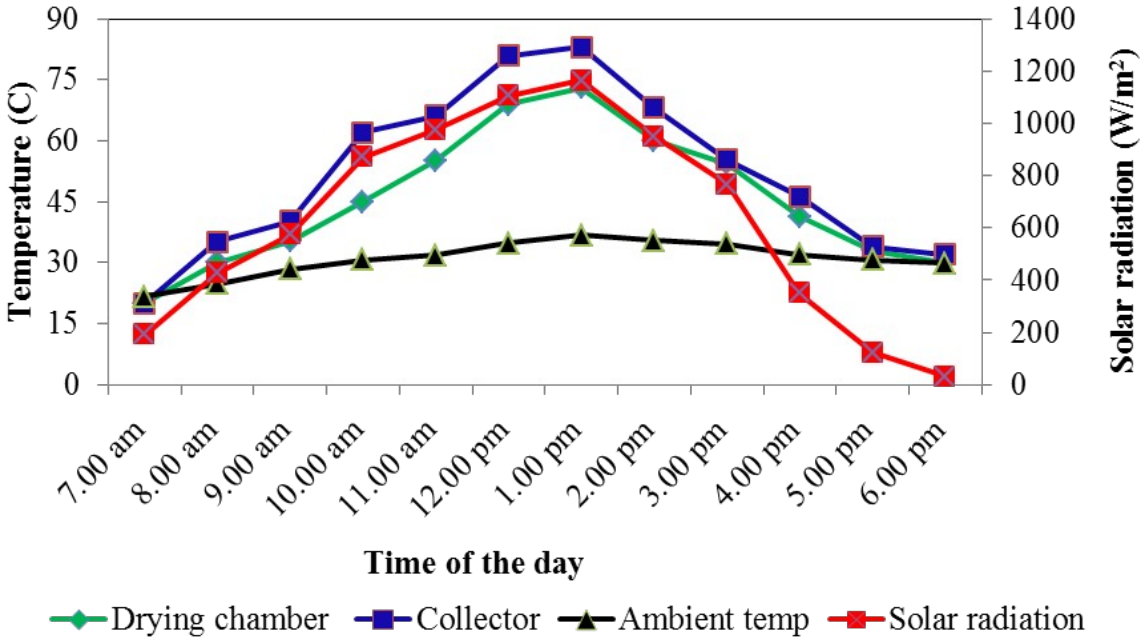

Figure : Solar radiation and thermal profile inside the tunnel dryer (TD) under no load condition during experimental days (n=3).

4.1.1.2 Temperature and humidity profiles during dry season

Fig. 13-15: show the variation of the air drying temperature and relative humidity inside the dryers with the time of the day during solar drying under no load condition during the season. The results showed that, relative humidity decreases with the increase of drying air temperature. The maximum ambient humidity was 53.9% at 22.1°C in the morning at 7:30 am, which decreased to minimum value of 26.5% at 33.3°C between 12:00 and 1:00 pm and increased to 38.2 % at 6:00 pm. High relative humidity of 64.6% was observed inside the CCD at 7:30 am,

which decreased to 0% between 11:00 and 1:00 pm at maximum temperature of 55°C and increased again to 38.2 % at 6:00 pm at temperature of 33.2°C (Fig. 13).

Similarly, relatively humidity of 57.4% were observed inside the CMD at 7:30 am which decreased to minimum values of 7 at maximum drying air temperature of 50°C at 1:00 pm (Fig. 14). Furthermore, relatively much higher relative humidity of 62.4 % was respectively in TD at 7:30 am which decreased to 0% at maximum drying air temperature of 73°C at 1:00 pm and between 10:00 am to 3:00 pm respectively (Fig. 15).

Figure : Variation of air temperature and humidity inside the drying chamber of cabinet direct dryer (CCD) during experimental days (n=3) in dry season.

Figure : Variation of air temperature and humidity inside the drying chamber of cabinet mixed mode dryer (CMD) during experimental days (n=3) in dry season.

Figure : Variation of air temperature and humidity inside the drying chamber of tunnel dryer (TD) during experimental days (n=3) in dry season.

Temperature and humidity are among the important factors determining how quickly the food dries. Solar dryers generate higher temperatures and lower relative humidities than ambient conditions due to their ability to trap radiant energy on solar collector and concentrates heat inside the drying chamber. By heating the air, its humidity is reduced and thus its efficiency as a vehicle for removal of moisture is increased resulting in increased drying rates (Dadashzadeh, 2006). Similarly Bala *et al*. (2009); Olalusi and Bolaji (2008) and Ayyappan and Mayilsamy (2010) found the drying processes being enhanced by the heated air at very low humidity. In addition, the higher temperatures attained in solar drying also act as a deterrent to insect and microbial infestation (Bala and Janjai, 2009). These findings show that, solar drying can be considered as a better alternative solution to all drawbacks of natural drying and artificial mechanical drying experienced by developing countries.

Various authors have recommended different drying conditions for solar drying fruits and vegetable, which seem to be similar to findings of this study. Hassan (1995) recommended drying air temperature between 55 to 75°C for fruits and vegetables while Eissen *et al.* (1985) recommended air velocity between 6 to 72 (m/min). The drying air relative humidity was recommended at its lowest values from 10 to 20 % by Bains *et al.* (1989). Infonet-biovision, (2012) reported that, in tropical countries, solar dryers can be used to dry fresh produce when average relative humidity is below 50% during drying period.

4.1.1.3 Temperature and humidity profiles during the rainy season

Fig. 16-18: show variations of the air drying temperature and relative humidity inside the solar dryers under no load condition during the rainy season. Contrary to dry season, the decrease in relative humidity with increase in air temperature was relatively low. High ambient relative humidity of 75.5-90 % was observed during the experimental period, which was slightly decreased reduced to minimum value of 45.3 % at 1:00 pm before a rise to 65.5 % at 6:00 pm (Fig. 16). Similar trend was also observed inside the dryers, where high relative humidity of 84 % was recorded inside the CDD at 7:30 am, which decreased to 43.6% at 2:00 pm and then elevated to 62.3 % at 6:00 pm (Figure 16). A similar high humidity of 82 % was recorded inside the CMD at 7:00 am which was reduced to 41 % at 1:00 pm and rose to 59.9 % at 6:00 pm (Fig. 17). Attempts to dry samples during the experimental period resulted into severe darkening of the produce being dried inside the cabinet dryers as depicted in Plate 4.

Relatively higher humidity reduction was observed in tunnel dryer. High values of 78.8 % was significantly reduced to minimum value of 23.3% at 13:00 hours where temperature was maximum and rose again to 62% at the end of day, 6:00 pm (Fig. 18).

Figure : Variation of air temperature and humidity inside the drying chamber of cabinet direct dryer (CDD) during experimental days (n=3) in rainy season.

Figure : Variation of air temperature and humidity inside the drying chamber of cabinet mixed mode (CMD) during experimental days (n=3) in rainy season.

Plate : Darkening of products being dried inside the dryer during rainy season (Photo courtesy: Mongi, R. J).

Figure : Variation of air temperature and humidity inside the drying chamber of tunnel dryer (TD) during experimental days (n=3) in rainy season.

The low reduction in relative humidity with increase in temperature suggest that, drying conditions and performance of a solar dryer is significantly dependent on the prevailing weather conditions, which make consistent drying not always possible (Sanni *et al.*, 2012). The high relative humidity of the air inside the dryer has negative effect on the dryer's water removal capacity and drying rates. According to Mercer (2008), the moisture content of the air near the surface of the material being dried can increase to levels nearing saturation and its boundary layer can reduce the rate at which moisture can be removed from the surface of the product. It is therefore, not advisable to apply solar drying when the environmental relative humidity is high.

Moreover, different airflow systems could be responsible for variation in humidity reductions between the cabinet and tunnel dryers. The tunnel dryer has the advantage of its forced airflow system to remove more moisture from the dryer than cabinet counterparts which are characterised by conventional airflow mode. Low moisture rate removal favours and prolongs chemical reactions in the products being dried resulting into burn or brown colour as observed in cabinet dried samples. However, despite the relatively higher reduction in tunnel dryer, its performance seemed to be affected as well during this season. This shows that, the effect of weather and its conditions on solar drying kinetics is independent of the method used and it further explains why drying operation should be avoided during cloudy or rainy seasons. Hussain *et al.* (2008), Nahar (2009) and Bala *et al.* (2009) have similarly found the performance of the solar dryer be very good

during summer but very poor during winter. As far as weather and humidity are concerned, dry weather with low humidity are ideal drying conditions as also observed by Wazed *et al*. (2009).

4.1.1.4 Air velocity

Fig. 19 shows the variations of the air velocity during the time of drying at different seasons. There are variations in air velocity between time of the drying day and between seasons. Dry season had higher values of 3.6 m/s at 1:00 pm than wet season which had maximum value of 1.8 at the same time. The minimum recorded values were 1.5 and 0 m/s at the end of day, 6:00 pm for dry season and wet season, respectively.

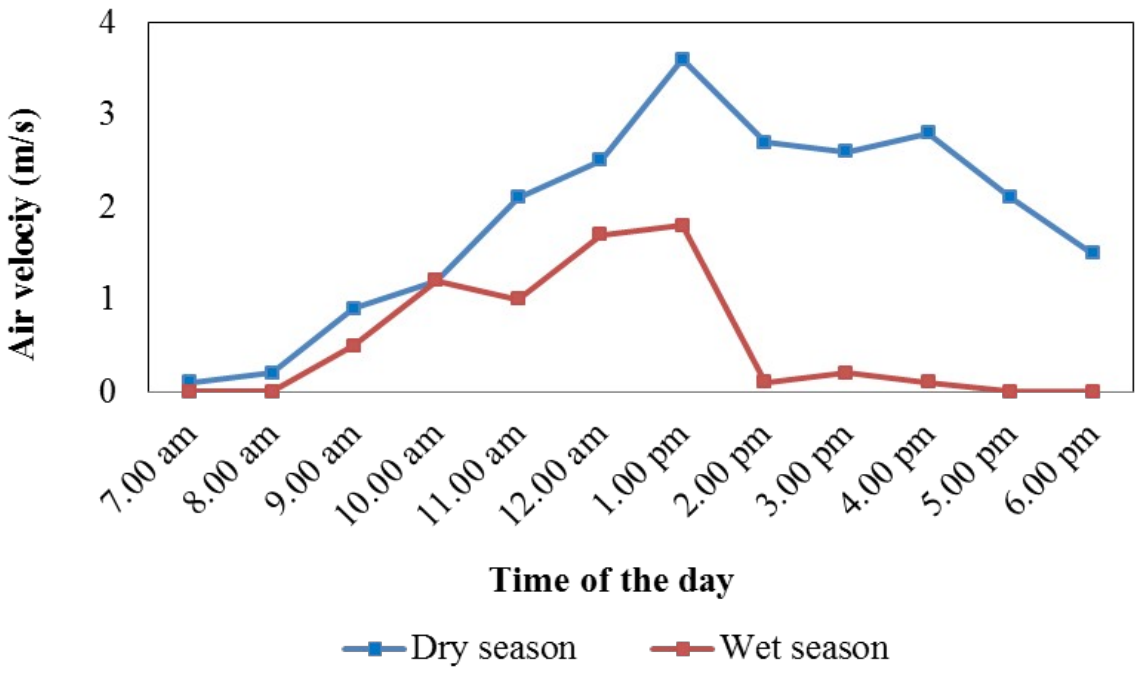

Figure : Variation of air velocity during experimental days (n=3) at different seasons.

Air velocity is an important drying condition in the overall performance of dryer due to its mass transfer role. The drying rate increases with increase in temperature and air velocity (Ndukwu, 2009). The findings showed that, air velocity varies with season and time of drying within the seasons. Design and modes of airflow determine the rate of air flowing in the dryers in addition to air velocity and other climatic conditions. Forced airflow mechanism, uses device to increase the air speed, thus allowing more air into the drying system with corresponding increase in dryers performance given optimal levels of other parameters. On the other hand, cabinet dryers use convectional air flow mechanism, which depends only on ambient air speed to push air into dryer, which means fluctuation of any kind in the air speed, leads to significant effect on the flow rate and overall performance of the dryer.

4.1.1.5 Collector efficiency

Results for collector efficiencies for the three dryers are shown in Table 7. It shows that, tunnel dryer had significantly ($p<0.05$) higher collector efficiency than cabinet dryers which had statistically similar efficiencies. Among the factors that have contributed to the difference could be the design parameters such as collector materials and type of collector, and air flow parameters such as air flow rate, and mode of flow. Tunnel dryer uses forced airflow system which increases the energy output-input ratio and overall efficiency. Moreover, the larger collector surface area in the tunnel dryer than in cabinet dryers could have contributed to more energy output from the collector and thus

increased the efficiency. The principal requirement of collector designs is a large contact area between the absorbing surface and air (Kalogirou, 2009). It should be noted that, since solar radiation and temperature are the key basic factors for solar dryer performance and vary with location and seasons, then the solar collector efficiency levels will also vary accordingly in some areas and seasons.

Table : Collector efficiencies of solar dryers

Drying method	Efficiency (%)
Cabinet direct dryer (CDD)	32.4[a]
Cabinet mixed-mode dryer (CMD)	34.2[a]
Tunnel dryer (TD)	57.5[b]

Data presented as arithmetic means ± SD (n = 2).

Means in column with different superscript letters are significantly different at $p<0.05$.

4.1.2 Drying kinetics at load test

4.1.2.1 Moisture content change

(i) Mango

Fig. 20 shows the moisture content changes in mango with drying time in three dryers. There was a significant ($p<0.05$) variation in moisture reduction between cabinet and tunnel dryers. The initial moisture content of 79% was reduced to 16 % in all dryers with the tunnel dryer

having the highest reduction per given unit time than the cabinet dryers. A shorter curved line observed for tunnel dryer compared to longer linear line shown by cabinet dryers which reflects longer drying time.

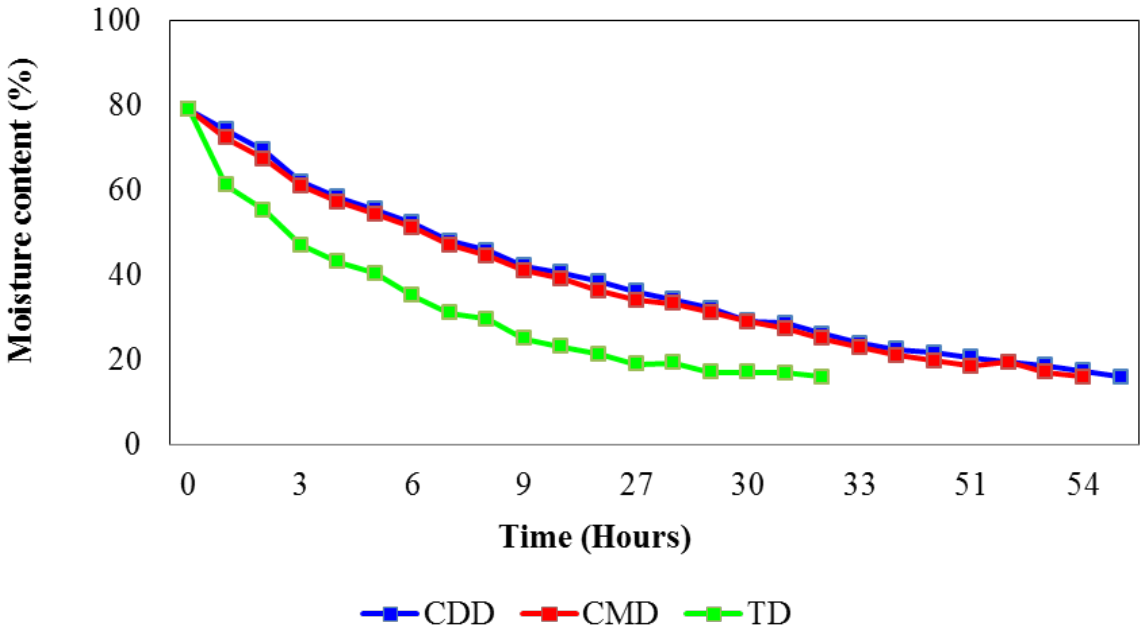

Figure : Variation of the moisture content of mango with the time during solar drying in cabinet direct (CDD), mixed mode (CMD) and tunnel (TD) dryers.

(ii) Banana

Fig. 21 shows the moisture content changes in banana with drying time in three dryers. There was a significant ($p<0.05$) variation in moisture reduction between cabinet and tunnel dryers. The initial moisture content of 72% was reduced to 17.1% in all dryers with the tunnel dryer having the highest reduction per given unit time than the cabinet dryers especially after the fourth hour of drying. A shorter curved line was observed for tunnel dryer compared to longer linear line shown by cabinet dryers, which reflects longer drying time.

Figure : Variation of the moisture content of banana with the time during solar drying in cabinet direct (CDD), mixed mode (CMD) and tunnel (TD) dryers.

(iii) Pineapple

Moisture content changes in pineapple with drying time in three dryers are shown in Fig. 22. There was a significant ($p<0.05$) variation in moisture reduction between cabinet and tunnel dryers. The initial moisture content of 80.6% was reduced to 15.2% in all dryers with the tunnel dryer having the highest reduction per given unit time than the cabinet dryers. A shorter curved line observed for tunnel dryer compared to longer linear line shown by cabinet dryers indicates longer drying time.

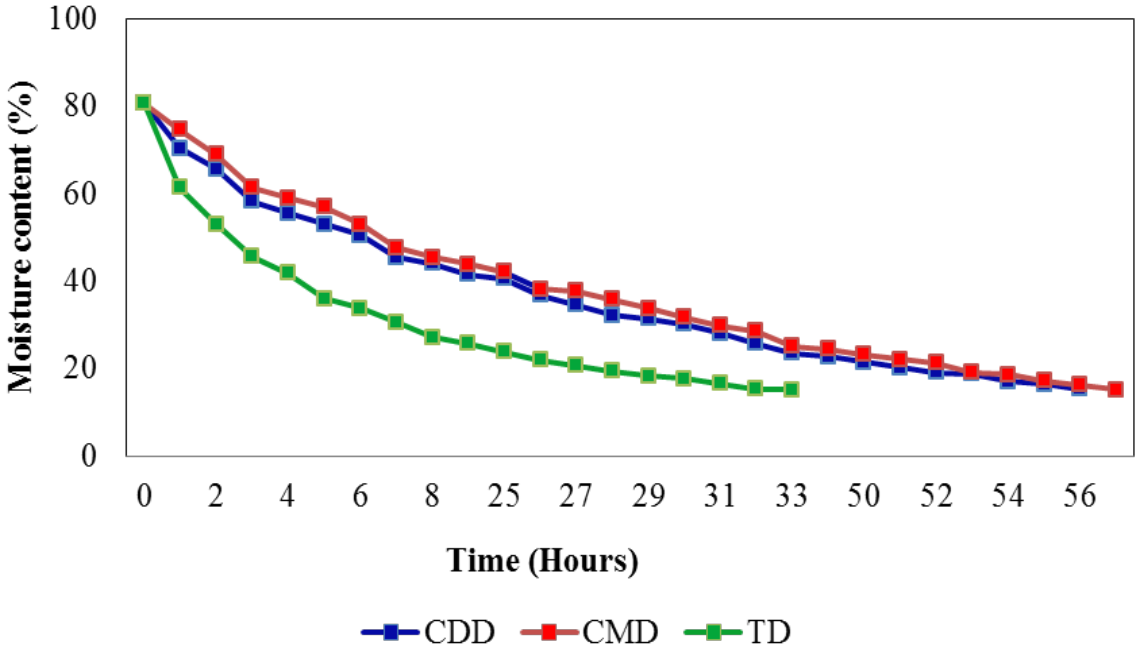

Figure : Variation of the moisture content of banana with the time during solar drying in cabinet direct (CDD), mixed mode (CMD) and tunnel (TD) dryers.

(iv) Tomato

The moisture content change in tomato with drying time is shown in Fig. 23: The initial moisture content of 93.18% (FW) was reduced to 14.1% (FW) in all dryers with the tunnel dryer having higher reduction per given unit time coupled with shorter drying time. Contrary to banana, all dryers had shorter curved lines reflecting shorter drying times.

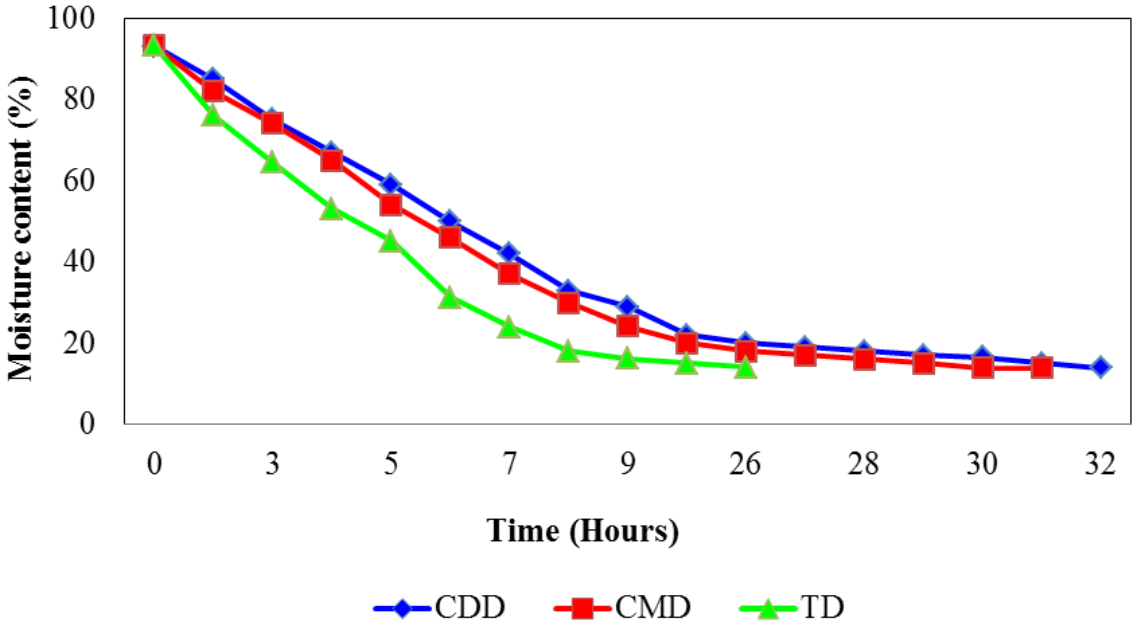

Figure : Variation of the moisture content of tomato with the time during solar drying in cabinet direct (CDD), mixed mode (CMD) and tunnel (TD) dryers.

4.1.2.2 Drying times and rates

Results for drying rates for mango, banana pineapple and tomato are shown in Table 8. There were significant ($p<0.05$) variations in drying rates between cabinet and tunnels dryers for both products at similar drying conditions and loading density of 2.91 kg/m^2. The tunnel dryer took 32 hours to dry 58.2 kg of mango from moisture content of 79 to 16 % (FW) with mean drying rate of 1.36 kg per hour while direct cabinet dryer (CDD) and mixed-mode (CMD) dryer took 55 and 54 hours to dry 9.6 and 8 kg of mango from same initial to final moisture contents ranges with mean drying rates of 0.13 and 0.11 kg/hour, respectively. Pineapple in all drying methods showed similar drying time and rate finding to these (Table 8).

Table : Drying times and rates of fruits and vegetable

Fruit	Dryer	Drying time (Hours)	Drying rate (Kg/hour)
Mango			
	CDD	55[a]	0.13[a]
	CMD	54[a]	0.11[a]
	TD	32[b]	1.36[b]
Banana			
	CDD	57[a]	0.11[a]
	CMD	58[a]	0.09[a]
	TD	33[b]	1.17[b]
Pineapple			
	CDD	56[a]	0.13[a]
	CMD	57[a]	0.11[a]
	TD	33[b]	1.35[b]
Tomato			
	CDD	31[a]	0.22[a]
	CMD	32[a]	0.17[a]
	TD	26[b]	1.57[b]

Data presented as arithmetic means ± SD (n = 2).

Means within fruit/vegetable in column with different superscript letters are significantly different at $p<0.05$.

Similar trend was also observed in banana, where tunnel dryer took 33 hours to dry 58.2 kg of products from moisture content of 72 to 17.1 % (FW) with mean drying rate of 0.1.17 kg per hour while direct cabinet dryer (CDD) and mixed-mode (CMD) dryer took 57 and 58 hours to dry 9.6 and 8 kg of banana from same initial to final moisture contents ranges with mean drying rates of 0.11 and 0.9 kg/hour respectively (Table 8). As for tomato, significantly ($p<0.005$) shorter drying times and higher drying rate for tunnel dryer were also observed. It took 26 hours to dry the same 58.2 kg of tomato from moisture content of 93.18 to 14% (FW) with mean drying rate of 2.06 kg/hour. The cabinet dryers (CDD and CMD) took 31 and 32 hours to dry 9.6 and 8 kg of tomato respectively to the same initial and final moisture contents values with drying rates of 0.28 and 0.24 kg/hr respectively.

These findings have revealed that, moisture content decreased with increasing drying time which agrees with other studies (Bala *et al.*, 2009; Eze and Agbo, 2011). The observed variations in drying kinetics (drying time and rate) between drying methods could greatly be influenced by temperature which is a determinant that affect the internal working principle of the dryer, the relative humidity of the drying air, airflow rates and material interconnection (Ajadi *et al.,* 2007; Kaya *et al.,* 2007). The drying air temperature had the greatest effect on the whole drying process, and on the drying time of fruits and vegetables within its increasing rate-period, constant rate-period and falling rate-period. Therefore, the better drying kinetics observed in tunnel dryers lied in its ability to collect more heat in the drying

chamber which in combination with its constant uniform air circulation control, immediately removes moisture collected in the drying chamber (Hawlader *et al.*, 2008). Gewali *et al*. (2005) reported similar finding showing better drying kinetics in tunnel dryer than solar cabinet dryers and thus accepted it to be suitable for drying almost all kinds of fruits and vegetables with satisfactory quality. Moreover, the variations in drying rates between products dried under the similar drying conditions and loading density as observed in this study could be explained by their differences in moisture contents and compositions (Alonge and Adeboye, 2012). Composition and structure of the food has influence on the mechanism of moisture removal, for instance, the orientation of fibres in vegetables (e.g. celery) allow more rapid moisture movement along their length than across the structure. In short, moisture is removed more easily from intercellular spaces than from within cells (Greensmith, 1998).

Different drying times of fruits and vegetables using solar dryer have been reported by several authors. According to Loma (2006), fruits dry in 2-6 days and vegetables in 3-5 days depending on temperatures and humidity while Coronet Consultant, (2006), reports 1-2 and 3 days to dry fruits and vegetables respectively using solar dryer which agrees with the findings of this study. Fruits are considered dry when there is no visible moisture, pieces are pliable, not sticky, and have lost approximately 80% moisture while dried vegetables become brittle with no visible moisture, shatter if hit with a hammer, and have lost approximately 90% moisture (Loma, 2006).

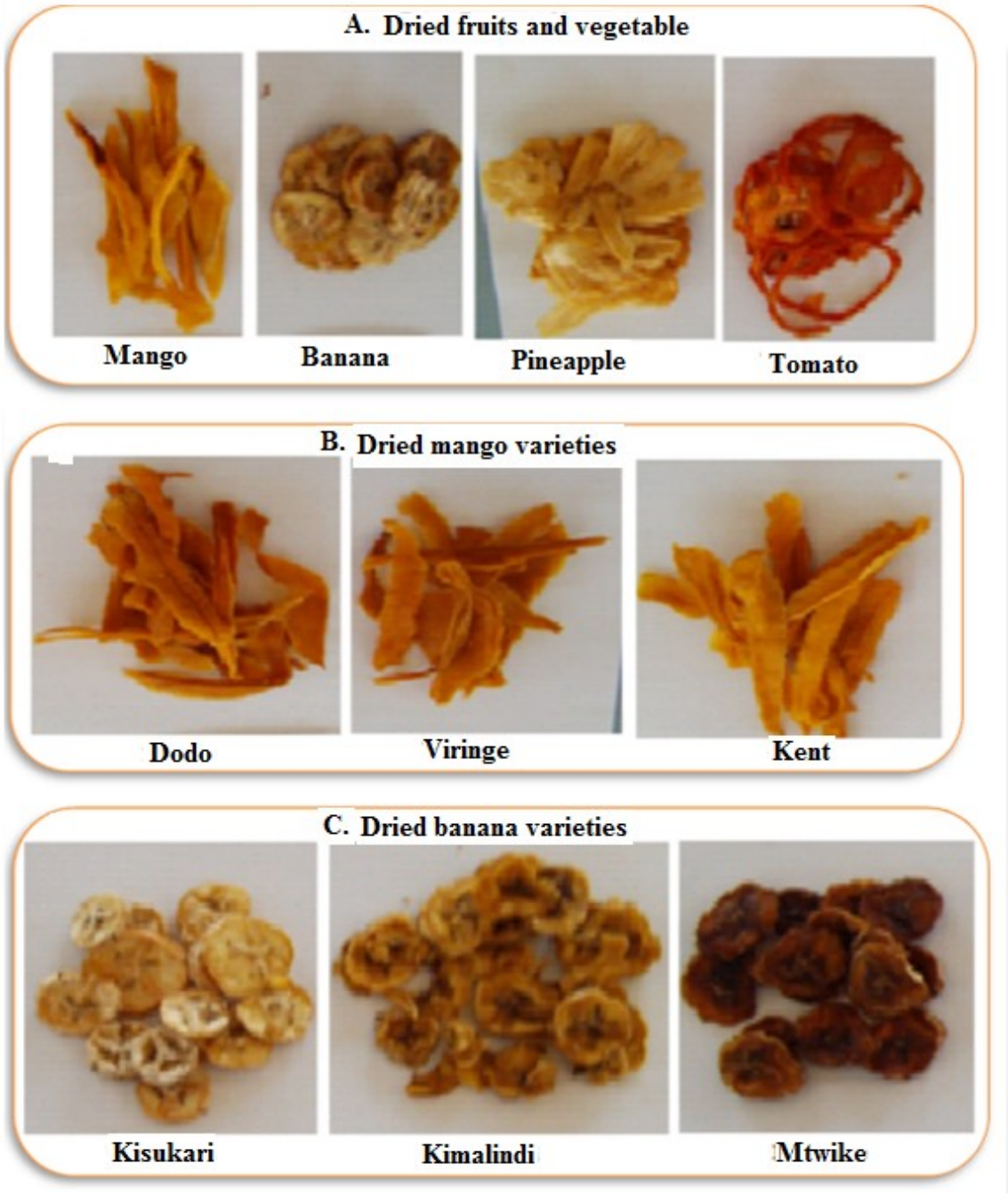

Plate : Dried fruit and vegetable samples (A), dried mango varieties (B) and dried banana varieties (C) (Photo courtesy: Mongi, R. J).

4.2 Effects of Solar Drying on Quality of Dried Fruits and Vegetables

4.2.1 Biochemical quality

4.2.1.1 pH and Acidity

(i) Mango

The pH and titratable acidity of mango varieties are shown in Table 9. The results show variation between varieties with cv. *Kent* having highest pH with corresponding lowest acidity than cv. *Dodo and Viringe*. Furthermore, fresh samples for all varieties had significantly ($p<0.05$) higher pH values ranging from 3.46 to 4.27 with corresponding lower acidity values than dried ones with values ranged from 3.23 to 4.20. The variation between drying methods was significant ($p<0.05$) with cabinet dried samples having higher pH values that ranged from 3.20 to 4.20 than tunnel dried samples with pH value ranging from 3.23 to 4.12.

(ii) Banana

Table 10 shows pH and titratable acidity of fresh and dried banana varieties. The results show that, banana had highest pH values with corresponding lowest acidity values than pineapple, mango, and tomato samples. The pH values ranged from 4.53 to 4.68 in *cv. Kisukari*, 4.51 to 4.67 in cv. *Kimalindi* and 4.58 to 4.68 in cv. *Mtwike*. No significant ($p<0.05$) variation in pH was observed between varieties. The results also showed a significant variation between fresh and dried samples in all varieties. Fresh samples had higher values ranging from 4.67 to 4.68 than dried samples that ranged from 4.51 to 4.63. The

variation between drying methods was significant ($p<0.05$) with cabinet dried samples having higher pH values than tunnel dried samples.

Table : pH and acidity of fresh and dried mango varieties

Variety	Drying method	pH	Titratable Acidity (%)
Dodo	Fresh (FR)	3.83^{a}	0.77a
	Cabinet direct dryer (CDD)	3.76^{b}	0.83^{b}
	Cabinet mixed-mode dryer (CMD)	3.74^{b}	0.85^{b}
	Tunnel dryer (TD)	3.67^{c}	0.90^{c}
Kent	Fresh (FR)	4.27^{a}	0.47^{a}
	Cabinet direct dryer (CDD)	4.20^{b}	0.51^{b}
	Cabinet mixed-mode dryer (CMD)	4.18^{b}	0.49^{b}
	Tunnel dryer (TD)	4.12^{c}	0.54^{c}
Tanga	Fresh (FR)	3.46^{a}	1.07^{a}
	Cabinet direct dryer (CDD)	3.36^{b}	1.15^{b}
	Cabinet mixed-mode dryer (CMD)	3.33^{b}	1.18^{b}
	Tunnel dryer (TD)	3.23^{c}	1.25^{c}

Data presented as arithmetic means ± SD (n = 3).

Means within variety in column with different superscript letters are significantly different ($p<0.05$).

Table : pH and acidity of fresh and dried banana varieties

Variety	Drying method	pH	Titratable Acidity (%)
Kisukari			
	Fresh (FR)	4.68[a]	0.09[a]
	Cabinet direct dryer (CDD)	4.63[b]	0.13[b]
	Cabinet mixed-mode dryer (CMD)	4.61[c]	0.14[c]
	Tunnel dryer (TD)	4.53[d]	0.21[c]
Kimalindi			
	Fresh (FR)	4.67[a]	0.09[a]
	Cabinet direct dryer (CDD)	4.61[b]	0.14$_b$
	Cabinet mixed-mode dryer (CMD)	4.59[b]	0.15b
	Tunnel dryer (TD)	4.51[c]	0.22[c]
Mtwike			
	Fresh (FR)	4.68[a]	0.09[a]
	Cabinet direct dryer (CDD)	4.64[b]	0.12[b]
	Cabinet mixed-mode dryer (CMD)	4.61[b]	0.14[b]
	Tunnel dryer (TD)	4.58[c]	0.17[c]

Data presented as arithmetic means ± SD (n = 3).

Means within variety in column with different superscript letters are significantly different ($p<0.05$).

4.2.1.3 Pineapple

The pH and titratable acidity of pineapple variety are shown in Table 11. There was a significant variation in pH and acidity values between the drying methods. Fresh samples had highest pH values 3.73 with corresponding lowest acidity value of 0.85 % compared to dried

samples having pH values ranging from 3.53-3.69 with corresponding higher acidity value that ranged from 0.88-1.012 %.

Table : pH and acidity of fresh and dried pineapple varieties

Variety	Drying method	pH	Titratable Acidity (%)
S. Cayenne	Fresh (FR)	3.73 a	0.85[a]
	Cabinet direct dryer (CDD)	3.69[b]	0.88[b]
	Cabinet mixed-mode dryer (CMD)	3.63[b]	0.93[b]
	Tunnel dryer (TD)	3.53[c]	1.012[c]

Data presented as arithmetic means ± SD (n = 3).

Means in column with different superscript letters are significantly different ($p<0.05$).

4.2.1.4 Tomato

Table 12 shows pH and titratable acidity of tomato varieties. The results show that tomato had the relatively higher pH values with corresponding lower acidity than mango and pineapple but lower than banana. The pH values ranged from 4.47 to 4.59 in *cv. Tanya*, 4.5 to 4.6 in cv. *Cal J* and 4.48 to 4.58 in cv. *Onyx*. No significant ($p>0.05$) variation in pH was observed between varieties. The results also showed a significant variation between fresh and dried samples in all varieties with fresh samples having higher values than dried samples (Table 12). The effect of drying methods was significant ($p<0.05$) with

cabinet dried samples having higher pH values than tunnel dried samples.

Table : pH and acidity of fresh and dried tomato varieties

Var.	Drying method	pH	Titratable Acidity(%)
Tanya	Fresh (FR)	4.59[a]	0.16[a]
	Cabinet direct dryer (CDD)	4.56[b]	0.18[b]
	Cabinet mixed-mode dryer (CMD)	4.51[b]	0.22[b]
	Tunnel dryer (TD)	4.47[c]	0.25[c]
Cal J	Fresh (FR)	4.6[a]	0.15[a]
	Cabinet direct dryer (CDD)	4.55[b]	0.19[b]
	Cabinet mixed-mode dryer (CMD)	4.52[b]	0.21[b]
	Tunnel dryer (TD)	4.5[c]	0.23[c]
Onyx	Fresh (FR)	4.58[a]	0.17[a]
	Cabinet direct dryer (CDD)	4.54[b]	0.20[b]
	Cabinet mixed-mode dryer (CMD)	4.5[b]	0.23[b]
	Tunnel dryer (TD)	4.48[c]	0.25[c]

Data presented as arithmetic means ± SD (n = 3).

Means within variety in column with different superscript letters are significantly different ($p<0.05$).

The pH and acidity varies between fruits and vegetables and there are inversely related. The low pH in mango and pineapple and high pH in banana and tomato agree with the statement that, most fruits have low

pH and acidic in nature while most vegetables have high pH and less acidic. Food and Drug Authority (2010) defined low-acid food as the one to which acid(s) or acid food(s) has been added to produce a finished equilibrium pH of 4.6 or below. Fruit acidity is an important component of fruit organoleptic quality and is mainly due to the presence of malic and citric acids, the main organic acids found in most ripe fruits (Bugaud *et al*., 2013).

These findings suggest that, solar drying has significant effect on the pH of fruits and vegetables. The pH reduction in dried samples could be associated with concentration of organic acids due to remove of water and similar finding was also reported by Hii *et al*., 2009) and Afolabi *et al*. (2011). The combination of concentrated organic acids and low water activity in dried fruits offers protection against microbial growth and thus prolong their shelf lives. Probably this explains why fruits in this study were more stable with a longer shelf life than vegetable. Apart from microbial protection, titratable acidity is an indication of the degree of sourness of fruits (Afolabi *et al*., 2011).

Moreover, different drying kinetics of the dryers could be accounted for the observed variations in pH and titratable acidity among the dried samples. Slow drying process lead to evaporation/and or degradation of more organic acids than fast process (Hii *et al*., 2009) which could probably be one of the reasons why cabinet dried samples had higher pH values than tunnel dried samples. Gallali *et al*. (2000) and Hii *et al*.

(2009) have also reported the effect of drying methods on pH and acidity of fruits and vegetables.

4.2.2 Phytochemicals

4.2.2.1 Total phenolic compounds (TPC)

The total phenolic compounds (TPC) of fresh and dried fruit and vegetable varieties are shown in Table 13. The results showed a significant differences ($p<0.05$) in TPC among the fresh fruits and vegetable analysed. The significant highest TPC contents (mgGAE/100g DM) were found in tomato cv. *Onyx* (538.9±1.4), followed by mango cv. *Dodo* (315.3±5.4), pineapple cv. *Smooth cayenne* (282.9±4.2) and the lowest in banana cv. *Kisukari* (139.3±2.3). The effect of drying methods on TPC was significant ($p<0.05$). All fresh samples had higher TPC levels but decline significantly in dried samples with exception of tunnel dried tomatoes. The cabinet direct and mixed mode samples had statistically similar values ($p>0.05$).

Table : Total phenolic contents (mgGAE/100g DM) of fresh and dried fruits and vegetables

Fruit/Veg	Var	Drying method			
		FR	CDD	CMD	TD
		Mean	Mean (%)	Mean (%)	Mean (%)
Banana		315.3±5.4[a]	261.3 ± 6.7 (83)[b]	263.4 ± 3.1 (84)[b]	291.8 ± 5.4 (93)[c]
	Viringe	311.4±1.5[a]	261.6 ± 1.3 (84)[b]	259.2 ± 3.8 (83)[b]	292.9 ± 0.6 (94)[c]
	Kent	239.4±7.9[a]	184.3 ± 1.8 (77)[b]	181.1 ± 0.8 (76)[b]	201.5 ± 4.4 (84)[c]
	Kisukari	139.3±2.3[a]	81.2 ± 0.5 (58)[b]	83.0 ± 0.8 (59)[b]	105.96 ± 2.1 (76)[c]
	Kimalind	189.2±2.7[a]	116.9 ± 0.8 (62)[b]	118.1 ± 1.5 (62)[b]	145.90 ± 6.4 (77)[c]
	Mtwike	173.6±4.2[a]	98.5 ± 0.4 (57)[b]	100.3 ± 1.8 (58)[b]	133.70 ± 4.4 (77)[c]
Pineapple	*Smooth cayenne*	282.9±4.2[a]	226.7 ± 3.1 (80)[b]	232.8 ± 4.6 (82)[b]	262.5 ± 4.5 (92)[c]
Tomato	*Tanya*	476.6±8.6[a]	448.2 ± 0.8 (94)[b]	454.6 ± 3.1 (95)[b]	587.2 ± 1.3 (123)[c]
	Cal J	448.2±5.8[a]	418.1 ± 4.8 (79)[b]	415.7 ± 2.8 (79)[b]	588.1 ± 5.8 (112)[c]
	Onyx	538.9±1.4[a]	512.9 ± 0.9 (95)[b]	511.6 ± 1.7 (95)[b]	675.5 ± 1.5 (125)[c]

Data presented as arithmetic means ± SD (n = 3).
Data in parentheses represent percent recovery relative to untreated.
Means within fruit/ vegetable in row with different superscript letters are significantly different ($p<0.05$).

The effect of varieties in percentage TPC recovery of dried products in each drying methods are shown in Fig. 24: There were significant differences ($p<0.05$) in recoveries between the fruits/vegetable species and between the varieties within the specie in each dryer. The highest recoveries between the species were found in mango varieties (82.87-94.06%) and the lowest in banana varieties (56.79-77.05%). The highest recoveries between the varieties within the species for all drying methods were found in *Viringe* for mango (83.23-94.05%), *Kimalindi* for banana (61.79-77.10%) and *Onyx* for tomato (81.88-90.62%). *Kent*, *Kisukari* and *Cal J* varieties of mango, banana and tomato had the lowest percentage recoveries in drying method.

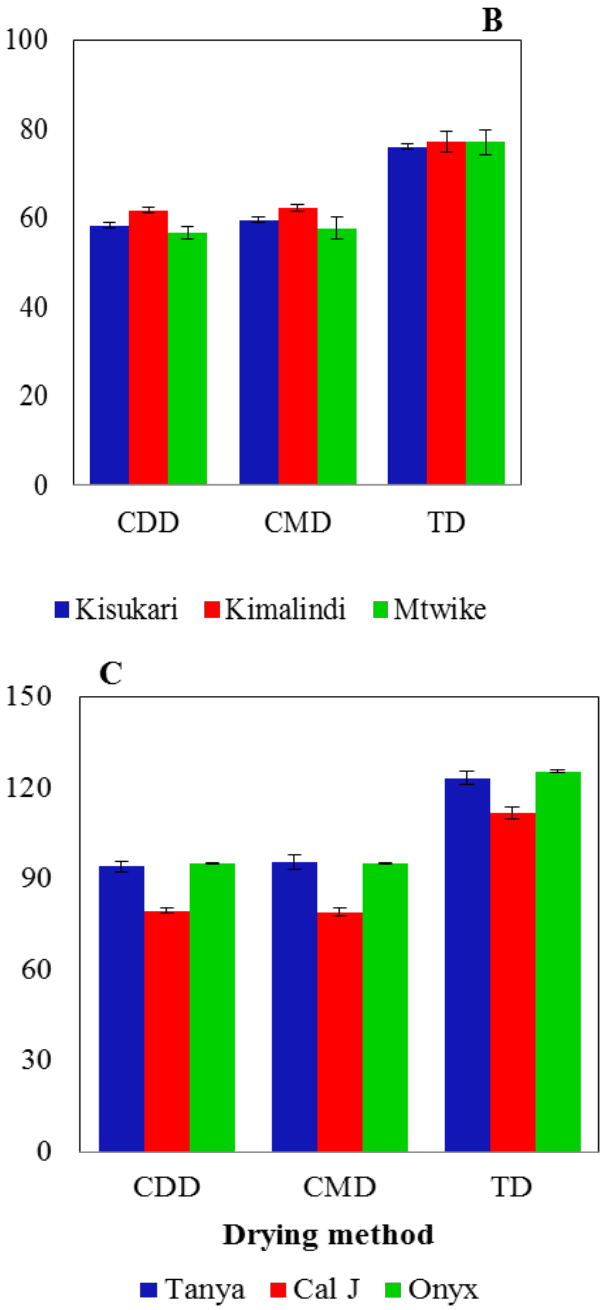

Figure : **Recoveries of TPC in varieties of Mango (A), Banana (B) and Tomato (C) in three drying methods (mean±SD, n=3). Bars with different letter indicates means are significantly different at $p<0.05$ for varieties in each drying method.**

The level of polyphenolic compounds present in fruits and vegetable depends on cultivar, growth condition (soil, fertilizer, temperature, and cultivation techniques), storage, transport conditions and processing technology (Bennett *et al.*, 2011). The findings suggest that, drying has variable effects on TPC contents of plant samples. It could result in little or no change, significant declines or enhancement of the TPC (Hamroun-Sellami *et al.*, 2013). Chang *et al*. (2006) found that, all methods of thermal drying (microwave, oven and sun drying) resulted in sharp decline in TPC in dried vegetable leaves. The decline is attributed to degradation of phenols during drying (Suvarnakuta *et al.*, 2011). Bennett *et al.* (2011) reported that, the phenolics present in fresh fruit and vegetables are susceptible to oxidative degradation by polyphenol oxidase (PPO) during drying, which leads to intermolecular condensation reactions and their amount decreased. Similar decline in polyphenolic content after drying has been reported in prune (Caro *et al.*, 2004), persimmons (Park *et al.*, 2006), mulberry leaves (Katsube *et al.*, 2009), apricots (Madrau *et al.*, 2008), olive mill waste (Obied *et al.*, 2008) and ginger leaves (Chan *et al.*, 2009).

Among the dried samples, the tunnel dried samples had less percentage phenolic loss (6-16%) than cabinet dried samples (17-42%). This difference might be due to greater enzymatic degradation by PPO as direct and mixed mode dryers took comparatively longer drying time compared to tunnel drier resulting to additional enzymatic reactions (Chan *et al.*, 2009). The higher TPC contents in tunnel dried tomato than fresh samples and generally lower decline in TPC for other tunnel dried

samples could be attributed to the release of more bound phenolic compounds from breakdown of cellular constituents due to high drying temperature (Boetang *et al.*, 2008; Vega-Galves *et al.*, 2009). Along with that, the application of temperature in the 70-90ºC range associated with faster dehydration reduces the opportunity for PPO oxidation process that accompanies drying (Uhlig and Walker, 1996). This is consistent with the findings of this study. Similar increase in polyphenolic contents after drying has been reported in sweet potatoes (Mao *et al.*, 2010), prune (Caro *et al.*, 2004) tomatoes (Dewanto *et al.*, 2002; Chang *et al.*, 2006) and shiitake mushroom (Choi *et al.*, 2006). In general, the significant effect of different drying methods on total phenolic compound of fruits, vegetables and herbs has been widely reported (Zhang *et al.*, 2012; Hamrouni-Sellami, 2013). These findings suggest that, amongst other factors, such as maturity stage and light exposure, phenolic composition varies with cultivars (Segura-Carretero *et al.*, 2010). Similar variation in TPC between varieties of the fruits were reported in dried apricot (Madrau *et al.*, 2009), palm (Piga *et al.*, 2005) and mango (Ribeiro, *et al.*, 2007).

4.2.1.2 Ferric Reducing Antioxidant Power (FRAP)

The mean Ferric Reducing Antioxidant Power (FRAP) of fresh and dried fruits and vegetables varieties are shown in Table 14. The results showed a significant differences ($p<0.05$) in FRAP between fresh fruits/vegetable analysed. The significant highest FRAP contents (µmol/100g DM) were found in tomato cv. *Tanya* (46.8±0.5), followed by mango cv. *Viringe* (28.5±0.4), pineapple cv. *Smooth cayenne* (24.8±0.5)

and the lowest in banana cv. *Kisukari* (10.8±0.1). The influence of drying methods on FRAP level was significant ($p<0.05$). Fresh samples had higher FRAP levels but decreased significantly in dried samples in all drying methods. Tunnel dried samples had significantly less FRAP loss (6-13%) than cabinet dried samples (14-56%) The direct and mixed dried samples were statistically similar ($p>0.05$) in antioxidant activity.

Table : Ferric Reducing Activity Power (FRAP) (µmol/100 g DM) of fresh and dried fruits and vegetables varieties of three solar drying methods

Fruit	Var.	Drying method			
		Fresh	**Direct**	**Mixed**	**Tunnel**
		Mean	Mean (%)	Mean (%)	Mean (%)
Mango	*Dodo*	27.3 ± 0.3[a]	21.3 ± 0.2[b](79)	21.6 ± 0.1[b] (80)	25.1 ± 0.4[c] (93)
	Viringe	28.5 ± 0.4[a]	24.2 ± 0.5 [b](86)	24.1 ± 0.1[b] (86)	26.9 ±0.5[c] (96)
	Kent	23.1 ± 0.4[a]	15.1 ± 0.2 [b](65)	14.9 ± 0.2[b] (64)	20.3 ± 0.2[c] (88)
Banana	*Kisukari*	10.8±0.1[a]	5.7 ± 0.1 [b](53)	6.0 ± 0.2[b] (55)	8.5 ± 0.2[c] (78)
	Kimalind	15.8±0.2[a]	8.6 ± 0.0[b] (55)	8.9 ± 0.0 [b](57)	12.6 ± 0.5[c] (80)
	Mtwike	14.5±0.2[a]	6.4 ± 0.0[b] (44)	6.7±0.0[b] (46)	13.1 ± 0.3[c] (90)
Pineapple	*Smooth cayenn*	24.8±0.5[a]	18.4 ± 0.2[b] (74)	18.2 ± 0.1[b] (73)	23.1 ± 0.3[c] (93)

	e				
Tomato	*Tanya*	46.8±0.5[a]	27.9±0.3[b] (60)	28.3±0.4[b] (60)	43.0±0.4[c] (92)
	Cal J	44.6±1.6[a]	23.8±0.5[b] (53)	24.4±0.3[b] (55)	39.2±0.4[c] (88)
	Onyx	44.6± 0.3[a]	26.5±0.2[b](59)	25.7±0.6[b] (58)	38.6± 0.3[c](87)

Data presented as arithmetic means ± SD (n = 3).
Data in parentheses represent percent recovery relative to untreated.
Means within fruit/vegetable in row with different superscript letter are significantly different ($p<0.05$).

The influence of varieties in percentage FRAP recoveries within each fruit/vegetable samples in each drying method was significant ($p<0.05$) as indicated in Fig. 25. The highest recoveries were found in *Viringe* for mango (83.23-94.05%), *Kimalindi* for banana (61.79-77.10%) and *Onyx* for tomato (81.88-90.62%).

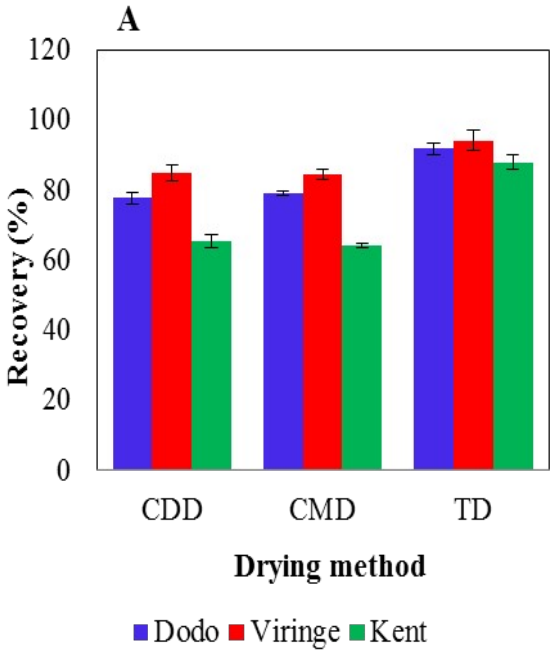

Figure : Recoveries of FRAP in three varieties of Mango (A), Banana (B) and Tomato (C) in three drying methods (mean±SEM, n=3). Bar means with different letter are significantly different at p<0.05 for varieties in each drying method.

The differences in the antioxidant activities among the fruits and vegetables samples could be attributed to their polyphenol contents and composition and to other non-phenolic antioxidants present in samples such as vitamin C, vitamin E, Mallard reaction products, β-carotene and lycopene (Hassanien, 2008; Ali, 2010). Drying affects the antioxidant activity of fruits and vegetables differently (Kuljarachanan *et al.*, 2009; Chantaro *et al.*, 2008; Choi *et al.*, 2006). Chemical and enzymatic processes during drying and/or storage can lead to either loss of phenolic-related antioxidant capacity or may generate chemical derivatives with little or no change, significant declines or enhancement in antioxidant capacity (Bennet *et al.*, 2011). Nevertheless, the best drying method leads to the least alteration in phenolic content and enhances antioxidant activity of the sample. Madrau *et al.* (2009) found that, high drying temperature gave a product with better polyphenol content with enhanced antioxidant activity. Similar effect of drying on antioxidant capacity of fruits and vegetable has been reported in apple (Anwar *et al.*, 2011), sage (Hamrouni-Sellami, 2013) and blume

(Sathishkumar *et al.*, 2009). The influence of varieties in antioxidant capacity of dried fruits has also been reported in apricot (Madrau *et al.*, 2009).

4.2.1.3 Correlation between TPC and FRAP

The correlation analysis between total phenolic and antioxidant activity of the fresh and dried fruits and vegetable are shown in Fig. 26: There were a strong positive correlations between the TPC and antioxidant activities in fresh (R^2 = 0.9709) and dried samples (R^2 = 0.8636). About 97.09 and 86.36 % of variability in FRAP value (antioxidant activity) in fresh and dried fruits respectively, are explained by total phenolic contents. This finding implies that, the antioxidant activity of plants materials including fruits and vegetables are strongly dependent on the TP contents (Anwar *et al.*, 2011; Zhang *et al.*, 2012). Similar correlation between total phenolic contents and antioxidant activities in plants have widely been reported in various studies (Zhao *et al.*, 2010; Sreeramulu *et al.*, 2010; Mao *et al.*, 2010).

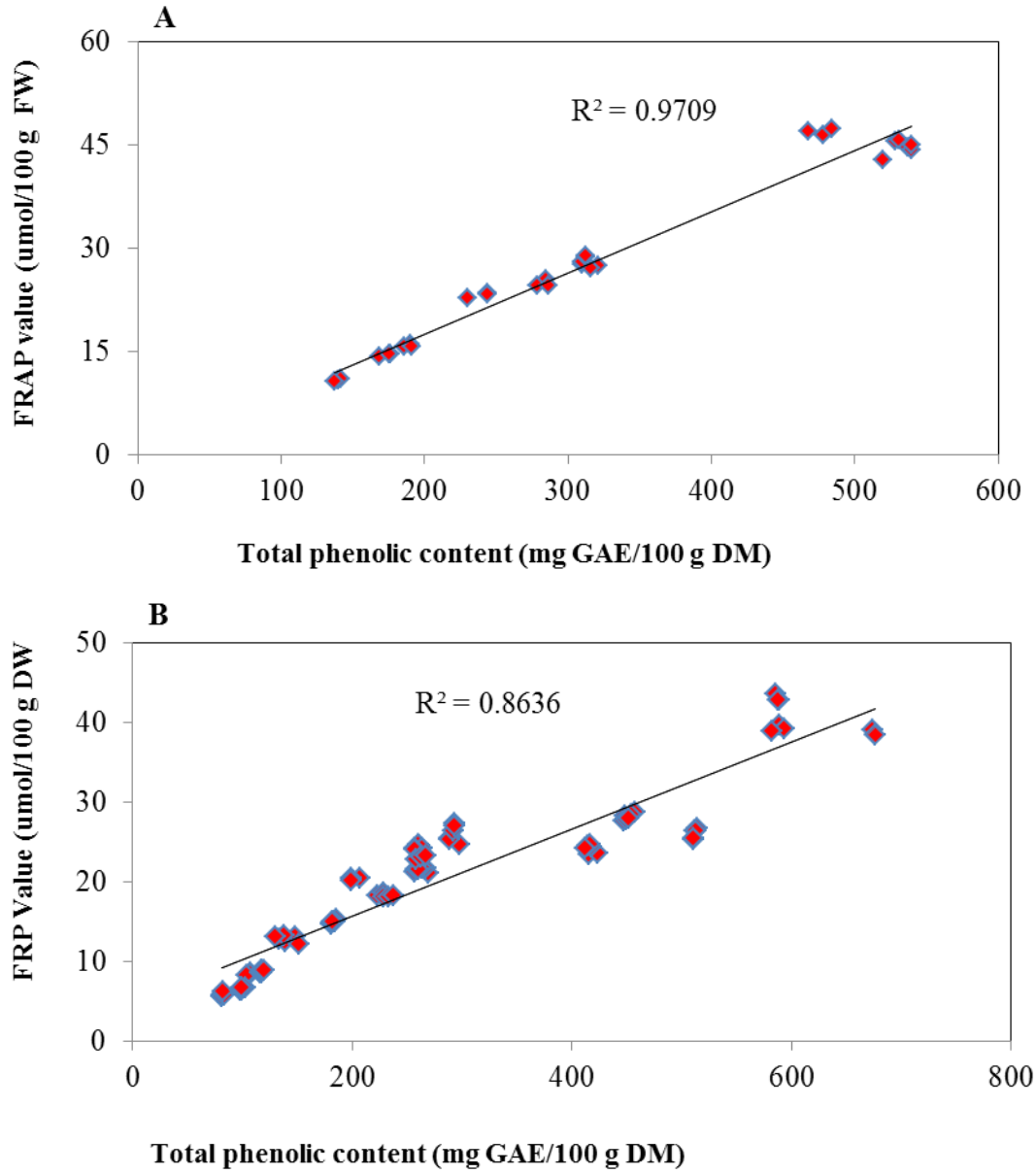

Figure : Correlation between total phenolic contents and FRAP in fresh (A) and dried (B) fruits and vegetable.

4.2.3 Nutritional quality

4.2.3.1 Proximate composition

(i) Mango

The proximate composition of fresh and dried mango varieties (g/ 100g DM) is shown in Table 15. The results show that, there were significant

differences ($p<0.05$) in proximate values between fresh and dried samples. Fresh samples had highest moisture ranging from 77.8±0.2 to 79.1±0.1 g/100 g FW, protein ranging from 4.0±0.1 to 4.5±0.1 and fat contents ranging from 1.3±0.0 to 1.4±0.1 g/100g DM respectively than cabinet and tunnel dried samples. The variations in proximate values between the drying methods were also significant ($p<0.05$). The cabinet dried samples had higher moisture, protein and fat contents than the tunnel while on the other hand, the dried samples had significantly ($p<0.05$) higher fibre, ash and carbohydrate contents than their fresh counterparts.

The variations between the drying methods were significant ($p <0.05$). The cabinet dried sample had higher moisture and protein contents than tunnel dried samples, which had higher fat, ash, fibre and carbohydrate contents than tunnel dried samples. The percentage recovery results showed that, between 79-80% protein, 64-65% fat, 98-100% crude fibre and 96-97% ash were retained in cabinet dried samples while between 73% protein, 78-80% fat, 100% of crude fibre and 100% of ash were retained in tunnel dried samples as shown in Table 15.

Table : Proximate composition (g/100 g) and percentage recoveries (%) of fresh and dried mango varieties between different drying methods

Cultivar	Drying method	MC (WB)	Protein (DM)	Fat (DM)	Crude fibre (DM)	Ash (DM)	CHO (DM)
Dodo	FR	79	4.5±0.1^{a}	1.3±0.0^{a}	4.4±0.1^{a}	2.7±0.0^{c}	8.1
	CDD	16.5	3.6±0.1^{b} (80)	0.9±0.0^{c} (69)	4.3±0.2^{a} (98)	2.6±0.6^{b} (97)	72.1
	CMD	16	3.6±0.1^{b} (80)	0.9±0.0^{c} (69)	4.2±0.3^{a} (97)	2.6±0.1^{b} (96)	72.7
	TD	14	3.4±0.1^{c} (73)	1.1±0.3^{b} (85)	4.4±1.3^{a} (100)	2.7±0.3^{a} (100)	74.4
Viringe	FR	79.1	4.2±0.2^{a}	1.4±0.1^{a}	4.4±0.0^{c}	2.6±0.1^{c}	8.6
	CDD	16.4	3.4±0.1^{b} (79)	0.9±0.1^{c} (64)	4.3±0.5 ^{a}(98)	2.5±0.1^{b} (96)	72.5
	CMD	16.2	3.4±0.1 ^{b} (79)	0.9±0.1 ^{c}(65)	4.3±0.6^{a} (98)	2.6±0.4^{b} (97)	72.6
	TD	14.1	3.1±0.1^{c} (73)	1.1±0.2 ^{b}(78)	4.4±0.9^{a} (100)	2.7±0.1^{a} (100)	74.6
Kent	FR	77.8	4.0±0.0^{a}	1.3±0.1^{a}	4.0±0.1^{c}	2.8±0.0^{c}	9.9
	CDD	16.6	3.2±0.1^{b} (79)	0.8±0.2^{c} (65)	3.9±0.3^{a} (97)	2.7±0.1^{b} (97)	72.6
	CMD	16.7	3.2±0.2^{b} (79)	0.8±0.2^{c} (65)	3.9±0.1 ^{a}(97)	2.7±0.4^{b} (96)	72.5
	TD	13.9	2.9±0.1^{c} (73)	1.0±0.7 ^{b}(80)	4.0±1.1^{a} (100)	2.8±0.4 ^{a}(100)	75.2

Data presented as arithmetic means ± SD (n = 3).
Data in parentheses represent percent recovery relative to untreated.
Means within variety in column with different superscript letters are significantly different at $p<0.05$.

The effect of variety on proximate composition of fresh sample and dried samples within drying methods is shown in Table 16. The results show that, among fresh samples, *Dodo* variety had highest protein and fibre contents of 4.5±0.1 and 4.4±0.1 g/100g DM, respectively, while *Kent* variety had lowest values of 4.0±0.0 and 4.0±0.1 g/100g DM respectively. *Viringe* variety had statistically similar proximate values to Dodo, except for protein. Moreover, the results showed significant (p>0.05) varietal variations in percentage fat recoveries in each drying methods with *Dodo* variety having higher values (69-85%) than *Viringe* and *Kent* varieties (64-80%) (Table 16).

Table : Proximate composition (g/100 g) and percentage recoveries (%) between dried mango varieties in different drying methods

Drying method	Var.	Protein	Fat	Crude fibre	Ash	CHO
FR	*Dodo*	4.5±0.1[a]	1.3±0.0[a]	4.4±0.1[a]	2.7±0.0[c]	79
	Viringe	4.2±0.2[b]	1.4±0.1[a]	4.4±0.0[a]	2.6±0.1[c]	79.1
	Kent	4.0±0.0[c]	1.3±0.1[a]	4.0±0.1[b]	2.8±0.0[c]	77.8
CDD	*Dodo*	3.6±0.2(80)[a]	0.9±0.0 (69)[a]	4.3±0.2 (98)[a]	2.6±0.1 (97)[a]	72.1
	Viringe	3.4±0.1 (80)[a]	0.9±0.1(64)[b]	4.3±0.5(98)[a]	2.5±0.1 (96)[a]	72.5
	Kent	3.2±0.1 (79)[a]	0.8±0.2 (65)[b]	3.9±0.3(97)[a]	2.7±0.0 (97)[a]	72.6
CMD	*Dodo*	3.6±0.1 (80)[a]	0.9±0.0 (69)[a]	4.2±0.3 (97)[a]	2.6±0.1(96)[a]	72.7
	Viringe	3.4±0.1 (79)[a]	0.9±0.1 (65)[b]	4.3±0.6 (98)[a]	2.6±0.0 (97)[a]	72.6
	Kent	3.2±0.2 (79)[a]	0.9±0.0 (65)[b]	3.9±0.1 (97)[a]	2.7±0.2(96)[a]	72.5
TD	*Dodo*	3.4±0.1 (73)[a]	1.1±0.3 (85)[a]	4.4±1.3 (100)[a]	2.7±0.0 (100)[a]	74.4
	Viringe	3.1±0.1 (73)[a]	1.1±0.2 (78)[b]	4.4±0.9 (100)[a]	2.7±0.1 (100)[a]	74.6
	Kent	2.9±0.1 (73)[a]	1.0±0.7 (80)[b]	4.0±1.1 (100)[a]	2.8±0.0 (100)[a]	75.2

Data presented as arithmetic means ± SD (n = 3).

Data in parentheses represent percent recovery relative to untreated. Means within drying method in column with different superscript letters are significantly different at $p<0.05$.

(ii) Banana

Table 17 shows the proximate composition of fresh and dried banana varieties. There were significant differences ($p<0.05$) between fresh and dried samples. Fresh samples had highest moisture, protein and fat contents that ranged from 70.8±0.2 to 71.7±0.1 g/100 FW, 4.1±0.1 to 4.7±0.1 and 1.1±0.0 to 1.9±0.1 g/100g DM respectively than cabinet and tunnel dried samples. The cabinet dried samples had moisture, protein and fat content ranging from 16.6±0.1 to 17.8±0.1, 3.3±0.1 to 3.9±0.1 and 0.7±0.1 to 0.8±0.1 g/100g DM respectively while the tunnel dried samples had moisture, protein and fat content ranged from 13.9-15.3, 2.9 ± 0.1 to 3.3±0.1 and 0.9 to 1.0 g/100g DM respectively. The dried samples, however had significantly ($p<0.05$) higher fibre, ash and carbohydrate contents than their fresh counterparts.

The obtained results also show that, variation between the drying methods were significant ($p <0.05$) with cabinet dried sample having higher moisture and protein contents than tunnel dried samples. Furthermore, it has been observed that, between 72-84% protein, 64-70% fat, 97-100% crude fibre and 97-99% ash were retained in cabinet dried samples while 72-74% protein, 75-81%, fat, 100 % of crude fibre and 99-100% % ash were retained in tunnel dried samples during drying (Table 17).

Table : Proximate composition (g/100 g) and percentage recoveries (%) of fresh and dried banana varieties

Cultivar	Drying method	MC (WB)	Protein	Ether extract DM)	Crude fibre	Ash	CHO
Kisukari							
	FR	70.8	4.1±0.1[a]	1.1±0.0[a]	2.0±0.3[a]	2.7±0.1[a]	19.3
	CDD	16.6	3.3±0.0[b] (82)	0.8±0.0[c] (70)	1.9±0.7[a](97)	2.7±0.4[a] (98)	74.7
	CMD	16.7	3.4±0.1[b] (84)	0.7±0.0[c] (68)	1.9±0.8[a] (98)	2.6±0.3[a] (97)	74.7
	TD	13.9	2.9±0.1[c] (72)	0.9±0.1[b] (81)	2.0±0.8[a] (100)	2.7±0.1[a] (99)	77.6
Kimalindi							
	FR	71.7	4.7±0.2[a]	1.2±0.0[a]	2.0±0.3[a]	2.7±0.0[a]	17.7
	CDD	17.8	3.8±0.1[b] (82)	0.8±0.0[c] (64)	2.0±0.5[a] (100)	2.6±0.3[a] (97)	72.9
	CMD	17.8	3.9±0.1[b] (84)	0.8±0.0[c] (65)	1.9±0.6[a] (97)	2.7±0.2[a] (99)	72.9
	TD	14	3.3±0.5[c] (72)	0.9±0.1[b] (75[)]	2.0±0.1[a] (100)	2.7±0.3[a] (100)	77.1
Mtwike							
	FR	71.4	4.4±0.1[a]	1.2±0.0[a]	2.1±0.2[a]	2.8±0.1[a]	18.1
	CDD	17.7	3.8±0.1[b] (74)	0.8±0.1[c] (67)	2.1±0.3[a] (100)	2.7±0.1[a] (97)	72.9
	CMD	17.1	3.7±0.2[b] (72[)]	0.8±0.1[c] (66)	2.1±0.9[a]	2.7±0.1[a] (97)	73.6

TD	15.3	3.2±0.1[c] (74)	1.0±0.0[b] (79)	2.1 ±0.8[a] (100)	2.7±0.1[a] (99)	75.7

Data presented as arithmetic means ± SD (n = 3).

Data in parentheses represent percent recovery relative to untreated.

Means within variety in column with different superscript letters are significantly different at $p<0.05$.

The effect of variety on proximate composition of fresh sample and dried samples within drying methods is shown in Table 18. The varietal variation in protein content of fresh samples was significant ($p<0.05$). *Kisukari* variety had higher protein contents of 4.7±0.1 than *Mtwike* and *Kimalindi* varieties with values of 4.4±0.1 and 4.1±0.1 g/100g DM respectively. The CDD and TD samples showed significant ($p<0.05$) varietal variations in percentage fat recoveries with *Kisukari* having higher values than *Kimalindi and Mtwike*. The samples dried in cabinet mixed mode dryer showed a significant varietal variation in percentage protein recovery with *Mtwike* having higher values (86%) than *Kisukari* and *Kimalindi* (82%) (Table 18).

Table : Proximate composition (g/100 g) and percentage recoveries (%) between dried banana varieties in different drying methods

Method	Cultivar	Protein	Fat	Crude fibre	Ash	CHO
FR	*Kisukari*	4.1±0.1^{c}	1.1±0.0^{a}	2.0±0.3^{a}	2.7±0.1^{a}	19.3
	Kimalindi	4.7±0.2^{a}	1.2±0.0^{a}	2.0±0.3^{a}	2.7±0.0^{a}	17.7
	Mtwike	4.4±0.1^{b}	1.2±0.0^{a}	2.1±0.2^{a}	2.8±0.1^{a}	18.1
CDD	*Kisukari*	3.3±0.0 (82)^{b}	0.8±0.0 (70)^{a}	1.9±0.7 (97)^{a}	2.7±0.4 (98)^{a}	74.7
	Kimalindi	3.8±0.1 (82)^{b}	0.8±0.0 (64)^{b}	2.0±0.5 (100)^{a}	2.6±0.3 (97)^{a}	72.9
	Mtwike	3.8±0.1 (86)^{a}	0.8±0.1 (67)^{ab}	2.1±0.3 (100)^{a}	2.7±0.1 (97)^{a}	72.9
CMD	*Kisukari*	3.4±0.1 (84)^{a}	0.7±0.0 (68)^{a}	1.9±0.8 (98)^{a}	2.6±0.3 (97)^{a}	74.7
	Kimalindi	3.9±0.1 (84)^{a}	0.8±0.0 (65)^{a}	1.9±0.6 (97)^{a}	2.7±0.2 (99)^{a}	72.9
	Mtwike	3.7±0.2 (85)^{a}	0.8±0.1 (66)^{a}	2.1±0.9 (100)^{a}	2.7±0.1 (97)^{a}	73.6
TD	*Kisukari*	2.9±0.1 (72)^{a}	0.9±0.1 (81)^{a}	2.0±0.8 (100)^{a}	2.7±0.1 (99)^{a}	77.6
	Kimalindi	3.3±0.5 (72)^{a}	0.9±0.1 (75)^{b}	2.0±0.1 (100)^{a}	2.7±0.3 100)^{a}	77.1
	Mtwike	3.2±0.1 (74)^{a}	1.0±0.0 (79)^{a}	2.1 ±0.8 (100)^{a}	2.7±0.1 (99)^{a}	75.7

Data presented as arithmetic means ± SD (n = 3).
Data in parentheses represent percent recovery relative to untreated.
Means within drying method in column with different superscript letters are significantly different at $p<0.05$.

(iii) Pineapple

The proximate composition of fresh and dried pineapple is shown in Table 19. The results showed significant differences ($p<0.05$) between fresh and dried samples and between drying methods. As in other fruits used in this study, fresh samples had highest moisture, protein and fat contents of 80.6, 2.8±0.1, 1.1±0.1, and 1.1±0.0 g/100g DM, respectively than cabinet dried samples with moisture content of 18.6-18.8 g/100 g FW, protein, 2.4±0.1 and fat, 1.1±0.1 g/100g DM. Tunnel dried samples had moisture content of 15.2±0.1 g/100g FW, protein, 2.1±0.1 and fat 0.9±0.1 g/100g DM. The dried samples, however had significantly ($p<0.05$) higher fibre, ash and carbohydrate contents than their fresh counterparts.

The variation between the drying methods were significant ($p <0.05$) with cabinet dried sample having higher moisture, protein and fat contents than tunnel dried samples. The results further showed that, 85-86 % protein, 73-74% fat, 98-100% crude fibre and 100% ash were retained in cabinet dried samples while 76% protein, 82% fat, 100% crud fibre and 100% ash were retained with tunnel dried samples (Table 19).

Table : Proximate composition (g/100 g) and percentage recoveries (%) of fresh and dried pineapple variety

Cultivar	Drying method	Moisture (FW)	Protein	Fat	Crude fibre	Ash	CHO
Smooth Cayenne							
	FR	80.6	2.8±1.3[a]	1.1±0.0[a]	3.6±0.0[c]	1.6±0.1[c]	10.3
	CDD	18.6	2.4±1.2[b] (86)	0.8±0.0 [b](74)	3.6±0.0[a] (100)	1.6±0.1[a] (100)	73
	CMD	18.8	2.4±1.3[b] (85)	0.8±0.1[b] (73)	3.5±0.0 a(98)	1.6±0.2[a] (100)	72.9
	TD	15.2	2.1±1.1[c] (76)	0.9±0.1 [ab](82)	3.6±0.0[a] (100)	1.6±0.2[a] (100)	76.6

Data presented as arithmetic means ± SD (n = 3).

Data in parentheses represent percent recovery relative to untreated.

Means in column with different superscript letters are significantly different at $p<0.05$.

(iv) Tomato

Table 20 shows the proximate composition of fresh and dried tomato varieties. There were significant ($p<0.05$) differences in proximate composition between fresh and dried samples and between drying methods. Fresh samples had higher moisture, protein and fat contents ranged from 92.0±0.1 to 92.3±0.1 g/100g FW, 14.4±0.1 to 16.5±1.1 and 6.2±0.1 to 6.7 ±0.1 g/100g DM, respectively than cabinet and tunnel dried samples. The cabinet dried samples had moisture, protein and fat content ranged from 14.2 to 14.9 g/100 g FW, 12.3±0.1 to 13.9±0.1 and 4.6±0.3 to 5.3±0.1 g/100g DM, respectively while the tunnel dried samples had moisture, protein and fat content ranged from 11.1 to 11.7 g/100g FW, 10.6 ± 0.1 to 12.8±0.1 and 5.6±0.8 to 6.0±0.2 g/100g DM, respectively. As in fruits, the dried samples had significantly ($p<0.05$) higher fibre, ash and carbohydrate contents than their fresh counterparts.

The variation between the drying methods were significant ($p <0.05$). The cabinet dried sample had higher moisture and protein contents than tunnel dried samples which had higher fat, ash, fibre and carbohydrate contents. The percentage retention results show between 84-87% protein, 72-78% fat, 97-98% crude fibre and 97-98% ash were retained in cabinet dried samples while between 74-80% protein, 88-89%, fat, 100% crude fibre and 99-100% % ash were retained in tunnel dried samples during drying (Table 20).

Table : Proximate composition (g/100 g) and percentage recoveries (%) of fresh and dried tomato varieties

Cultivar	Drying method	Moisture content (FW)	Protein	Fat	Crude fibre	Ash	CHO
Tanya							
	FR	92.2	16.5±1.1^{a}	6.7±0.1^{a}	7.6±0.9^{a}	9.3 ±0.1^{c}	0.0
	CDD	14.5	13.9±0.1^{b}(85)	5.2±0.1^{c}(76)	7.4±0.1^{a} (97)	9.1±0.3^{a} (98)	49.9
	CMD	14.2	13.7±0.2^{b}(84)	5.3±0.1^{c}(78)	7.4±0.0^{a} (97)	9.1±0.3^{a} (98)	50.3
	TD	11.1	12.4±0.1 ^{c}(76)	6.0±0.2^{b}(89)	7.6±0.0^{a} (100)	9.2±0.8^{a} (99)	53.7
Cal J							
	FR	92.3	14.4±0.9^{a}	6.2±0.1^{a}	7.4±0.4^{a}	9.5±0.2^{a}	0.0
	CDD	14.6	12.3±0.1^{b} (85)	4.6±0.3^{c}(74)	7.3±0.1^{a} (98)	9.3±1.1^{a} (98)	51.9
	CMD	14.7	12.4±0.3^{b} (86)	4.7±0.2^{c} (77)	7.3±0.0^{a} (98)	9.3±0.6^{a} (98)	51.6
	TD	11.7	10.6±0.1^{c} (74)	5.7±0.0^{b} (88)	7.4±0.0^{a} (100)	9.5±0.3^{a} (100)	55.1
Onyx							
	FR	92	16.0±0.5^{a}	6.4±0.2^{a}	7.5±1.1^{a}	10.1±0.0^{a}	0.0
	CDD	14.3	13.9±0.1^{b} (87)	4.7±0.2^{c} (73)	7.3±0.0^{a} (98)	9.9±0.0^{a} (98)	49.9
	CMD	14.9	13.8±0.2^{b} (86)	4.6±0.4^{c} (72)	7.4.0±0.5^{a} (98)	9.8±0.9^{a} (97)	49.5
	TD	11.1	12.8±0.1^{c} (80)	5.6±0.8^{b} (88)	7.5±0.3^{a} (100)	10.0±0.6^{a}(100)	53

Data presented as arithmetic means ± SD (n = 3).

Data in parentheses represent percent recovery relative to untreated.

Means within variety in column with different superscript letters are significantly different at $p<0.05$.

The effect of variety on proximate composition of fresh sample and percentage recoveries of dried samples within drying methods is shown in Table 21. The results showed that, the varietal differences in all proximate composition of fresh samples were significant ($p<0.05$) except for crude fibre values. *Tanya* and *Onyx* varieties had higher and statistically ($p>0.05$) similar protein and fat contents than *Cal J* variety while *Onyx* had higher ash content than *Tanya* and *Cal J* varieties. Among the dried samples, the samples dried in CDD showed significant ($p<0.05$) varietal variation in fat content recovery with *Tanya* and *Cal J* having higher values (74-76%) than *Onyx* with 73 % recovery. Similarly, a significant varietal variation was also observed in fat recoveries for samples dried in the CMD with *Tanya* and *Cal J* having statistically similar higher values (77-78%) than *Onyx* which had recovery of 72%.

Furthermore, the tunnel dried samples, showed a significant variation in protein content between varieties with *Onyx* having higher value of 80% than *Tanya* and *Cal J* with 76 and 74% respectively (Table 21).

Table : Proximate composition (g/100 g) and percentage recoveries (%) between dried tomato varieties in different drying methods

Drying method	Cultivar	Protein	Fat	Crude fibre	Ash	CHO
FR	*Tanya*	16.5±1.1^{a}	6.7±0.1^{a}	7.6±0.9^{a}	9.3 ±0.1^{b}	0.0
	Cal J	14.4±0.9^{b}	6.2±0.1^{b}	7.4±0.4^{a}	9.5±0.2^{b}	0.0
	Onyx	16.0±0.5^{a}	6.4±0.2^{ab}	7.5±1.1^{a}	10.1±0.0^{a}	0.0
CDD	*Tanya*	13.9±0.1(85)^{a}	5.2±0.1 (76)^{a}	7.4±0.1 (97)^{a}	9.1±0.3 (98)^{a}	49.9
	Cal J	12.3±0.1 (85)^{a}	4.6±0.3 (74)^{ab}	7.3±0.1 (98)^{a}	9.3±1.1 (98)^{a}	51.9
	Onyx	13.8±0.2 (87)^{a}	4.7±0.2 (73)^{b}	7.3±0.0 (98)^{a}	9.9±0.0 (98)^{a}	49.9
CMD	*Tanya*	13.7±0.2 (84)^{a}	5.3±0.1 (78)^{a}	7.4±0.0 (97)^{a}	9.1±0.3 (98)^{a}	50.3
	Cal J	12.4±0.3 (86)^{a}	4.7±0.2 (77)^{a}	7.3±0.0 (98)^{a}	9.3±0.6 (98)^{a}	51.6
	Onyx	13.8±0.2 (86)^{a}	4.6±0.4 (72)^{b}	7.4.0±0.5 (98)^{a}	9.8±0.9 (97)^{a}	49.5
TD	*Tanya*	12.4±0.1 (76)^{b}	6.0±0.2 (89)^{a}	7.6±0.0 (100)^{a}	9.5±0.3 (100)^{a}	53.7
	Cal J	10.6±0.1 (74)^{b}	5.7±0.0 (88)^{a}	7.4±0.0 (100)^{a}	9.5±0.3 (100)^{a}	55.1
	Onyx	12.8±0.1 (80)^{a}	5.6±0.8 (88)^{a}	7.5±0.3 (100)^{a}	10.0±0.6 (100)^{a}	53.0

Data presented as arithmetic means ± SD (n = 3).

Data in parentheses represent percent recovery relative to untreated.

Means within drying method in column with different superscript letters are significantly different at $p<0.05$**.**

The findings imply that, solar drying has significant effects on some proximate composition values of fruits and vegetables. It reduces moisture with corresponding increase in concentration of soluble solids implying that, one would consume more nutrients and calories in a comparable portion of dried fruit compared to fresh fruit. This has also been reported by Mepba *et al*. (2007). The lower moisture content in tunnel dryer than in cabinet dryers could be associated with its high drying temperature, which caused more moisture to evaporate and release of other organic compounds. According to Lefsrud (2008) drying may result in the release of organic compounds, volatile organic compounds (VOCs), destruction of pigments, and changes in chemical composition. The moisture content values observed in this study are in line with suggestion by Ajay *et al*. (2009) that, depending on the agricultural product, water content of properly dried food product varies from 5-25% with successful drying.

The decrease in protein content was found to be commensurate with the degree of heat applied. At increased temperature, protein undergoes denaturation and interacts with other food components, which may cause changes in solubility, texture and nutritive values (Damodaran, 2008). These findings agree with the reports by Morris *et al. (*2004) and Eze and Agbo (2011) that, nutritional losses during drying occur to great extent due to application of heat, thereby decreasing the concentration of some nutrients especially protein. In addition to heat, protein is susceptible to light oxidation, and non-enzymatic degradation (Perera, 2005). The non-enzymatic degradation might occur when reducing

sugars such as glucose, fructose and lactose react with certain amino acids to create an indigestible complex with consequence of reduced protein quality of the food (Morris *et al.*, 2004).

The oxidation reaction during drying could be accounted for by the decrease in fat content of dried samples (Perera, 2005). Although most of fruits and vegetables contain only small quantities of lipids, may undergo enzymatic hydrolysis in the initial phase of drying and autoxidation reaction of unsaturated fatty acids, producing hydroperoxides, ketones and acids, which may cause rancid and objectionable odours (Perera, 2005). This is known as rancidity and is an important problem in dried foods. Furthermore, the results show that, solar drying has no effects on crude fibre content of dried fruits and vegetables. This might be due to the fact that fibre is relatively insensitive to thermal processing, so its content is very similar in fresh and dried fruits and vegetables (Barret, 2007). Awogbemi and Ogunleye (2009) have also shown no change in fibre content of fruits and vegetables during drying.

The results also suggest that, the methods applied and varieties have varied effects on retention of some proximate composition values during drying. Different drying conditions and modes of operations such as drying air temperature, air flow rate and drying rates could be associated to these differences. For instance, the lower protein content in tunnel dried samples than cabinet dried samples could be due to

denaturation and non-enzymatic reactions caused by higher drying temperature inside the tunnel dryer. While on the other hand, the higher fat content in tunnel dried samples than in cabinet dried ones could be due to shorter exposure time to oxidizing agents favoured by shorter drying time of the tunnel dryer. As explained earlier, the plant composition varies according to variety among other factors. The variation might have caused different reactions and behaviour during drying resulted into different recovery values between the varieties within the fruit or vegetable. This was more pronounced in protein and fat contents. Nevertheless, no definite pattern in recovery has been observed or previously reported in published literature.

However, despite the statistically significant reductions in some proximate composition values, substantial amount of nutrients (>65%) were retained in all fruit and vegetable samples under all drying methods and varieties, revealing the potential of solar drying technology in preservation of agricultural produces especially in developing countries augmenting the findings of other studies (Bala *et al.*, 2009; Wakjira, 2010; Sagar and Suresh, 2010; Gatea, 2011).

4.2.3.2 Mineral contents

(i) Mango

The mineral contents of fresh and dried mango are shown in Table 22. The results show insignificant differences ($p>0.05$) in mineral contents between fresh and dried samples. Potassium was the most abundant mineral in mango ranged from 1166.3±0.3 to 1217±4 mg/100g DM in fresh samples and 1164.7±0.2 to 1213±0.2 mg/100g DM in dried

samples while iron was the least of all minerals ranged from 2.4 to 2.6±0.1 mg/100g DM in fresh samples and 2.2±0.1-25±0.1 mg /100g in dried samples. The variation between drying methods was insignificant ($p>0.05$).

(ii) Banana

The mineral contents of fresh and dried banana are shown in Table 23. There were no significant ($p>0.05$) differences in mineral contents between fresh and dried. Potassium had the highest values ranged from 1600.1±2.7 to 1782.9±2.5 mg/100g in fresh samples and 1594.7±0.1 to 1778±0.9 mg/100g DM in dried samples. The lowest mineral values observed was iron that ranged from 1.5 to 1.8 mg/ 100 g DM in fresh samples and 1.31.9±0.1 mg/100g in dried samples. No significant ($p>0.05$) variations in mineral contents were observed between the various drying methods.

Table : Mineral contents (mg/100g) of fresh and dried mango varieties

Cultivar		Mineral content (mg/100 g) DM					
		Ca	Fe	K	Mg	Na	P
Dodo							
	FR	40.8±0.3[a]	0.9±0.0[a]	941.7±0.3[a]	61.5±0.3[a]	11.7±0.7[a]	67.4±0.3[a]
	CDD	39.0±0.8[a]	0.9±0.1[a]	940.7±0.1[a]	60.8±0.1[a]	10.1±0.7[a]	67.0±0.1[a]
	CMD	38.2±0.1[a]	0.9±0.2[a]	939.7±0.2[a]	60.6±0.9[a]	10.0±2.5[a]	65.6±0.3.[a]
	TD	39.5±0.0[a]	0.9±0.0[a]	941.3±0.8[a]	61.1±0.1[a]	10.1±1.4[a]	66.8±0.8[a]
Viringe							
	FR	43.6±0.3[a]	1.0±0.0[a]	954.6±0.6[a]	62.6±0.3[a]	10.3±1.3[a]	66.9±0.3[a]
	CDD	42.1±0.8[a]	1.0±0.1[a]	954.0±0.1[a]	61.9±0.8[a]	9.5±0.1[a]	66.3±0.1[a]
	CMD	43.0±0.7[a]	1.0±0.2[a]	953.2±0.4[a]	62.0±1.6[a]	9.4±1.7[a]	65.4±1.0[a]
	TD	43.2±0.1[a]	1.0±0.0[a]	953.7±0.8[a]	62.3±0.9[a]	9.5±0.6[a]	65.8±0.1[a]
Kent							
	FR	34.4±0.7[a]	0.9±0.0[a]	885.9±4.0[a]	60.7±0.4[a]	9.2±0.4[a]	64.9±0.4[a]
	CDD	33.3±0.8[a]	0.9±0.1[a]	884.8±0.9[a]	59.1±0.1[a]	9.0±0.7[a]	63.2±0.1[a]
	CMD	33.1±0.5[a]	0.9±0.2[a]	885.3±0.2[a]	59.6±0.9[a]	9.0±0.5[a]	63.4±0.2[a]
	TD	34.0±0.1[a]	0.9±0.0[a]	885.4±0.6[a]	59.6±0.8[a]	9.1±1.4[a]	63.6±0.8[a]

Data presented as arithmetic means ± SD (n = 3).

Means in column with different superscript capital letters are significantly different at $p<0.05$.

Table : Mineral contents (mg/100g) of fresh and dried banana varieties

		Mineral content (mg/100g) DM					
Cultivar	**DryingMetho**	**Ca**	**Fe**	**K**	**Mg**	**Na**	**P**
Kisukari							
	FR	21.7±2.4^{a}	1.5±0.0^{a}	1354.1±0.6^{a}	104.8±0.5^{a}	3.5±0.0^{a}	89.8±0.2^{a}
	CDD	19.7±0.9^{a}	1.4±0.3^{a}	1353.0±0.2^{a}	100.0±0.8^{a}	3.3±0.2^{a}	88.1±1.5^{a}
	CMD	19.7±0.4^{a}	1.3±0.0^{a}	1353.3±0.2^{a}	100.2±0.8^{a}	3.4±0.1^{a}	88.4±1.6^{a}
	TD	20.0±0.6^{a}	1.4±0.1^{a}	1553.6±0.8^{a}	102.0±3.3^{a}	3.5±0.1^{a}	88.2±0.8^{a}
Kimalindi							
	FR	22.6±0.5^{a}	1.8±0.0^{a}	1428.5±2.5^{a}	114.8±0.0^{a}	4.2±0.2^{a}	93.2±0.3^{a}
	CDD	20.9±0.1^{a}	1.9±0.1^{a}	1426.8±0.9^{a}	114.4±1.5^{a}	3.8±0.8^{a}	91.5±0.4^{a}
	CMD	20.6±1.9^{a}	1.7±0.2^{a}	1426.6±0.9^{a}	113.2±0.4^{a}	4.0±0.7^{a}	90.9±0.1^{a}
	TD	21.7±0.0^{a}	1.8±0.1^{a}	1426.9±0.2^{a}	114.4±0.9^{a}	4.1±0.7^{a}	92.9±0.8^{a}
Mtwike							
	FR	24.4±0.1^{a}	1.8±0.0^{a}	1305.4±2.5^{a}	111.5±0.1^{a}	3.7±0.1^{a}	93.2±0.3^{a}
	CDD	23.8±0.9^{a}	1.7±0.1^{a}	1305.3±0.8^{a}	109.8±0.7^{a}	3.4±0.2^{a}	92.9±1.1^{a}
	CMD	23.8±0.9^{a}	1.7±0.1^{a}	1303.3±0.9^{a}	111.0±0.4^{a}	3.4±0.2^{a}	92.5±0.5^{a}
	TD	24.0±0.8^{a}	1.7±0.1^{a}	1303.2±0.8^{a}	110.8±0.8^{a}	3.6±0.1^{a}	93.0±0.2^{a}

Data presented as arithmetic means ± SD (n = 3).

Means within variety in column with different superscript letters are significantly different at $p<0.05$.

(iii) Pineapple

The mineral contents of fresh and dried pineapple are shown in Table 24. There were no significant ($p>0.05$) differences in mineral contents between fresh and dried samples. Potassium was the most abundant mineral ranging from 887.1±3.9 mg/100g DM in fresh samples and from 879±0.8 to 880.6±0.8 mg/100g DM in dried samples. Iron was the lowest mineral with fresh and dried samples having 3.0±0.1 and 2.8±0.1-2.9±0.1 mg/100g DM respectively. There was no significant ($p>0.05$) differences in mineral contents between the drying methods.

(iv) Tomato

The mineral contents of fresh and dried tomato are shown in Table 25. There were no significant ($p>0.05$) differences in mineral contents between fresh and dried samples. Potassium had the highest values ranged from 3204.4±10.9 to 3476.6±1.1 mg/100g in fresh samples and 3182.8±2.6 to 3467.5±7.9 in dried samples. As in fruits, tomato had lowest iron values.

Table : Mineral contents (mg/100g) of fresh and dried pineapple variety

Cultivar		Mineral content (mg/100g) DM					
		Ca	Fe	K	Mg	Na	P
S. cayenne	FR	73.1±0.4[a]	3.0±0.0[a]	604±0.4[a]	75.4±0.4[a]	11.5±0.3[a]	53.1±0.4[a]
	CDD	71.8±0.1[a]	3.0±0.1[a]	603.1±0.8[a]	74.8±0.5[a]	10.5±0.8[a]	52.2±0.9[a]
	CMD	72.1±0.2[a]	2.8±0.1[a]	602.3±0.8[a]	74.8±0.5[a]	11.4±0.2[a]	52.3±0.9[a]

		1[a]	[a]	2[a]	[a]	[a]	[a]
	TD	73.0±0.	2.9±0.1	602.5±0.	74.7±0.8	10.7±0.1	53.0±0.3
		8[a]	[a]	1[a]	[a]	[a]	[a]

Data presented as arithmetic means ± SD (n = 3).

Means in column with different superscript letters are significantly different at $p<0.05$.

Table : Mineral contents (mg/100g) of fresh and dried tomato variety

Cultivar		Mineral content (mg/100g) DM					
		Ca	**Fe**	**K**	**Mg**	**Na**	**P**
Tanya							
	FR	136.8±1.	7.4±0.	3401.7±2.1	188.4±1	47.9±1.0	379.8±3.
		9[a]	3[a]	[a]	.0[a]	[a]	0[a]
	CDD	134.4±0.	7.2±0.	3397.9±0.8	187.1±0	45.7±1.1	374.1±0.
		3[a]	2[a]	[a]	.8[a]	[a]	5[a]
	CMD	134.3±0.	7.3±0.	3396.3±0.5	187.2±1	44.8±1.6	375.9±0.
		6[a]	2[a]	[a]	.0[a]	[a]	2[a]
	TD	135.3±0.	7.3±0.	3399.7±0.9	188.0±2	46.5±0.1	378.4±0.
		4[a]	0[a]	[a]	.4[a]	[a]	8[a]
Cal J							
	FR	137.6±0.	6.7±1.	3204.4±10.	180.6±0	42.0±0.9	373.9±9.
		9[a]	1[a]	9[a]	.9[a]	[a]	1[a]
	CDD	135.8±1.	5.8±0.	3182.8±2.6	179.5±0	39.9±1.1	370.4±0.
		1[a]	1[a]	[a]	.8[a]	[a]	8[a]
	CMD	135.5±0.	6.0±0.	3184.2±0.8	178.5±0	39.8±0.8	370.5±0.
		2[a]	2[a]	[a]	.1[a]	[a]	0[a]
	TD	136.5±0.	6.6±0.	3195.2±0.8	179.8±0	40.2±0.1	370.4±7.
		7[a]	4[a]	[a]	.0[a]	[a]	2[a]
Onyx							
	FR	137.9±2.	8.1±0.	3476.6±1.1	182.6±1	41.8±1.0	381.5±1.
		1[a]	1[a]	[a]	.0[a]	[a]	1[a]
	CDD	135.8±1.	7.9±0.	3467.3±4.4	181.3±0	40.0±1.1	371.6±0.
		1[a]	1[a]	[a]	.1[a]	[a]	8[a]
	CMD	135.5±0.	7.8±0.	3466.7±0.1	180.9±0	39.6±0.8	372.9±0.
		2[a]	2[a]	[a]	.6[a]	[a]	1[a]
	TD	136.5±0.	7.9±0.	3467.5±7.9	181.8±0	40.1±0.1	373.7±0.

	7[a]	1[a]	[a]	.8[a]	[a] 8[a]

Data presented as arithmetic means ± SD (n = 3).

Means within variety in column with different superscript letters are significantly different at $p<0.05$.

Potassium and magnesium were the most abundant minerals while iron was the least available mineral in all fresh and dried samples. This is comparable to the findings obtained in other studies in various vegetables (Iqbal *et al*., 2006), apple (Lowor and. Agyente-Badu, 2009) and amaranthus (Mepba *et al*., 2007). With exception of calcium, all mineral content values (mg/ 100 g FW) in all fresh samples were within or slightly above the reported values in Tanzania Food Composition Table by Lukmanji *et al*. (2008). The observed variation might have resulted from species, variety, genetic, geographic, climatic, environmental condition, agronomic factor and seasonal variations (Gul and Safdar, 2009; Adepoju *et al*., 2012).

The observed insignificant differences in all mineral contents between fresh and dried samples and between different drying methods indicate that, solar drying temperatures had little or no effect on mineral contents of dried products. Most minerals have fairly low volatility at high temperatures of up to 550-600°C (Nielsen, 2010) which means the solar drying air temperature is of little consequences for their contents. The results are in agreement with Ogbadoyi *et al.* (2011) and Kresic (2004) who found drying to have no effect on amaranthus species and candied celeriac, respectively.

Generally, fruits and vegetables are important sources of minerals in human diet which are important for vital body functions such as acid base and water balance. Potassium is necessary for bone health, energy metabolism and the maintenance of the electrochemical balance that allows nerve cells to transmit impulses and muscles to contract (Dickinson, 2002). The cell and low blood potassium is a life threatening problem (Wardlaw and Kessel, 2002). The findings revealed that, one would need to consume 574-642 g of dried mango, 386-422 g of dried banana, 918-960 g of dried pineapple and 152-173 g of dried tomato to meet the RDA of 4700 g/day set by USDA (2010). Magnesium is a required co-factor for more 300 enzyme system and is required for energy production in the body (Dickinson, 2002). Based on the findings of this study, consumption of 747-811 g of dried mango, 409-442 g of dried banana, 630-658 g of dried pineapple and 239-260 g WB of dried tomato would be enough to meet RDA of 400 mg /day (USDA, 2010).

Calcium is mainly associated with the pectic substance of the cell wall and could significantly influence texture and more than 99% of calcium in the body is used as a structural component of bones and teeth. It represents about 40% of all the minerals present in the body (Wardlaw and Kessel, 2002). Based on the findings of this study, one would need to consume a lot of fresh and dried fruits to meet the RDA of 1000 g/day set by USDA (2010). For instance, the adult person would require consuming 2.7-2.8 kg of dried mango, 4.9-6.2 kg of dried banana, 1.6-1.7 kg of dried pineapple and 0.8-0.9 kg WB of dried tomato to meet

the RDA. Phosphorus functions to buffer body fluids to maintain a normal pH, to temporarily store and transfer energy derived from metabolic fuels, and to activate many catalytic protein through phosphorylation (Mepba *et al.*, 2007). Consumption of 1.2-1.3 kg of dried mango, 1.6 kg of dried banana, 881-960 g of dried pineapple and 208-221 g FW of dried tomato would be enough to meet RDA of 400 mg /day (USDA, 2010).

It has been reported that, fruits and vegetables are generally poor sources of iron (Mepba *et al.*, 2007), which suggests consumption of large quantities of fruits and vegetables to meet the Recommended Daily Allowance (RDA) of 45 mg/day. For instance a person would need to consume 5.5-6.3 kg of dried mango, 2.9-4.1 kg of dried banana, 1.8-1.9 kg of dried pineapple and 640-909 g WB of dried tomato to meet the indicated RDA.

4.2.3.3 Vitamin C

(i) Mango

The Vitamin C contents of fresh and dried mango varieties are shown in Fig. 27: The results show significant differences ($p<0.05$) in vitamin C contents between fresh and dried samples and between the drying methods. Fresh samples had highest values of 105.4-119.7 mg Lasc/100g DM, which decreased significantly to 22.1-25.1 and 51.9-65.1 mg Lasc/100g DM in cabinet dryers and tunnel dryer respectively. The percentage vitamin C recovery show that, 54.4-55.7 % was retained in tunnel dryer compared to 18.4-23.8 % in cabinet dryers.

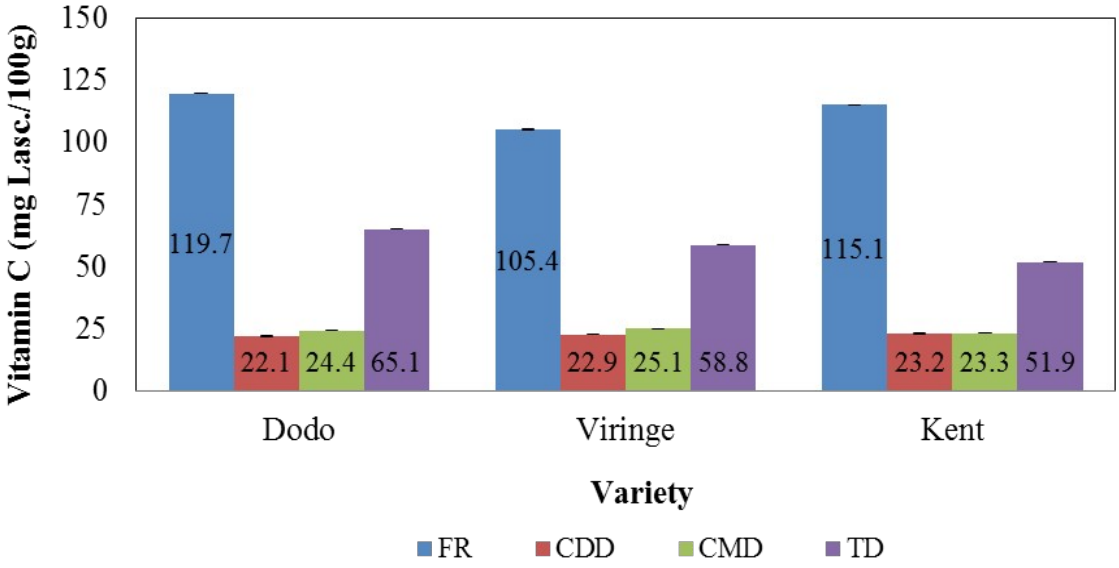

Figure : Vitamin C (mg/Lasc/100g) contents of fresh and dried mango varieties in different dryer. Each bar represent arithmetic means ± SD (n = 3).

(ii) Banana

Fig. 28 shows the Vitamin C contents of fresh and dried banana. There were significant differences ($p<0.05$) in vitamin C contents between fresh and dried samples and between the drying methods. Fresh samples had higher values of 28.3-29.1 mg Lasc/100g DM than dried samples with values of 3.8-5.2 and 8.3-8.4 mg Lasc/100g in cabinet dryers and tunnel dryer respectively. The percentage vitamin C recovery results showed that, values as low as 12.9-21.6% were retained in cabinet dryers compared to 29-32% retained in tunnel dryer.

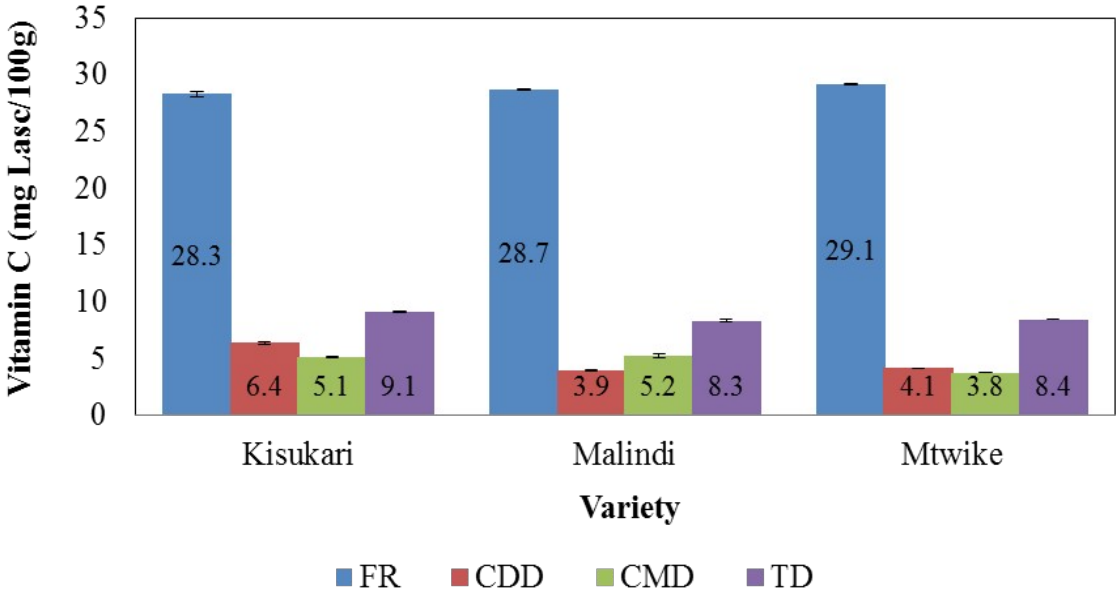

Figure : Vitamin C contents (mg/Lasc/100g) of fresh and dried banana varieties at different dryers. Each bar represent arithmetic means ± SD (n = 3).

(iii) Pineapple

The vitamin C contents of fresh and dried pineapple are shown in Fig. 29: It shows that, there were significant differences ($p<0.05$) in vitamin C contents between fresh and dried samples and between the dried samples from different drying methods. Fresh samples had higher values of 68.8 mg Lasc/100g DM than dried samples with values of 19.1-20.9 and 35.3 mg Lasc/100g DM in cabinet dryers and tunnel dryer respectively. The percentage recoveries were 29.8-30.4 in cabinet dryers and 51.3 % in tunnel dryer.

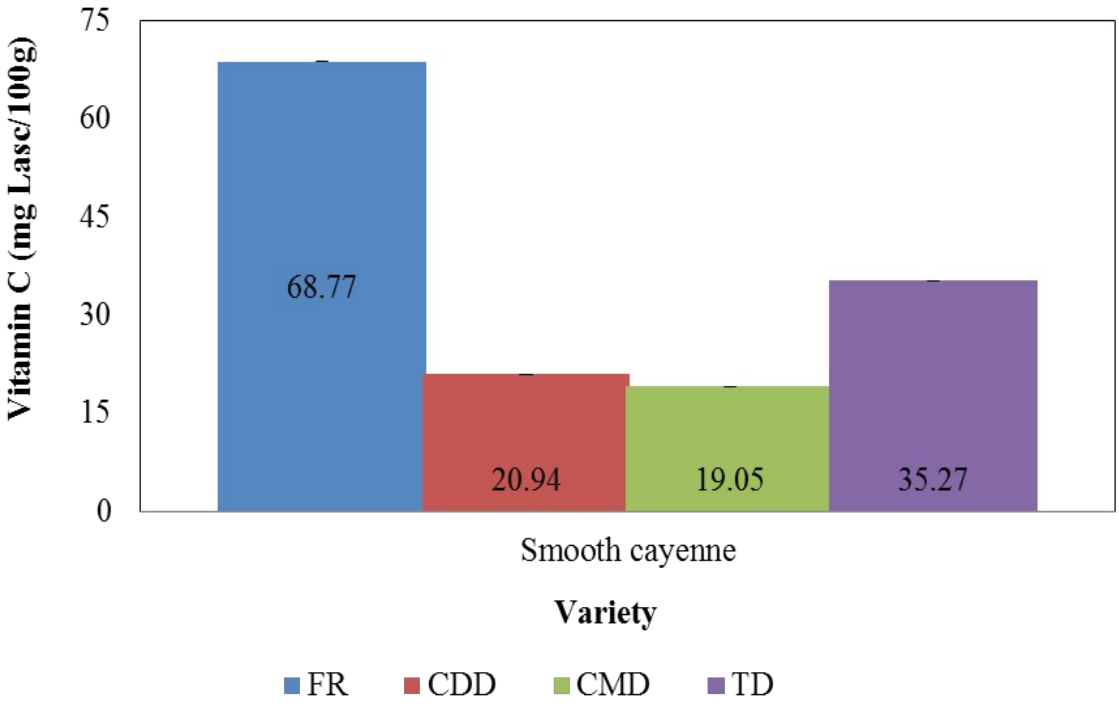

Figure : Vitamin C contents (mg/Lasc/100g) of fresh and dried pineapple at different dryers. Each bar represent arithmetic means ± SD (n = 3).

(iv) Tomato

The vitamin C contents of fresh and dried tomato varieties are shown in Fig. 30: The results showed that, there were significant differences ($p<0.05$) in vitamin C contents between fresh and dried samples and between the dried samples processed under different drying methods. Fresh samples had highest values of 115.1-126.8 mg Lasc/100g DM, which decreased significantly during drying to 26.0-28.7 and 35-37.3 mg Lasc/100g in cabinet dryers and tunnel dryer respectively. These are equivalent to recoveries of 21.0-24.4% in cabinet dryers and 28.9-31.1 % in tunnel dryer.

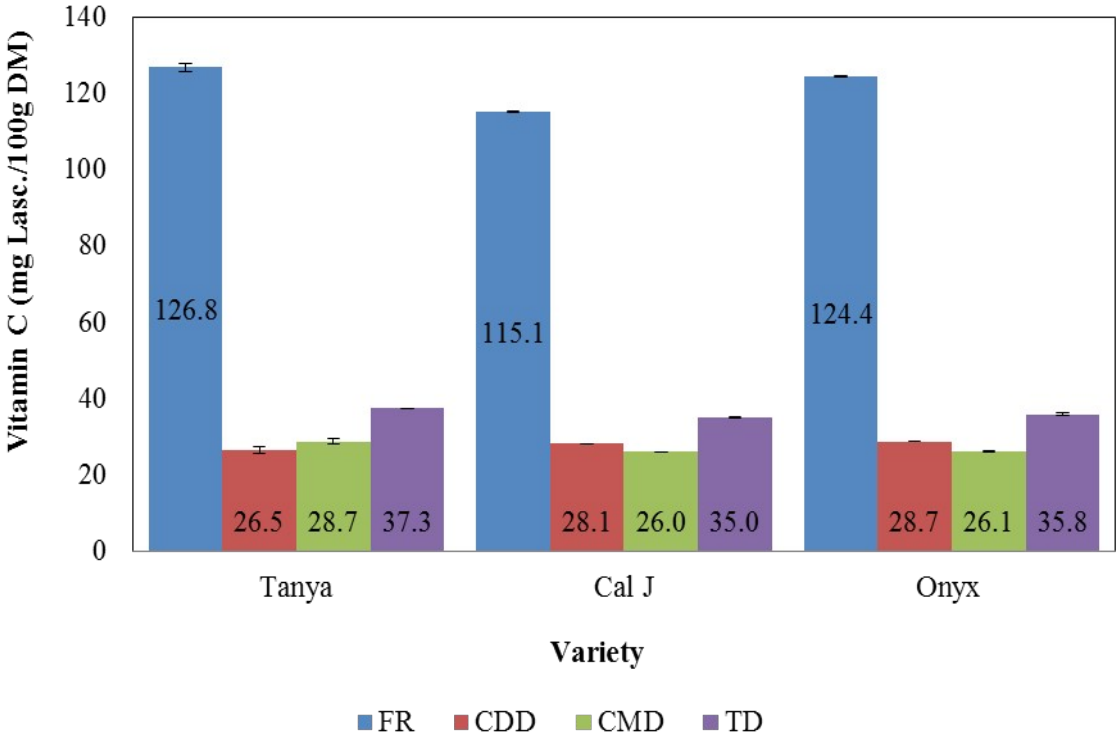

Figure : Vitamin C contents (mg/Lasc/100g) of fresh and dried tomato varieties at different dryers. Each bar represent arithmetic means ± SD (n = 3).

The high vitamin C loss during drying shows that, it is the least stable nutrient during processing (Cernîşev and Sleagun, 2007)**.** In general, its retention after drying is relatively low and it is often taken as an index of the nutrient quality of processes even if quite high contents can be reported for dry products, due to the evaporation of water and the concentration effect (Bonazzi and Dumoulin, 2011). This is mainly because of its high sensitivity to oxidation and leaching into water-soluble media during processing of fruits and vegetables (Giovanelli *et al.,* 2002 and Franke *et al*., 2004). Vitamin C may be oxidized to dehydroascorbic acid under aerobic conditions, followed by hydrolysis and further oxidation thus subjected to appreciable change during the drying process. The loss of vitamins C due to drying has widely been reported. Lavelli *et al*. (1999) showed that, up to 88% was lost in dried

tomato while Goula and Adamopoulos (2006) reported 90 % or higher loss of the vitamin C in dried tomato halves. Similarly, Ogbadoyi *et al*. (2011) reported a greater loss (83.07%) of the vitamin C in sun dried amaranthus species. The reported losses are similar to the findings of this study with exception of tunnel dried samples. The degradation of vitamin C is associated with quality loss in a product (Giovanelli *et al.,* 2002).

The observed variation in vitamin C contents between and within the fruits and vegetable varieties could be influenced by presence of dissolved oxygen, pH 4.0 and water activity level in the products (Bulent-Koc, 2007; Rahman *et al*., 2007). The high pH and rate of enzymatic oxidation as manifested by severe browning in banana may be accounted for its highest vitamin C loss. This was further supported by Methakhup *et al*. (2003) who found the rate of ascorbic acid oxidation to be pH dependent, showing a maximum at pH 5.0 and minimum at a pH range of 2.5 to 3.0. In the same line, Naggy (1980) found vitamin C stability was dependent on the acid content of the fruits and its loss was lower in citrus than in non-citrus and vegetables. Leaching is another important factor that could have led to loss of vitamin C along with the water during the preparation and drying process (Kirimire *et al*., 2010).

The differences in vitamin C degradation between the drying methods could be influenced by temperature, drying kinetics and water activity. The high temperature in the tunnel dryer inactivated the ascorbic acid

oxidase and offered vitamin protection towards enzymatic oxidation (Leong and Oey, 2012). In addition to enzyme inactivation, the shorter drying time in tunnel dryer than in cabinet dryers reduced the exposure time to oxidizing agents resulted into relatively lower vitamin C degradation in its samples. This is in agreement with Santos and Silva, (2008) that suggested that, the longer the drying period (low temperatures, high relative humidity, thick products), the lower the retention of ascorbic acid. Other studies in tomato (Leong and Oey, 2012), broccoli (Munyaka *et al*., 2010) and cow pea leaves (Wawire *et al*., 2011) have similarly reported an increase or relatively reduced loss in vitamin C with increasing drying air temperature. However, McLaughlin and Magee (1998), Caixeta *et al*. (2002) and Wennermark *et al*. (1994) have contrastingly observed a decrease in vitamin C content with increasing drying temperature.

Moreover, the relatively higher moisture content in cabinet dried samples than in tunnel dried samples could have contributed to their relatively higher vitamin C degradation. Vitamin C stability is reduced in aqueous state than in the dry state (Kiremire, 2010). Vitamin C retention is also improved by all drying processes under an inert atmosphere, which reduce the presence of O^2 as evidenced in tunnel dried samples. Similar effect of drying methods in vitamin C were also reported in tomato (Perumal, 2007), mango (Kabasa *et al.,* 2004), vegetables (Kirimire *et al*., 2010) and Indian Gooseberry powder (Srzednicki *et al*., 2009).

Physiologically, vitamin C functions as an effective water-soluble antioxidant that readily scavenge reactive oxygen species (ROS) and also a cofactor in numerous physiological reactions, including the post-translational hydroxylation of proline and lysine in collagen and other connective tissue proteins, collagen gene expression, synthesis of norepinephrine and adrenal hormones, activation of many peptide hormones, and synthesis of carnitine (Johnston *et al.*, 2007). It is apparently shown that, one would need to consume large quantities of dried fruits and vegetables to meet RDA of 75 and 90 mg/day for women and men respectively and 45 mg/day for children 9-12 years old (USDA, 2010) due to high loss.

4.2.3.4 Sugar profile

(i) Mango

Table 26 shows the sugar profile of fresh and dried mango varieties. The results showed that, sucrose was the most abundant sugar that ranged from 35.58±0.7 in *Dodo* to 48.82±0.1 g/100 g DM in *Kent variety.* Glucose was the least available sugar that ranged from 2.98±0.1 in *Viringe* to 4.16±0.1 g/100g DM in *Kent*. Among the varieties, Kent had highest sugar than other varieties in both fresh and dried samples. The results also showed significant ($p<0.05$) variations in sugars between drying methods. Tunnel dried samples had significantly lower sugar than fresh and cabinet dried samples which had statistically ($p>0.05$) similar values. Between 87 to 93 % sugar was

recovered in tunnel dried samples compared to 98-99% in fresh and cabinet dryers.

Table : Sugar profile (g/100 g DM) and percentage recoveries (%) of fresh and dried mango varieties

Cultivar	Drying method	Glucose	Fructose	Sucrose
Dodo	FR	3.65±0.1[a]	14.84±0.1[a]	39.35±0.0[a]
	CDD	3.61±0.1[a] (99)	14.76±0.1[a] (99)	38.86±0.2[a] (99)
	CMD	3.61±0.1[a] (99)	14.72±0.1[a] (99)	38.69±0.6 [a](98)
	TD	3.40±0.1[b] (93)	13.67±0.1 [b](92)	35.58±0.7[b] (90)
Viringe	FR	3.44±0.1[a]	16.78±0.1[a]	43.8±0.1[a]
	CDD	3.35±0.1[a] (97)	16.67±0.2[a] (99)	43.00±0.2[a] (98)
	CMD	3.27±0.2 [a](95)	16.65±0.1[a] (99)	42.67±0.2[a] (97)
	TD	2.98±0.1[b] (87)	15.14±0.1 [b](90)	40.94±1.0[a] (93)
Kent	FR	4.16±0.0[a]	19.81±0.0[a]	49.86±0.0[a]
	CDD	4.15±0.0 [c](99)	19.56±0.2[c] (99)	48.82±0.6 [b](98)
	CMD	4.16±0.1 [c](100)	19.69±0.1 [c](99)	48.82±0.1[b] (98)
	TD	3.66±0.1[b] (87)	17.56±0.0[b] (89)	47.00±0.1 [a](94)

Data presented as arithmetic means ± SD (n = 3).
Data in parentheses represent percent recovery relative to untreated.
Means within variety in column with different superscript letters are significantly different at $p<0.05$.

(ii) Banana

The sugar profile of fresh and dried banana varieties has shown in Table 27. Sucrose was the most abundant sugar ranging from 18.28±0.7 in *Mtwike* to 22.47±0.0 g/100g DM in *Kisukari* variety. Fructose was the least available sugar ranged from 8.03±0.1 in *Mtwike* to 10.70±0.0 g/100g DM in *Kisukari* variety. The *Kisukari* variety had highest sugar levels than other varieties in both fresh and dried samples. The effect of drying methods on sugar was significant ($p<0.05$) with tunnel dried

samples having significantly lower sugar values than fresh and cabinet dried samples. No significant ($p>0.05$) differences were observed between fresh and cabinet dried samples. The recovery results show between 83 to 89 % sugar was retained in tunnel dried samples and between 96 to 99% in fresh and cabinet dried samples.

Table : Sugar profile (g/100 g DM) and percentage recoveries (%) of fresh and dried banana varieties

Cultivar	Drying method	Glucose	Fructose	Sucrose
Kisukari	FR	11.62±0.0^{a}	10.70±0.0^{a}	22.47±0.0^{a}
	CDD	11.50±0.0^{a} (99)	10.67±0.1^{a} (99)^{a}	22.29±0.1^{a} (99)
	CMD	11.56±0.1^{a} (99)	10.54±0.0^{a}(99)	22.37±0.1^{a} (99)
	TD	10.35±0.0^{b} (89)	9.09±0.1^{b} (85)	20.11±1.1^{b} (90)
Kimalindi	FR	10.97±0.0^{a}	9.90±0.0^{a}	21.55±0.0^{a}
	CDD	10.96±0.0^{a} (100)	9.82±0.0^{a}(99)	21.42±0.2^{a} (99)
	CMD	10.97±0.0^{a}(100)	9.82±0.1^{a} (99)	21.42±0.1^{a} (99)
	TD	9.04±0.0^{b} (82)	8.19±0.0^{b} (83)	20.62±0.0^{b} (85)
Mtwike	FR	10.66±0.0^{a}	9.62±0.1^{a}	20.75±0.0^{a}
	CDD	10.62±0.0^{a}(99)	9.62±0.0^{a} (100)	19.92±0.1^{a} (96)
	CMD	10.63±0.0^{a} (99)	9.61±0.0^{a} (100)	20.01±0.2^{a} (96)
	TD	9.02±0.1 ^{b}(85)	8.03±0.1 ^{b}(83)	18.28±0.7 ^{b}(88)

Data presented as arithmetic means ± SD (n = 3).
Data in parentheses represent percent recovery relative to untreated.
Means within variety in column with different superscript letters are significantly different at $p<0.05$.

(iii) Pineapple

Table 28 shows the sugar profile of fresh and dried pineapple variety. Sucrose was also observed to be the most abundant sugar in pineapple ranging from 16.74±1.1 to 18.78±0.1 g/ 100 g, followed by fructose ranged from 13.31±0.5 to 14.73±0.0 and glucose that ranged from 12.29±0.6 to 13.81±0.1 g/100g DM. The effect of drying methods on sugar profile was significant ($p<0.05$) with tunnel dried samples having significantly lower sugar values than fresh and cabinet dried sample between which had statistically similar values. Between 87 to 89 % sugar was retained in tunnel dried samples compared to 96-99% in cabinet dried samples.

Table : Sugar profile (g/100 g DM) and percentage recoveries (%) of fresh and dried pineapple variety

Cultivar	Drying method	Glucose	Fructose	Sucrose
S. cayenne	FR	13.81±0.1[a]	14.73±0.0[a]	18.88±0.0[a]
	CDD	13.21±0.1[a](96)	14.60±0.1[a](99)	18.78±0.1[a](99)
	CMD	13.22±0.6[a](96)	14.66±0.1[a](99)	18.75±0.[1a](99)
	TD	12.29±0.6[b](89)	13.31±0.5[b](90)	16.74±1.1[b](87)

Data presented as arithmetic means ± SD (n = 3).

Data in parentheses represent percent recovery relative to untreated.

Means in column with different superscript letters are significantly different at $p<0.05$.

(iv) Tomato

The sugar profile of fresh and dried tomato varieties are shown in Table 29. Only glucose and fructose were detected in all fresh and dried tomato samples. Fructose was higher in all varieties ranged from 18.75±0.1 g/100g DM in *Onyx* to 22.22±0.1 g/100g DM in *Tanya* than glucose which ranging from 13.77±0.1 g/100g DM in to 16.36 g/ 100 g DM in the same varieties respectively. The effect of drying method on sugar profile of tomato was also significant ($p<0.05$) with fresh and cabinet dried samples having higher values than tunnel dried samples. The results showed between 91-94 % sugars were retained in tunnel dried samples compared to 99% in cabinet dried samples.

Table : Sugar profile (g/100 g DM) and percentage recoveries (%) of fresh and dried tomato varieties

Cultivar	Drying method	Glucose (DM)	Fructose (DM)
Tanya	FR	16.36±0.1^{a}	22.22±0.1^{a}
	CDD	16.30±0.1^{a} (99)	22.10±0.1^{c} (99)
	CMD	16.31±0.1 ^{a}(99)	22.06±0.1^{c} (99)
	TD	15.00±0.1^{b} (91)	20.75±0.1^{b} (93)
Cal J	FR	15.57±0.0^{a}	22.12±0.0^{a}
	CDD	15.45±0.1^{c} (99)	21.99±0.1^{c} (99)
	CMD	15.49±0.1 ^{c}(99)	22.09±0.1^{c} (99)
	TD	14.62±0.0^{b} (94)	20.87±0.1^{b} (94)
Onyx	FR	13.89±0.0^{a}	20.14±0.0^{a}
	CDD	13.80±0.1^{c} (99)	20.02±0.1^{c} (99)
	CMD	13.77±0.1 ^{c}(99)	20.04±0.0^{c} (99)
	TD	12.85±0.1 ^{b}(93)	18.75±0.1^{b} (93)

Data presented as arithmetic means ± SD (n = 3).

Data in parentheses represent percent recovery relative to untreated.

Means within variety in column with different superscript letters are significantly different at $p<0.05$.

Sucrose, glucose and fructose are the main soluble carbohydrates and their contents and the ratios play a vital role in deciding the flavour and quality of fruits (Sun *et al.*, 2011). The findings have shown that, sucrose was the most dominating sugars in fresh mango, banana and pineapple, which goes in line with other reports by Li *et al*. (2002) and Cordain, (2012). Fruits accumulate sucrose massively during the final stages of maturation (Lester *et al.*, 2001) while lesser quantities of fructose and glucose generally accumulate during development, and they decrease or remain unchanged during ripening (Beaulieu *et al.*, 2003). The low sugar contents in tomato show and support the reported finding by Jayaraman and Das-Gupta (2006) which showed vegetables to be generally low in sugar.

The significantly lower values in tunnel dried samples than fresh and cabinet dried samples may be associated to non-enzymatic browning reaction influenced by high drying temperature and low water activity (Manzocco *et al.*, 2001; Belitz *et al.*, 2004) According to Di Matteo *et al*. (2000) and Gallali *et al*. (2000), sugar contents in dried samples decrease significantly after drying at 60°C and above owing to thermal degradation. At this temperature, non-enzymatic browning reaction takes place resulting into brown pigment and loss of sugars in the products. The reaction is more severe near the end of the drying period when the moisture content is low and less evaporative cooling is taking place (Sagar and Suresh, 2010). A use of chemical solutions, drying at

low temperature, 55-65°C as a single-temperature regime and short drying time are among the recommended ways for minimizing Maillard brown reaction and its accompanied losses (Vega-Gálvez *et al.*, 2008; Sagar and Suresh, 2010).

Nevertheless, despite the loss in tunnel dried samples, substantially high amount of sugar was retained and concentrated in all dried samples making no difference between them and their fresh counterparts. It is therefore reasonably correct to conclude that, solar drying has no to very minimal effects on sugar contents of fruits and vegetables. The moisture removal due to drying concentrates sugars and products become sweeter than their fresh counterpart.

4.2.4 Sensory quality

4.2.4.1 Mango

(i) Quantitative Descriptive Analysis (QDA)

Mean intensity ratings of descriptive attributes are shown in Fig. 31: The results showed significant ($p<0.05$) differences in intensity scores between fresh and dried samples and between dried samples under different drying methods. Dried samples had significantly higher mean intensity scores in whiteness, hardness and sweetness than their fresh counterparts which had only higher colour scores (Appendix 10).

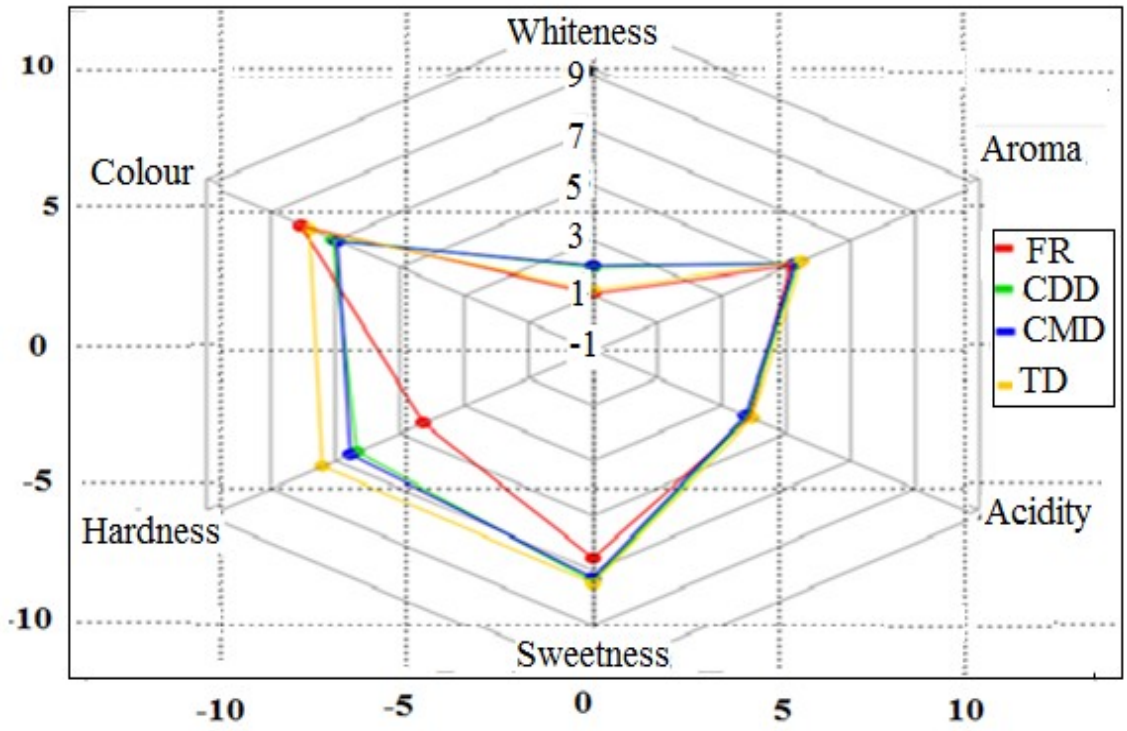

Figure : Spider plot showing mean intensity ratings of descriptive attributes of fresh and dried mango at different dryers.

(ii) Consumer studies

Mean hedonic scores for the analysed fresh and dried mango samples are presented in Table 30. With exception of taste attribute, consumers showed significant ($p<0.05$) differences in all other attributes evaluated. Fresh samples scored higher than fresh counterparts in colour, mouth feel and overall acceptability. Furthermore, drying methods differed significantly ($p<0.05$) in texture attribute only, with tunnel dryer having scored lowest value.

Table : Mean hedonic scores for the fresh and dried mango samples

Method	Attributes					
	Colour	**Taste**	**Aroma**	**Texture**	**Mouth feel**	**Accept.**
FR	8.0±0.7[a]	7.8±0.9[a]	7.1±1.3[a]	7.3±1.1[a]	7.5±1.3[a]	7.5±0.8[a]
CDD	7.0±1.0[b]	7.4±1.1[a]	7.4±1.5[a]	7.1±1.7[a]	6.7±0.9[b]	6.8±1.0[b]
CMD	6.8±0.9[b]	7.3±1.0[a]	6.2±1.6[b]	7.0±1.1[a]	6.7±0.9[b]	6.7±0.8[b]
TD	7.3±1.3[b]	7.5±0.7[a]	6.7±1.4[ab]	6.1±0.8[b]	6.3±1.5[b]	6.9±1.6[b]

Different letters along the column indicate values are significantly different ($p<0.05$).

(ii) Preference mapping

(a) Principal component of descriptive sensory data

Fig. 32 shows bi-plot with the two first significant principal components from Principal Component Analysis (PCA) on average sensory attributes. The obtained results showed principal component (PC) 1 accounted for 81.7% of the systematic variation in the data while principal component (PC) 2 accounted for 17.9%. Fresh and dried samples were well separated. Dried samples correlated positively with descriptive attributes whiteness, sweetness, hardness and aroma and they correlated negatively with acidity and colour attributes. Fresh samples correlated positively with attribute acidity and colour attributes. The findings indicate that, the variation between samples

was explained by attributes aroma, hardness, sweetness and whiteness on one side and attributes colour and acidity on the other side along PC 1, while PC 2 was mainly described by variation in whiteness and the remaining attributes.

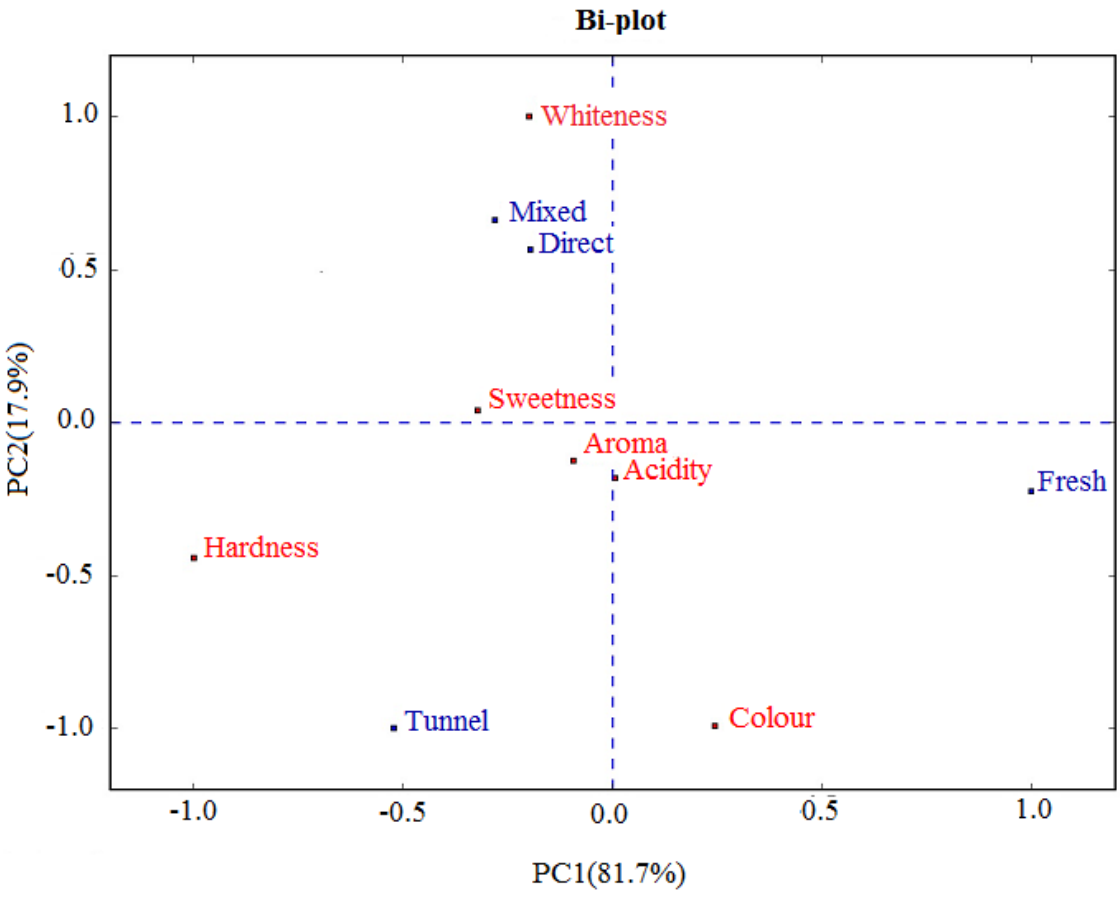

Figure : Bi-plot from PCA of descriptive sensory data for fresh and dried mango samples.

(b) Relationship between descriptive data and hedonic liking by PLSR

Fig. 33 shows the results from a partial least square regression (PLSR) using descriptive data as X-variables and liking rated by the consumers as *Y*-variables. The finding shows that, the explained variance was relatively high; the two first significant components described 61% of

the variation in *Y*. The figure shows that almost all the consumers fall to the right of the vertical Y-axis, outside the 50% explained circle which means that, the acceptance values of these persons go in the direction of fresh sample associated with colour and acidity. It indicates that, in mango consumer showed a strong preference for fresh samples than dried ones. The x-axis showed similar high preference for fresh and tunnel dried samples due to their high association with colour and acidity and none preferred direct and mixed dried samples due to their whiteness (loss in colour saturation).

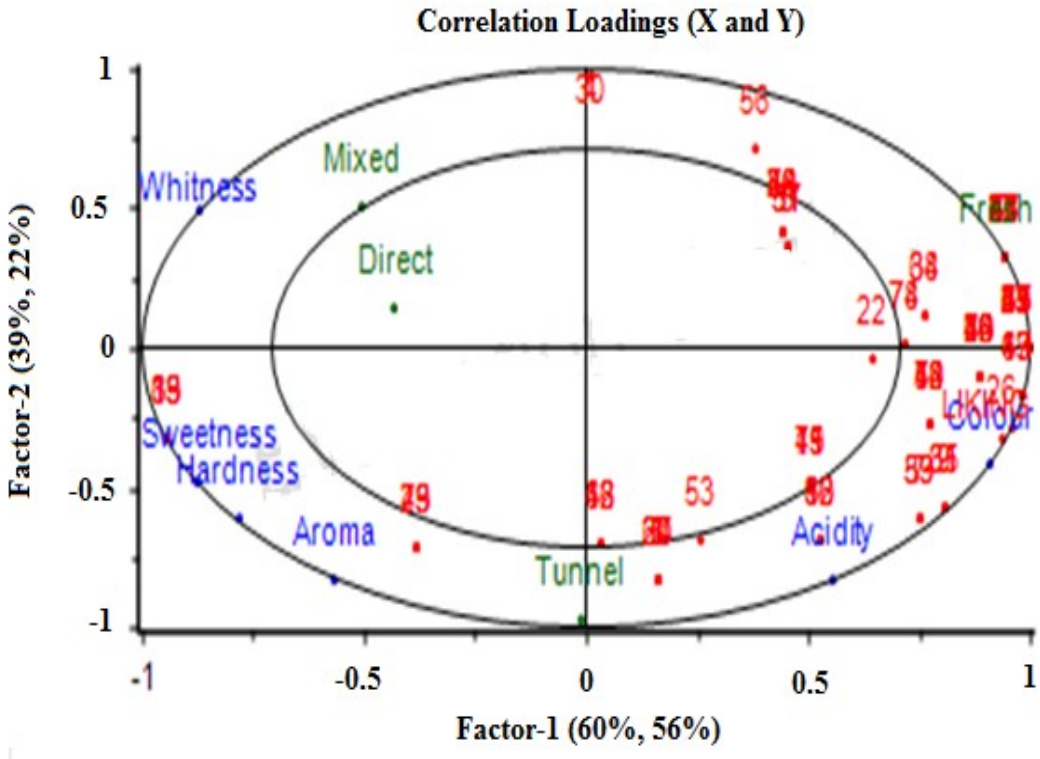

Figure : **Correlation loadings from a partial least squares regression of fresh and dried mango samples with descriptive data as X variables and hedonic rating as Y variables.**

4.2.4.2 Banana

(i) Quantitative Descriptive Analysis (QDA)

Fig. 34 shows mean intensity ratings of descriptive attributes of fresh and dried banana samples. The results showed significant ($p<0.05$) differences in mean intensity scores between fresh and dried samples and between drying methods. The dried samples had significantly higher mean intensity scores in hardness and sweetness than fresh counterparts which had higher colour and whiteness scores (Appendix 10).

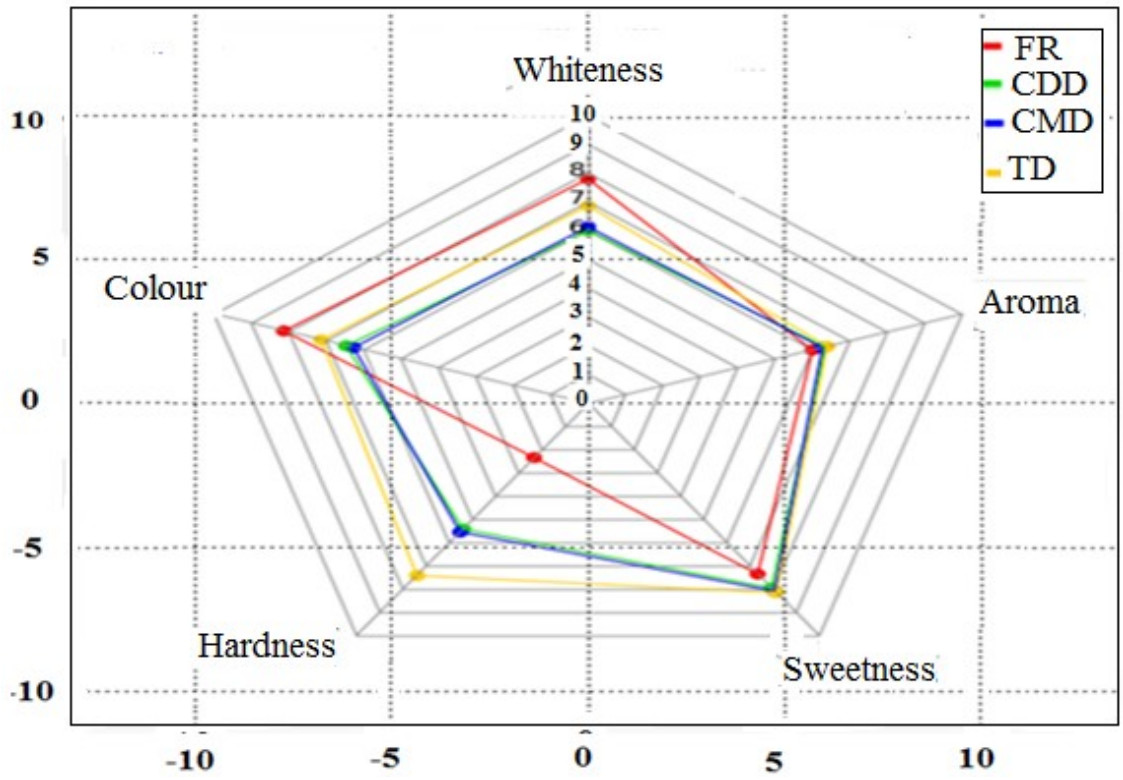

Figure : Spider plot showing mean intensity ratings of descriptive attributes of fresh and dried banana at different dryers.

(ii) Consumer studies

Table 31 shows hedonic scores for the analysed fresh and dried banana samples. Consumers showed significant ($p<0.05$) differences in hedonic scores in all attributes between fresh and dried samples. Drying methods differed significantly ($p<0.05$) in overall acceptability with tunnel dried samples being significantly least acceptable.

Table : Mean hedonic scores of fresh and dried banana samples

Method	Attributes					
	Colour	**Taste**	**Aroma**	**Texture**	**Mouth feel**	**Acceptability**
FR	7.5±1.1[a]	7.6±1.1[a]	7.6±1.1[a]	7.3±1.8[a]	7.3±1.1[a]	7.7±1.4[a]
CDD	6.3±1.8[b]	7.0±2.2[b]	6.8±1.5[b]	6.5±1.8[ab]	6.7±2.0[ab]	7.1±1.5[b]
CMD	6.3±1.8[b]	7.1±1.4[b]	6.4±1.3[b]	6.7±1.4[ab]	6.9±1.6[ab]	6.9±1.3[b]
TD	6.4±1.9[b]	6.9±2.5[b]	6.4±2.1[b]	6.0±2.3[b]	6.2±2.3[b]	6.3±1.6[c]

Different letters along the column indicate values are significantly different ($p<0.05$).

(iii) Preference mapping

(a) Principal component of descriptive sensory data

Fig. 35 shows bi-plot with the two first significant principal components from principal component analysis (PCA) on average sensory attributes. PC 1 accounted for 87.1% of the systematic variation in the data and PC 2 accounted for only 12.7%. The result shows that, fresh samples

correlated positively with sensory attributes whiteness and colour while dried samples correlated positively with hardness, aroma and sweetness attributes. Cabinet dried samples had similar properties. The variation between samples along PC 1 was explained by attributes aroma, hardness, sweetness on one side and attributes colour and whiteness on the other side while PC 2 was mainly described by variation in whiteness, colour and hardness on one side and attributes sweetness and aroma on the other side. The variations between samples were only along PC 1 and were explained by the two groups of attributes reported above.

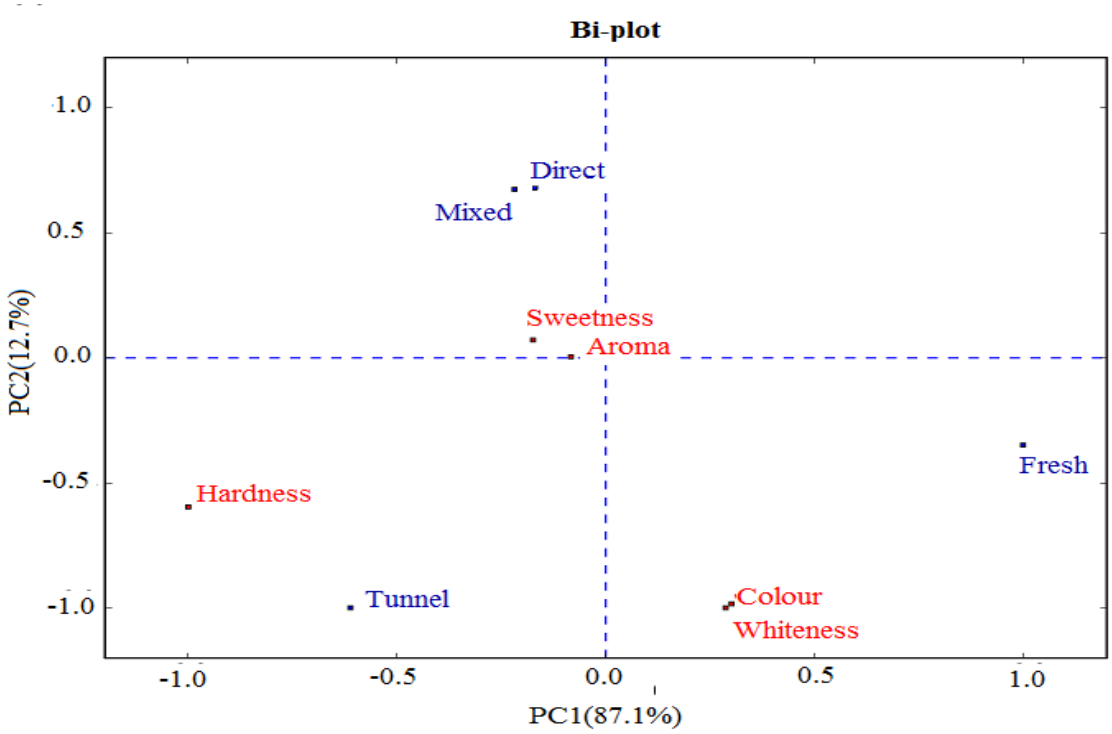

Figure : Bi-plot from PCA of significant descriptive sensory data for fresh and dried banana samples.

(b) Relationship between descriptive data and hedonic liking by PLSR

Fig. 36: shows the results from a PLSR using descriptive data as X-variables and liking rated by the consumers as *Y*-variables. The finding shows that, the two first significant components described 45% of the variation in *Y*. It further indicates that, most consumers fall to the right of the vertical Y-axis which means the acceptance values of these persons go in the direction of fresh sample associated with colour and whiteness attributes. Few consumers preferred direct and mixed samples associated with hardness, aroma and sweetness attributes. The x-axis shows high preference for direct and mixed dried samples than tunnel dried samples which is similar to overall acceptability observed in hedonic results (Table 31).

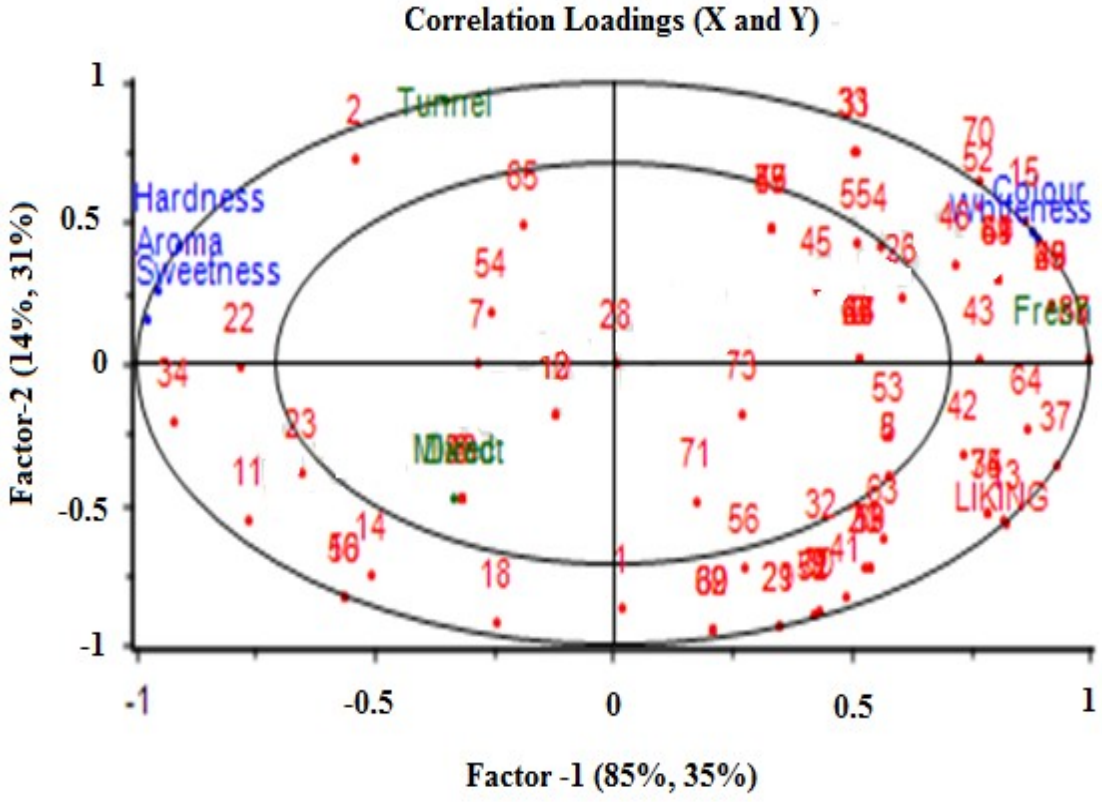

Figure : Correlation loadings from a partial least squares regression of fresh and dried banana samples with descriptive data as X variables and hedonic rating as Y variables.

4.2.4.3 Pineapple

(i) Quantitative Descriptive Analysis

Fig. 37 shows mean intensity ratings of descriptive attributes of fresh and dried pineapple samples. The results showed significant ($p<0.05$) differences in mean intensity scores between fresh and dried samples. Dried samples had higher mean scores in hardness and sweetness attributes than fresh samples while whiteness, colour, and aroma attributes scores were statistically similar between fresh and dried samples. Between the drying methods, panel members could be able to differentiate ($p<0.05$) acidity between cabinet and tunnel dried samples (Appendix 10)

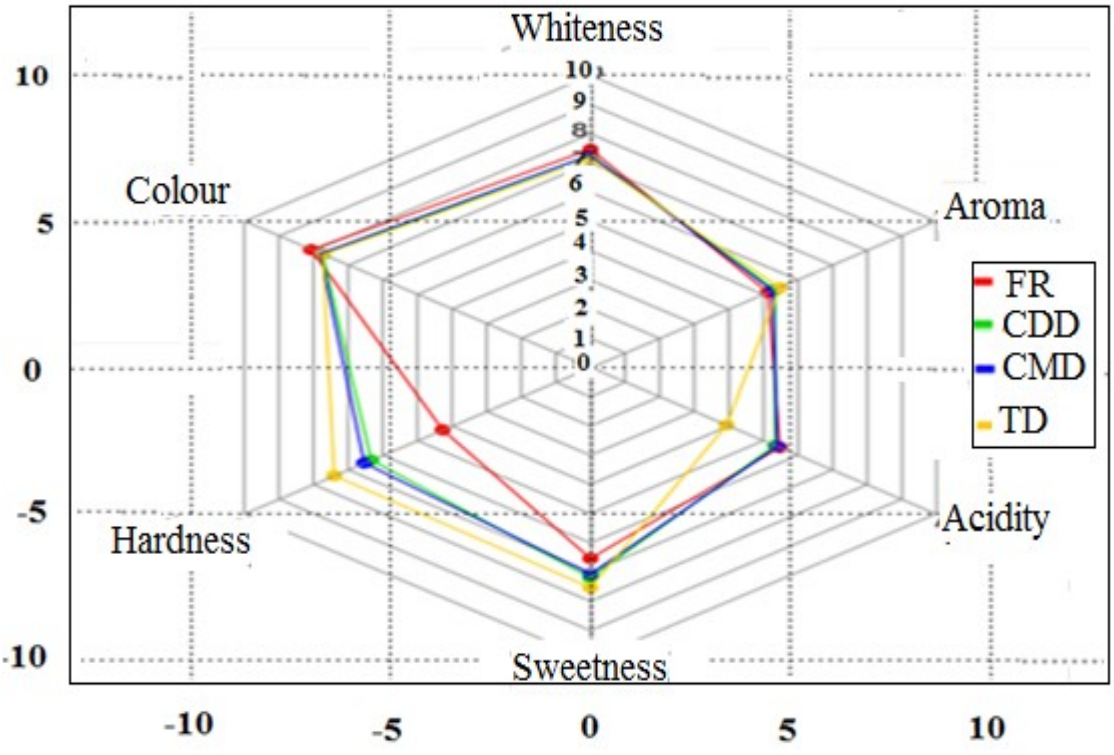

Figure : Spider plot showing mean intensity ratings of descriptive attributes of fresh and dried pineapple in different dryers.

(ii) Consumer studies

Mean hedonic scores for the analysed fresh and dried pineapple samples are shown in Table 32. Consumers showed significant ($p<0.05$) differences in mouth feel attribute only between fresh and dried samples while drying methods differed significantly ($p<0.05$) in texture attribute only, with tunnel dried samples scored lower than cabinet dryers. Overall, all samples were equally accepted.

Table : Mean hedonic scores of fresh and dried pineapple samples

Method	Attributes					
	Colour	Taste	Aroma	Texture	Mouth feel	Acceptability
FR	7.9±0.7^{a}	7.7±0.9^{a}	7.2±1.0^{a}	7.3±1.1^{a}	7.5±1.3^{a}	7.5±0.8^{a}
CDD	7.7±1.0^{a}	7.4±1.1^{a}	6.8±1.3^{a}	7.1±1.7^{a}	6.9±0.8^{b}	7.7±0.8^{a}
CMD	7.7±0.8^{a}	7.3±0.9^{a}	6.9±1.3^{a}	7.0±1.1^{a}	6.8±1.0^{b}	7.6±0.9^{a}
TD	7.6±0.6^{a}	7.5±1.3^{a}	6.7±1.4^{a}	6.1±0.8^{b}	6.4±1.5^{b}	7.4±1.1^{a}

Different letters along the column indicate values are significantly different ($p<0.05$)

(iii) Preference mapping

(a) Principal component of descriptive sensory data

Fig. 38 shows bi-plot with the two first significant principal components from principal component analysis (PCA) on average sensory attributes. PC 1 accounted for 89.8% of the systematic variation in the data and PC 2 only 9.9%. Tunnel dried samples were positively correlated with hardness, sweetness and aroma while fresh samples correlated positively with colour and whiteness sensory attributes. The variation in samples along PC 1 was mainly explained by colour, whiteness and acidity attributes on one side and aroma, hardness and sweetness attributes on the other side. The variation in samples along PC 2 was mainly explained by colour and acidity attributes.

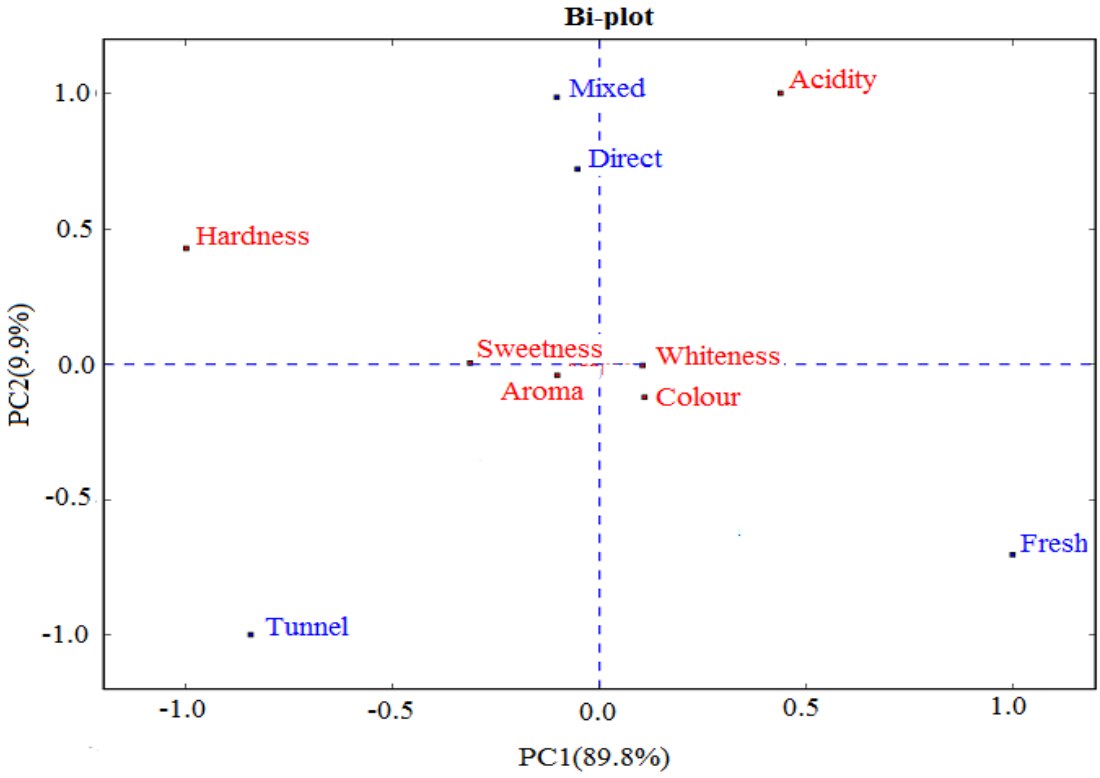

Figure : Bi-plot from PCA of descriptive sensory data for fresh and dried pineapple samples.

(b) Relationship between descriptive data and hedonic liking by PLSR

Fig. 39 shows the results from a PLSR using descriptive data as X-variables and liking rated by the consumers as *Y*-variables. It shows that, the two first significant components described 48% of the variation in *Y*. Most consumers fall to the right of the vertical Y-axis which means that consumer had highest preference for cabinet (direct and mixed) dried samples and fresh samples associated with acidity attribute and colour whiteness attributes respectively. Very few consumers preferred tunnel dried samples associated with hardness, sweetness and aroma attributes. The x-axis shows high preference for direct and mixed dried samples than fresh and tunnel dried samples. Interestingly, apart from showing the association between descriptive and hedonic data, PLSR had managed to detect the variation in sample liking which could not be detected by hedonic results (Table 32).

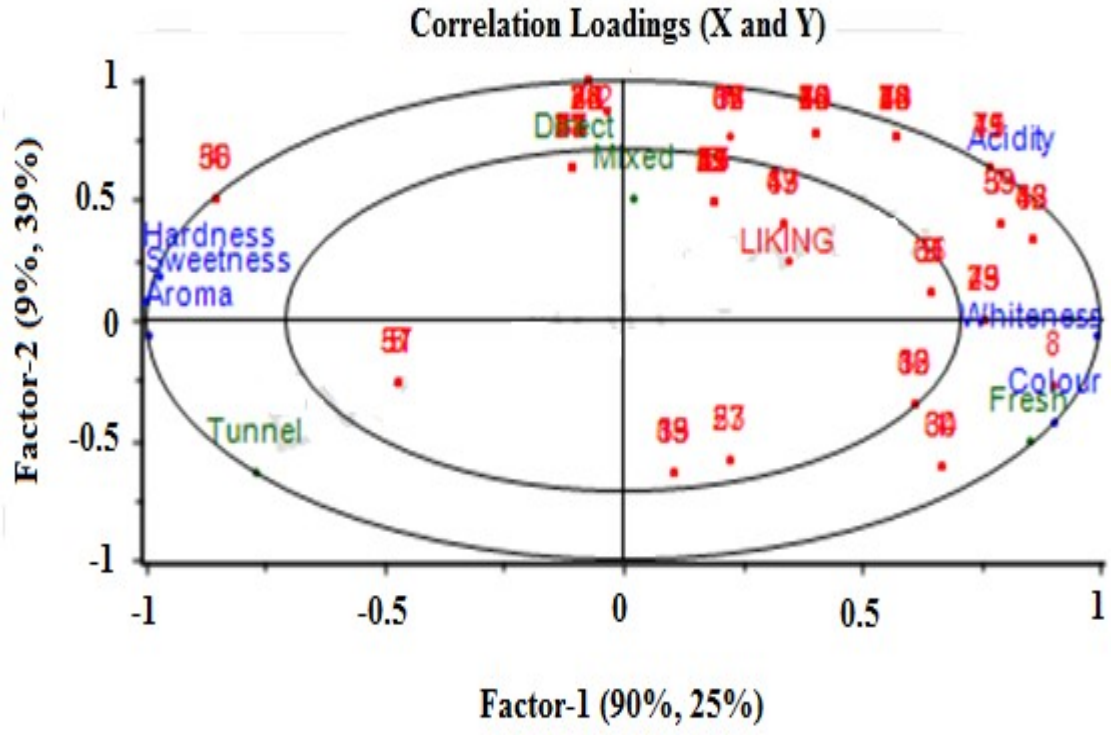

Figure : Correlation loadings from a partial least squares regression of fresh and dried pineapple samples with descriptive data as X variables and hedonic rating as Y variables.

4.2.4.4 Tomato

(i) Quantitative Descriptive analysis

Fig. 40 shows mean intensity ratings of descriptive attributes of fresh and dried tomato. The results show significant ($p<0.05$) differences in mean intensity scores between fresh and dried tomato samples. Dried samples had higher hardness and sweetness scores than fresh samples. There was also a significant differences ($p<0.05$) in acidity between cabinet and tunnel dried samples (Appendix 10).

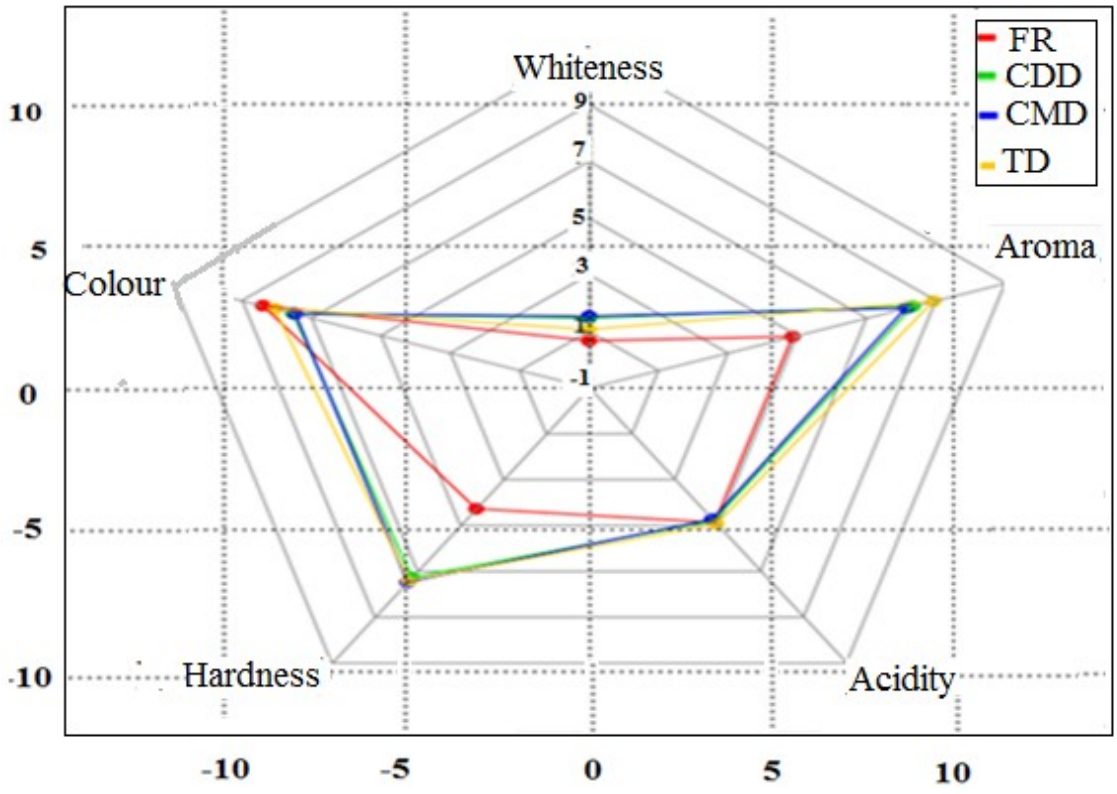

Figure : Spider plot showing mean intensity ratings of descriptive attributes of fresh and dried tomato samples in different dryers.

(ii) Consumer studies

Table 33 shows mean hedonic scores for the evaluated fresh and dried tomato samples There were significant ($p<0.05$) differences in colour, aroma and overall acceptability between fresh and dried samples. Furthermore, drying methods differed significantly ($p<0.05$) in texture attribute only with tunnel dried samples having scored higher values than cabinet dried samples.

Table : Mean hedonic scores of fresh and dried tomato samples

Method	Attribute			
	Colour	Aroma	Texture	Acceptability
FR	7.5±0.7	6.9±1.1[a]	7.2±1.1[a]	7.3±0.5[a]
CDD	6.9±0.7[a]	8.0±0.9[b]	7.7±0.9[a]	8.1±0.9[b]
CMD	6.8±0.6[b]	8.2±1.0[b]	7.4±0.8[a]	8.2±0.9[b]
TD	7.0±0.8[b]	8.5±0.7[b]	7.5±0.8[b]	8.5±0.7[b]

Different letters along the column indicate values are significantly different ($p<0.05$).

(iii) Preference mapping

(a) Principal component analysis of descriptive sensory data

Fig. 41 shows the bi-plot with the two first significant principal components from PCA on average sensory attributes of tomato. PC1 accounted for 96.6% of the systematic variation in the data and PC 2 only 3.3%. The result shows that, dried and fresh samples were well separated along PC 1 while fresh and tunnel dried samples were well separated from direct and mixed dried samples along PC 2. Dried samples correlated positively with whiteness, hardness and aroma attributes, while fresh samples correlated positively with colour and acidity attributes. These groups of attributes explain the variation in samples along PC 1 and PC 2.

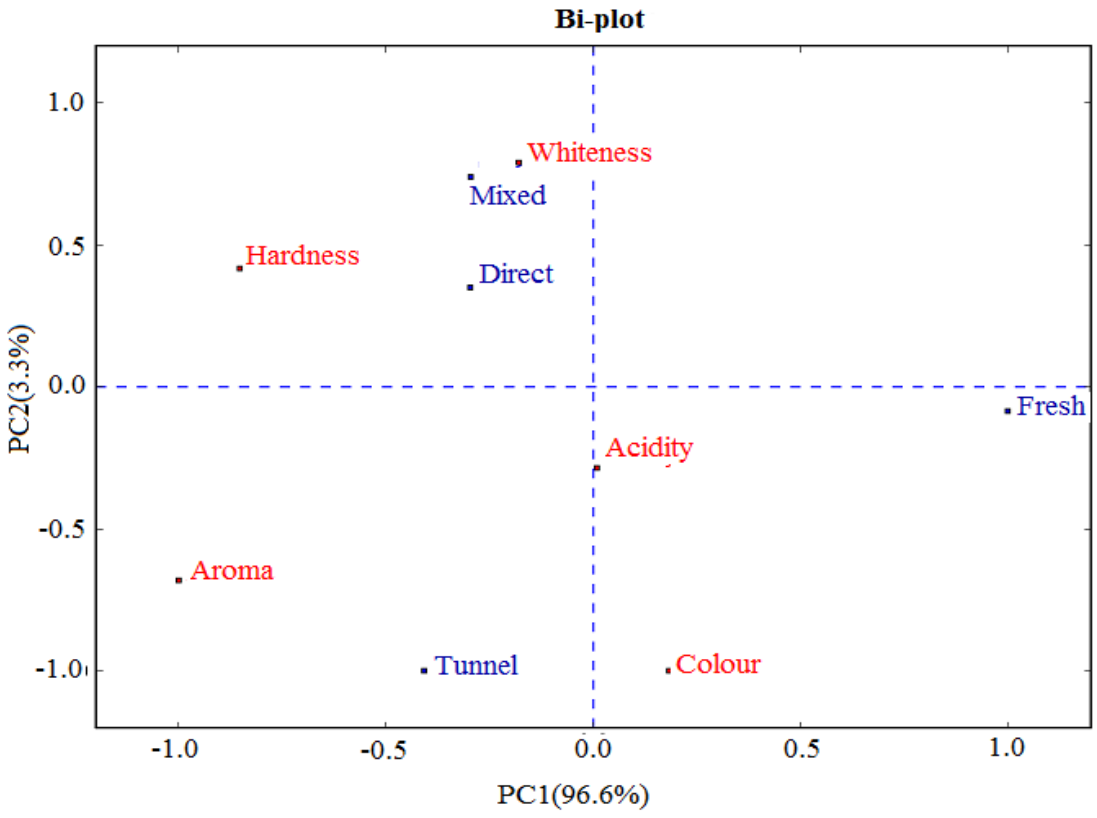

Figure : Bi-plot from PCA of descriptive sensory data for fresh and dried tomato samples.

(b) Relationship between descriptive data and hedonic liking by PLSR

Fig. 42 shows the results from a PLSR using descriptive data as X-variables and liking rated by the consumers as *Y*-variables. About 49% of the variation in Y was explained by the two first significant components. The findings show that, most consumers fall to the left of the vertical Y-axis which means that consumer had highest preference for all dried samples associated with aroma, hardness and whiteness attributes. Very few consumers preferred fresh samples associated with acidity and colour. The x-axis shows liking preference goes in the direction of aroma and hardness attributes characterising dried samples.

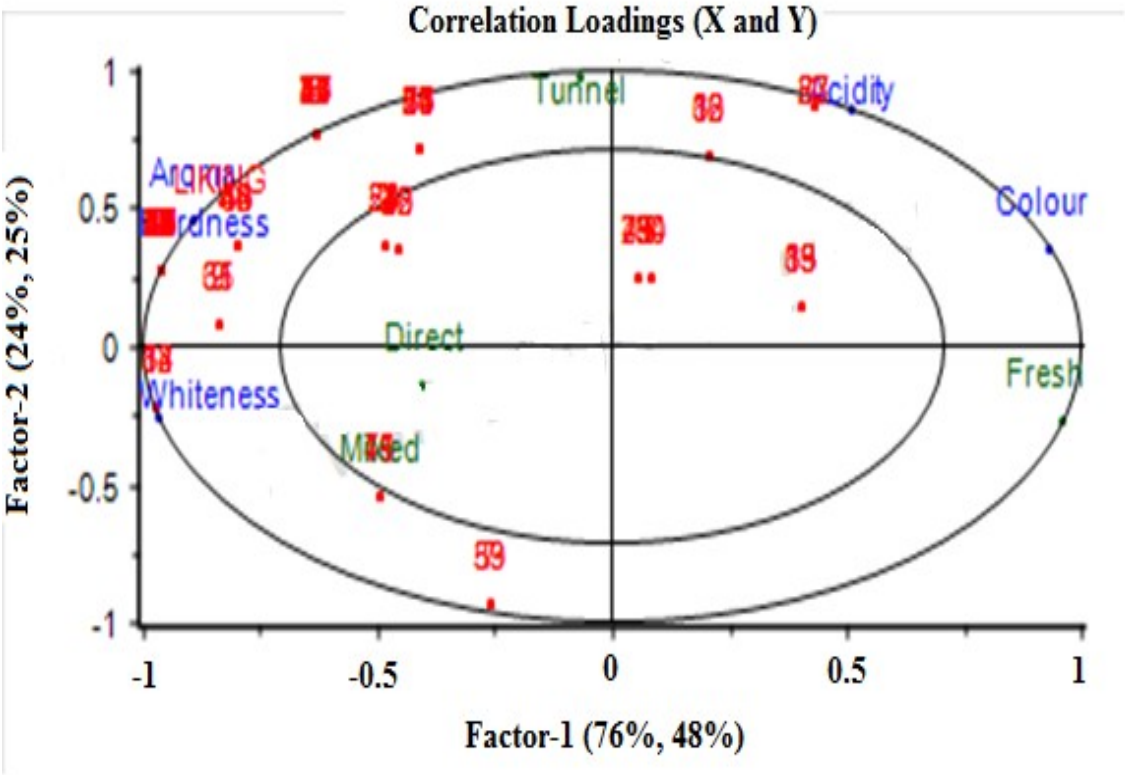

Figure : **Correlation loadings from a partial least squares regression of fresh and dried tomato samples with descriptive data as X variables and hedonic rating as Y variables.**

The findings imply that, solar drying has significant effect on sensory attributes of fruits and vegetables mainly colour and flavour compounds. Colour change during drying may be attributed to a number of chemical and biochemical reactions and the rates of such reactions depend strongly on the drying methods and the processing parameters (Bonazzi and Dumoulin, 2011; Al-Juamily *et al.*, 2007). Discoloration due to browning and pigment degradation is one of colour-related problem that is always encountered during drying and long-term storage of dried fruits and vegetables (Maskan, 2001). Phenolic compounds often contained in fruit and vegetable products are oxidized and polymerized to form brown pigments melanin (Perera, 2005). Some fruits like banana brown rapidly when their tissues are cut or bruised and exposed to air leading to reduced brightness and colour hue change. This could explain the reasons for significantly low colour scores in dried banana samples under both descriptive and consumer studies. It has been reported that, the change in the brightness of dried samples can be taken as a measurement of browning (Tijskens *et al.*, 2001). Krokida, Maroulis, and Saravacos (2001) found that the conventional air drying to cause extensive browning with a significant drop of the brightness and an increase in the redness and yellowness of dried potato.

The increase in sweetness in dried fruits samples could be attributed to moisture removal accompanied with increasing the concentration of flavour compounds in the remaining mass. For instance, sugars in fruits

are concentrated and dried products becomes sweeter that their fresh counterpart (UNIDO, 2001b). Texture is a quality parameter and its change in dried samples indicates a quality change. Gabas *et al. (*2007) associated changes occurring during drying to collapse of structure due to heat application with resulting firmer texture and increased chewiness. Various studies in tomato (Doymaz, 2007), mango (Mercer and Myhara, 2008), pineapple (Karim *et al.,* 2008 and banana (Cano-Chauca *et al.,* 2002) have reported changes in textural properties during drying.

The varied consumers' preferences provided insight into the sensory attributes that are important to individual consumer acceptability of samples. Preference mapping results showed colour and flavour as the most important drivers of consumer liking of fresh and dried fruits and vegetable samples under the study. Colour correlated closely to high consumers' preferences for fresh samples in mango and banana while flavour attributes of acidity and aroma correlated closely to consumer preferences for dried samples in pineapple and tomato respectively. Colour and appearance are the initial quality attributes that attract person to a food product. It is thus considered as an index of the inherent good quality of foods associated with the acceptability of food (Methakhup *et al*., 2003). On the other hand, flavour may have the largest impact on acceptability and desire to consume it again (Barrett *et al*., 2010). Therefore, drying methods that retains most sensory attributes especially colour and flavours of dried samples are of greater consideration for consumer acceptability and marketability. Preference

mapping results has shown close relationship between tunnel dryer and both attributes while only flavour has been associated with cabinet dryers.

4.2.5 Rehydration quality

4.2.5.1 Mango

The rehydration ratios of dried mango varieties at 50°C for one hour are shown in Fig. 3: There were significant differences ($p<0.05$) in rehydration ratios between drying methods. Tunnel dried samples had higher ratio ranging from 4.8 to 6.7 than cabinet dryers with values ranging 2.7 to 5.7.

4.2.5.2 Banana

Fig. 44 shows the rehydration ratios of dried banana varieties at 50°C for one hour. There were significant differences ($p<0.05$) in rehydration ratios between drying methods. In all varieties, tunnel dried samples had higher ratios ranging from 2.5 to 2.6 than cabinet dryers that ranged from 2.2 to 2.6. The ratio varies insignificantly ($p<0.05$) between the varieties.

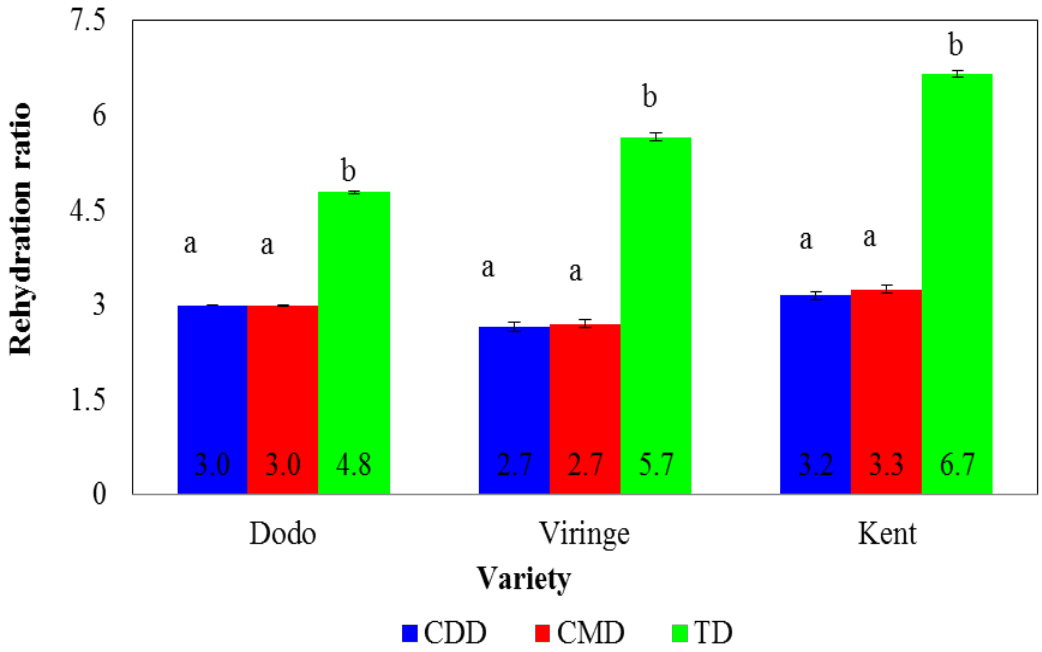

Figure : Rehydration ratio of mango varieties at 50°C for 60 minutes.

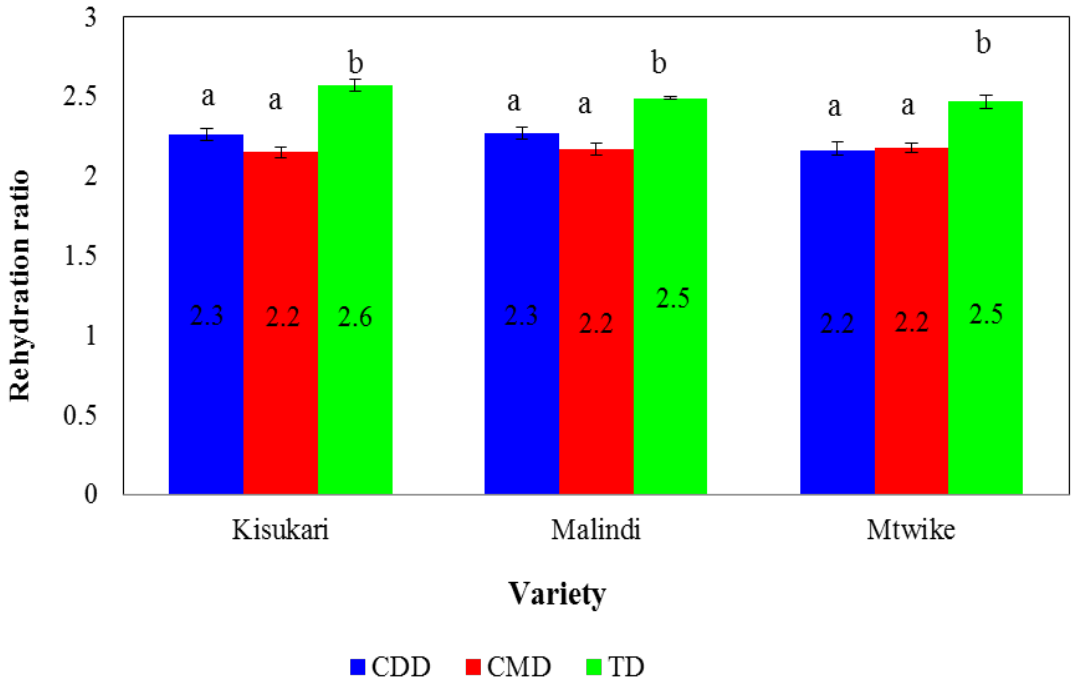

Figure : Rehydration ratio of banana varieties at 50°C for 60 minutes.

4.2.5.3 Pineapple

The rehydration ratio of dried pineapple is shown in Fig. 45: The results show that, there were significant differences ($p<0.05$) in rehydration

ratios between drying methods with tunnel dried samples having higher ratios of 3.6 than cabinet dried sample of 2.8.

4.2.5.4 Tomato

Fig. 46 shows the rehydration ratios of dried tomato varieties. The results show significant differences ($p<0.05$) in rehydration ratios between drying methods. Tunnel dried samples had higher ratio that ranged from 4.4 to 5.4 than cabinet dried ones that ranged from 3.7 to 4.4. The ratio varies insignificantly ($p<0.05$) between the varieties.

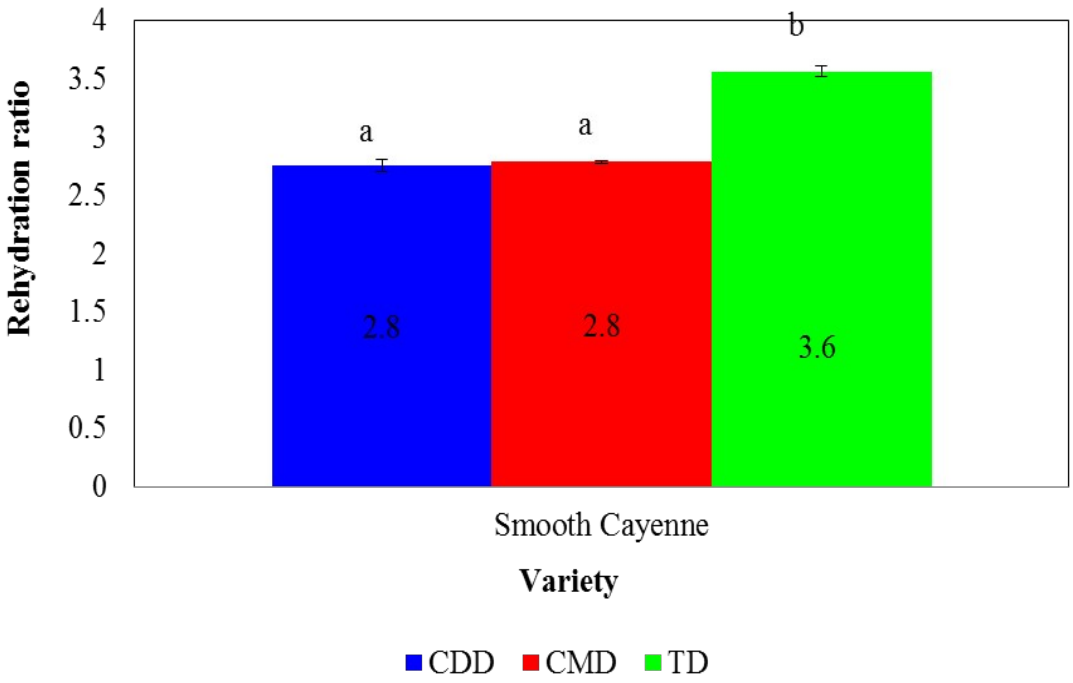

Figure : Rehydration ratio of pineapple at 50°C for 60 minutes.

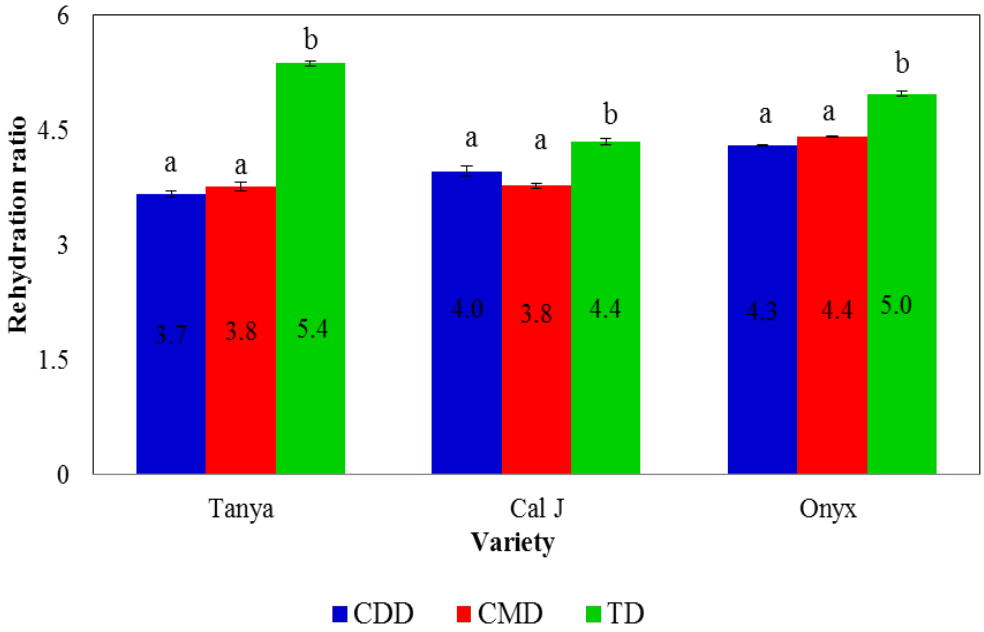

Figure : Rehydration ratio of tomato varieties at 50°C for 60 minutes.

The solar drying has statistically significant influence on the rehydration characteristic of the dried samples. A rapid and complete rehydration is an important property of dried products and is generally influenced by the method of processing, sample constitution, pre-drying treatment such as blanching and sulphiting, sample preparation prior to rehydration, extent of the structural and chemical changes induced by drying (Jayaraman and Das-Gupta, 1992; Krokida and Philippopoulos, 2005). The relatively higher rehydration capacity of tomato and tunnel dried samples than other products and cabinet dried samples, respectively, could be due to the shorter drying times associated with less textural damage during drying. Also, high drying rates for tunnel dryer do not allow for the cellular structure to collapse before it dries up. This allows for formation of a more porous structure, hence high capacity to imbibe water. The degree of cellular and structural disruption during drying, leads to loss of integrity and dense

structure of collapsed capillaries with reduced hydrophilic properties, as reflected by the inability to imbibe sufficient water to rehydrate fully (Krokida and Philippopoulos, 2005; Pandey and Singh, 2011).

The physical damages caused include shrinkage, increased or decreased porosity, and damage to microscopic structure (Witrowa-Rajchert and Lewicki, 2006). Prolonged drying times (slow drying velocity) of the cabinet dryers increased shrinkage and toughness with reduced hydrophilic properties and hence low rehydration capacity of their products. Hence, rehydration has been considered as a measure of the induced damage in the material during drying (Lewicki, 1998). Variation in rehydration capacity due to drying have also been reported in dried carrot (Strøm, 2011), dried tomato (Sacilik *et al*., 2006) and sweet potatoes (Pandey and Singh, 2011).

4.3 Shelf life of Dried Fruits and Vegetable

4.3.1 Effect of drying methods, storage time and packaging materials on microbial load

4.3.1.1 Mango

The effect of drying methods, storage time and packaging materials on microbial quality of dried mango cv. *Dodo* is shown in Figures 47-49. The results show significant ($p<0.05$) variations in microbial load between drying method. Tunnel dried samples had significantly lower total bacteria counts of 4.3E+03 cfu/g than cabinet ones ranging from 9.13E+03 to 9.33E+03 cfu/g. It had also lower fungi level (Fig. 47). The effect of storage time on microbial load was significant ($p<0.05$). Six months storage time resulted into higher total bacterial load of

1.0E+04 cfu/g than three and one month storage times with values of 7.6E+03 and 4.9E+03 cfu/g respectively. Same pattern but with lower levels were observed in fungi counts as indicated in Fig. 48.

The type of packaging materials used showed significant variations ($p<0.05$) in number of microbial load for the product they contained. High density polyethylene (HDPE) package had significantly ($p<0.05$) lower total bacterial count of 6.3E+03 and fungi count of 3E+03 cfu/g than low density polyethylene (LDP) package which had total bacteria and fungi counts of 8.8E+03 and 4.4E+03 cfu/g respectively (Fig. 49). The interaction between storage time and packaging materials was not significant ($p>0.05$). No coliform was detected in all samples in the study.

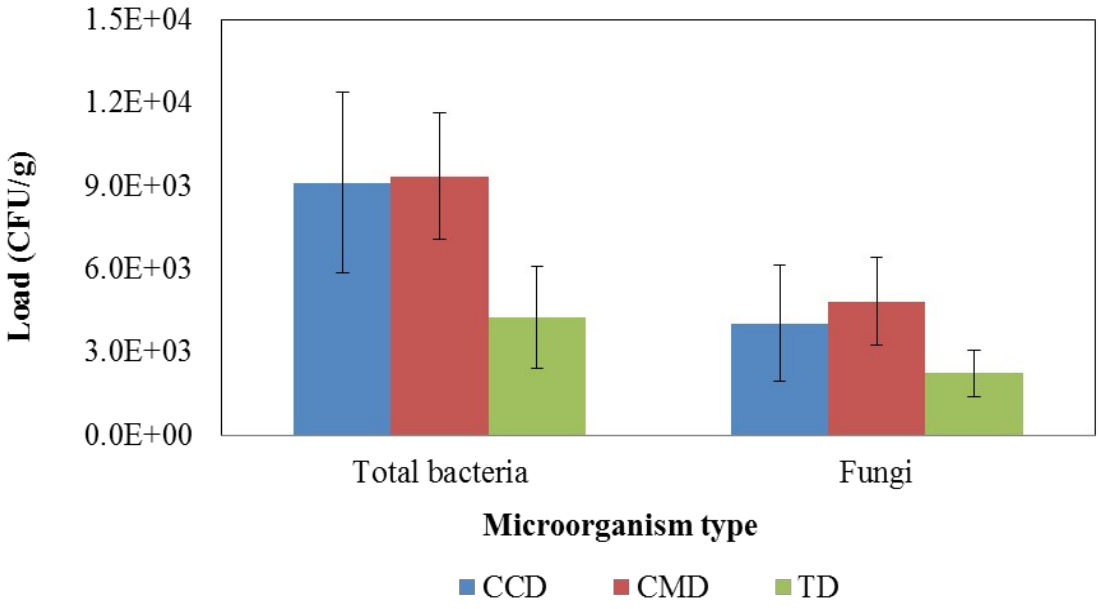

Figure : Effect of drying methods on microbial load (cfu/g) of mango cv. *Dodo*.

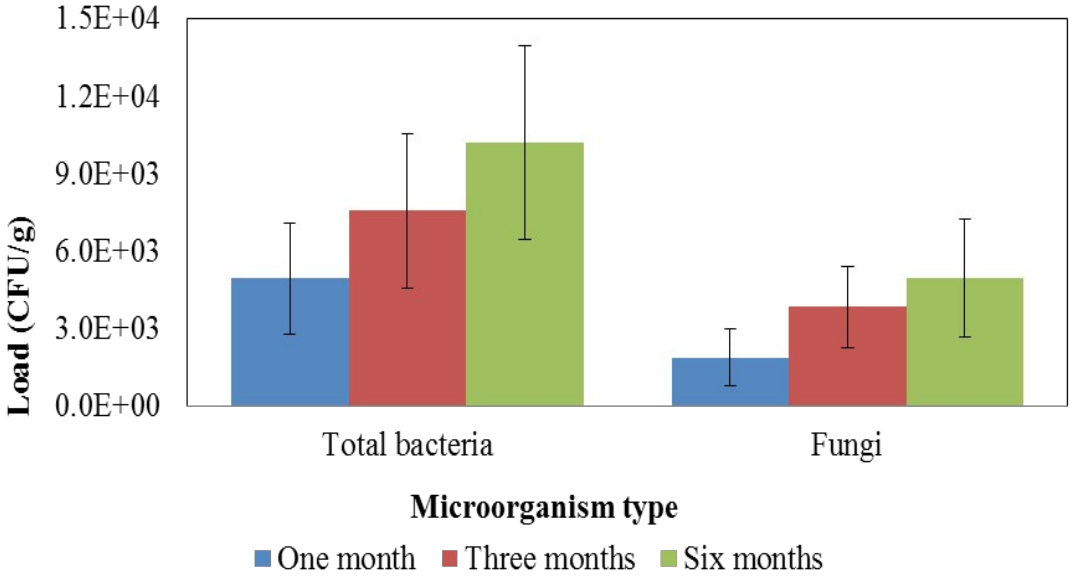

Figure : Effect of storage time on microbial load (cfu/g) of mango cv. *Dodo*.

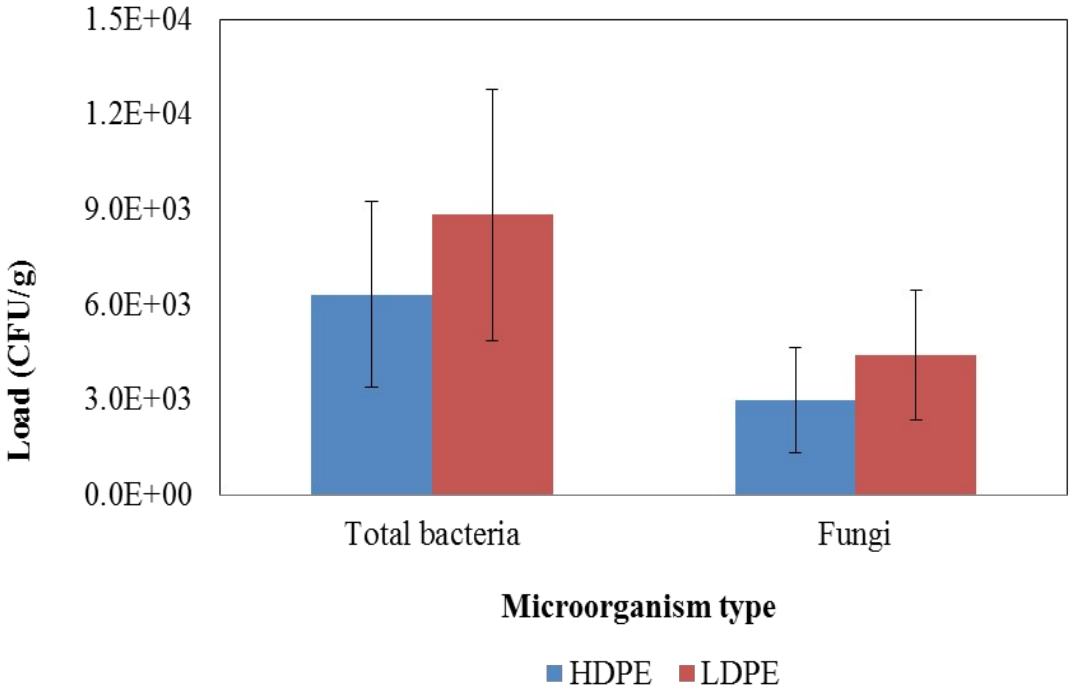

Figure : Effect of packaging materials on microbial load (cfu/g) of mango cv. *Dodo* for six month storage time.

4.3.1.2 Banana

Figures 50-52 shows the effect of drying methods, storage time and packaging materials on microbial quality of dried banana. The results

show significant ($p<0.05$) variations in microbial load between drying methods with tunnel dried samples having significantly ($p<0.05$) lower total bacterial counts of 3.5E+03 cfu/g than cabinet dried samples with total bacterial counts ranging from 5.4E+03 to 6.1E+03 cfu/g. Furthermore, the tunnel dried samples had significantly lower fungi level of 1.1E+03 cfu/g compared to cabinet dries samples that ranged from 2.1E+03 to 2.5E+03 cfu/g (Fig. 50). The effect of storage time on microbial load of dried banana was significant ($p<0.05$). Six months storage time had highest total bacterial load of 6.8E+03 cfu/g and lowest in one month storage time of 3.1E+03 cfu/g. A similar trend but lower values of 2.8E+03 cfu/g and 1E+03 cfu/g for six and one-month storage times respectively were observed in fungi (Fig. 51).

The effect of the type of packaging materials on microbial load was also significant ($p<0.05$) with high density polyethylene (HDPE) package having lower total bacterial and fungi counts of 4.0E+03 and 1.4E+03 cfu/g respectively than low density polyethylene (LDPE) package, which had total bacteria and fungi counts of 6.0E+03 and 2.4E+03 cfu/g, respectively (Fig. 52).

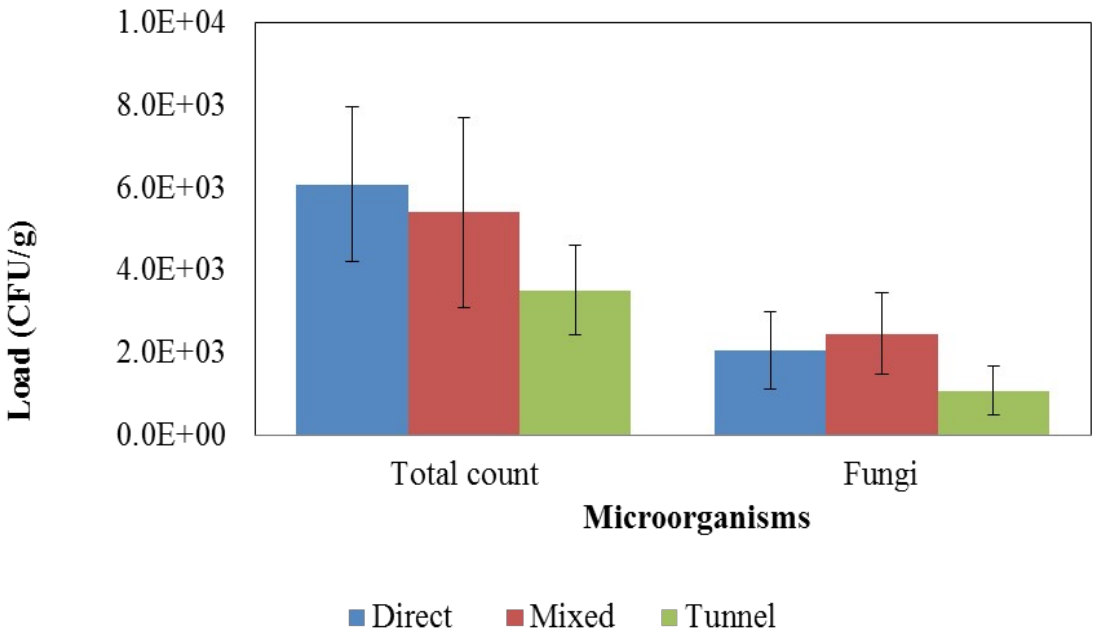

Figure : Effect of drying methods on microbial load (cfu/g) of banana cv. *Kisukari.*

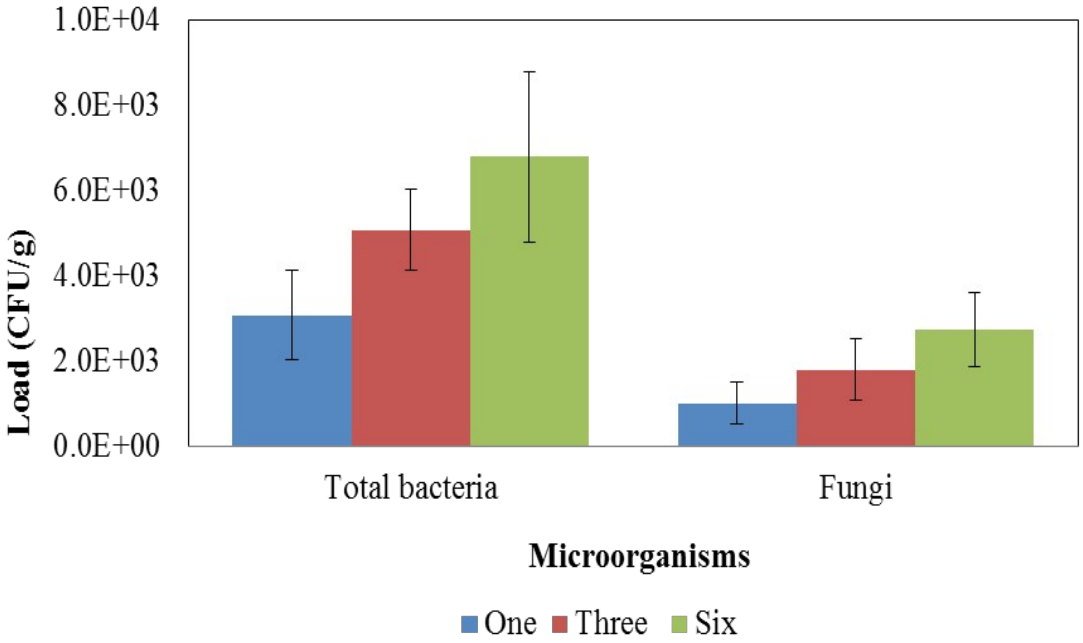

Figure : Effect of storage time on microbial load (cfu/g) of banana cv. *Kisukari*

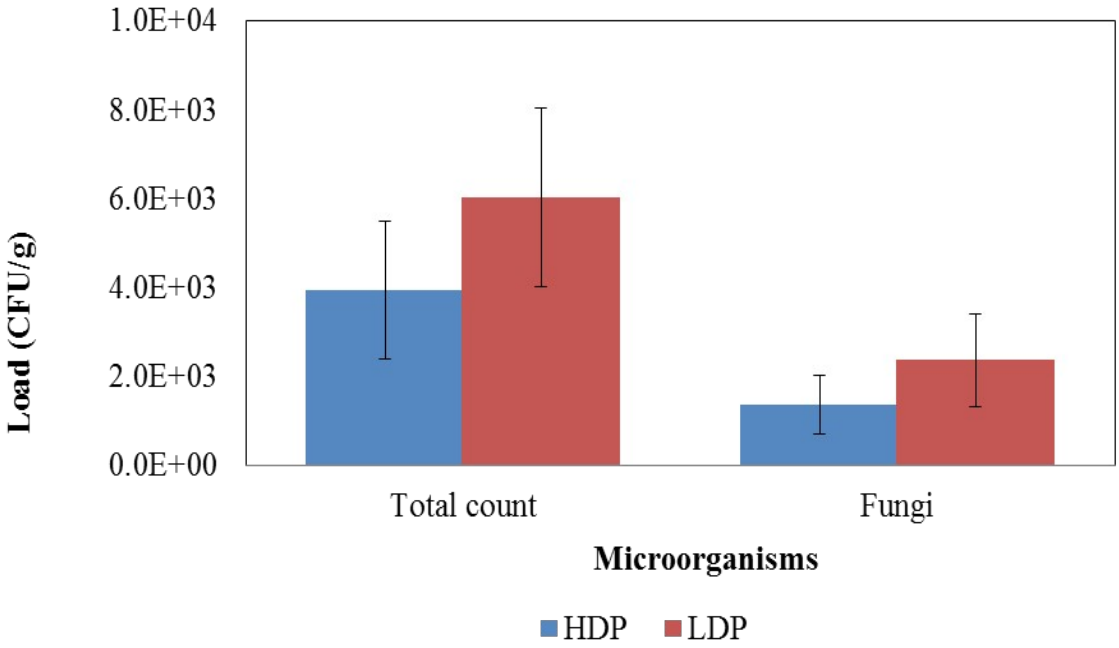

Figure : Effect of packaging materials on microbial load (cfu/g) of banana cv. *Kisukari for* six month storage time.

4.3.1.3 Pineapple

The effect of drying methods, storage time and packaging materials on microbial quality of dried pineapple are shown in Fig. 53-55. The results show significant ($p<0.05$) variations in microbial load between drying method. Tunnel dried samples had significantly lower total bacteria counts of 5.1E+03 cfu/g than cabinet dried ones with total bacterial count ranged from 9.8E+03 to 1.03E+04 cfu/g. As for fungi count, tunnel dried samples had lowest load of 3.5E+03 cfu/g compared to cabinet dried samples ranged 7.4E+03 to 7.8E+03 cfu/g (Fig. 53). The effect of storage time on microbial load of dried pineapple was significant ($p<0.05$). The highest total bacterial load of 1.1.E+04 cfu/g was in six-month storage time and lowest in one-month storage time of 5.6E+03 cfu/g. The fungi count of 9E+03 and 3.3E+03 cfu/g,

respectively, were observed in six and one-month storage times (Fig. 54).

The type of packaging materials had significant ($p<0.05$) effect on microbial load of the dried ($p<0.05$). The HDPE package had lower total bacterial and fungi loads of 6.7E+03 and 5.3E+03 cfu/g, respectively than LDPE package which had total bacteria and fungi counts of 9.7E+03 and 7.2E+03 cfu/g, respectively (Fig. 55).

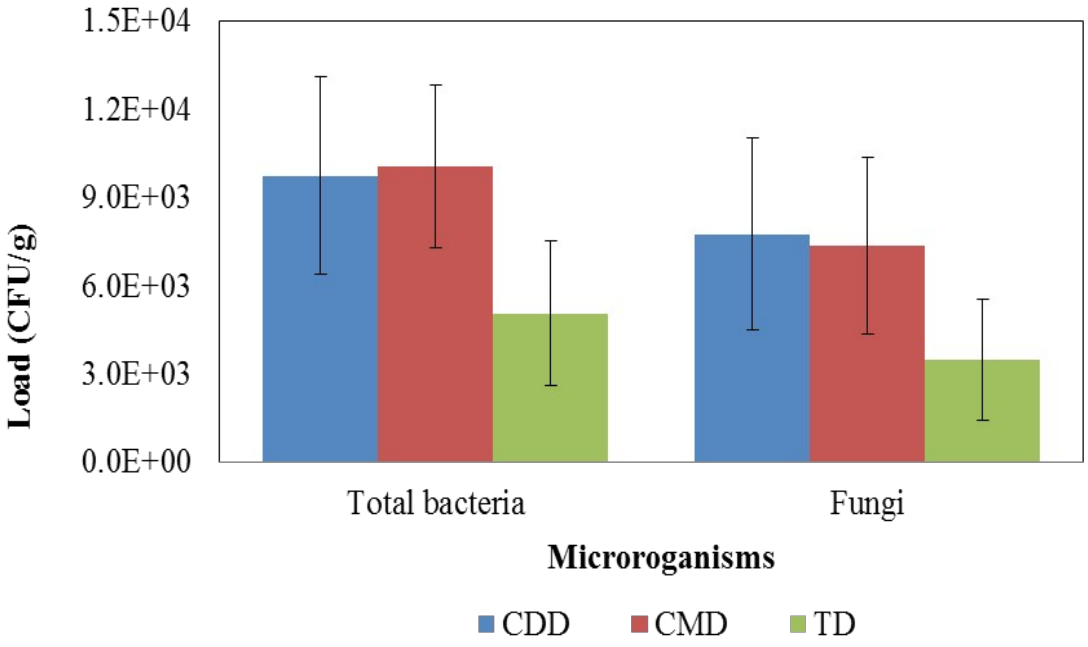

Figure : Effect of drying methods on microbial load (cfu/g) of pineapple.

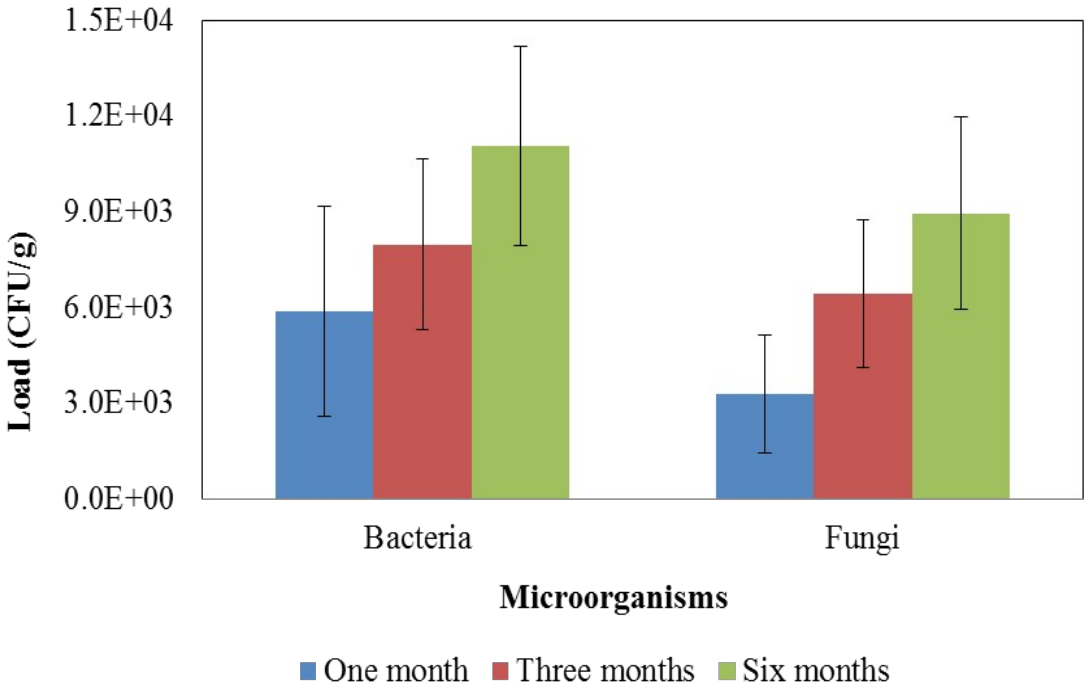

Figure : Effect of storage time on microbial load (cfu/g) of pineapple.

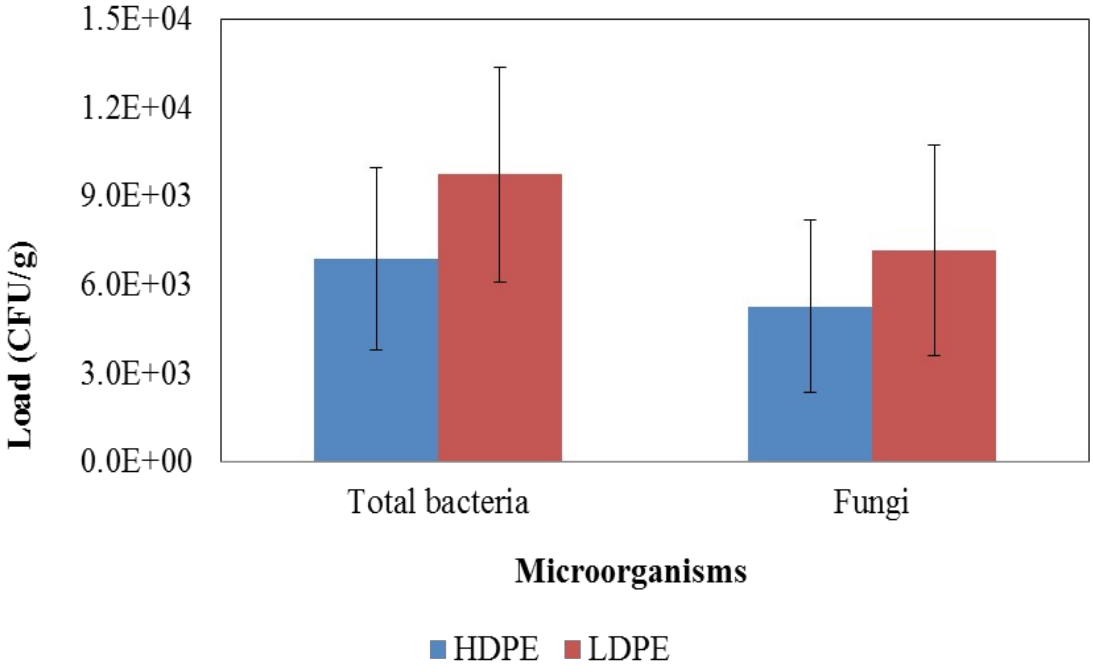

Figure : Effect of packaging materials on microbial load (cfu/g) of pineapple for six months storage time.

4.3.1.4 Tomato

The effect of drying methods, storage time and packaging materials on microbial quality of dried tomato is shown in Fig. 56-58. Compared to fruits, tomato had the highest microbial load approaching to the

maximum limits set by TBS (2009; 2010). Drying methods had significant ($p<0.05$) variation between the microbial load of dried samples with tunnel dried samples having lower total bacteria counts of 3.8E+05 cfu/g than cabinet dryers with counts ranged from 5.9E+05 to 7.1E+03 cfu/g. The tunnel dried samples had also significantly lower fungi level of 1.5E+05 cfu/g compared to cabinet dried samples with values ranging from 2.8E+05 to 3.4E+05 in (Fig. 56).

The effect of storage time on microbial load of dried tomato was also significant ($p<0.05$). Six-months storage time had highest total bacterial count of 7.6E+05 cfu/g while one-month storage time had lowest count of 3.4E+05 cfu/g. Relatively lower values of 4.1E+05 and 1.2E+05 cfu/g for six and one-month storage times were respectively observed in fungi (Fig. 57).

The results also showed significant ($p<0.05$) effects in microbial load due to type of packaging materials used. HDPE package had significantly ($p<0.05$) lower total bacterial and fungi counts of 4.9E+05 and 2.1E+05 cfu/g, respectively than LDPE package which had total bacteria and fungi counts of 6.3E+05 and 3.0E+05 cfu/g, respectively (Fig. 58).

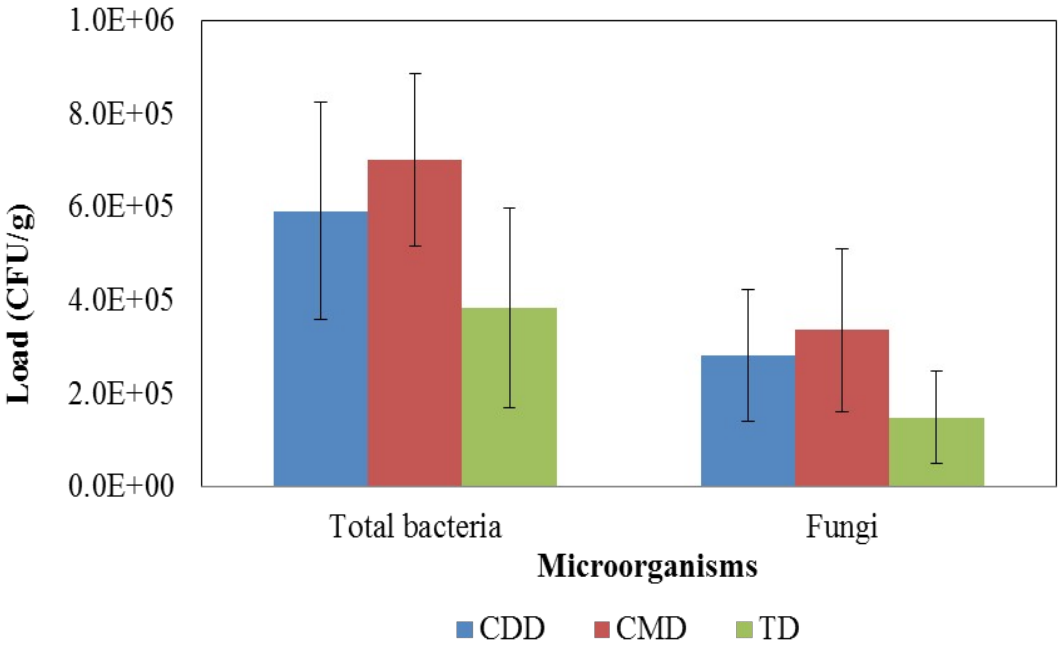

Figure : Effect of drying methods on microbial load (cfu/g) of tomato cv. *Tanya*

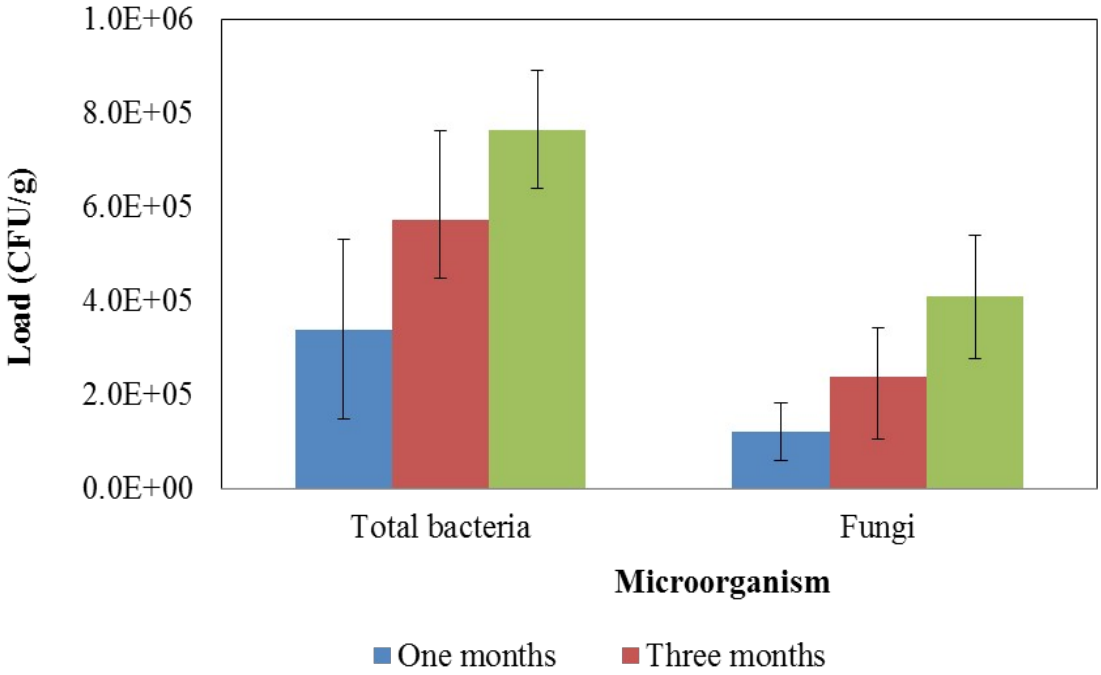

Figure : Effect of storage time on microbial load (cfu/g) of tomato cv. *Tanya*

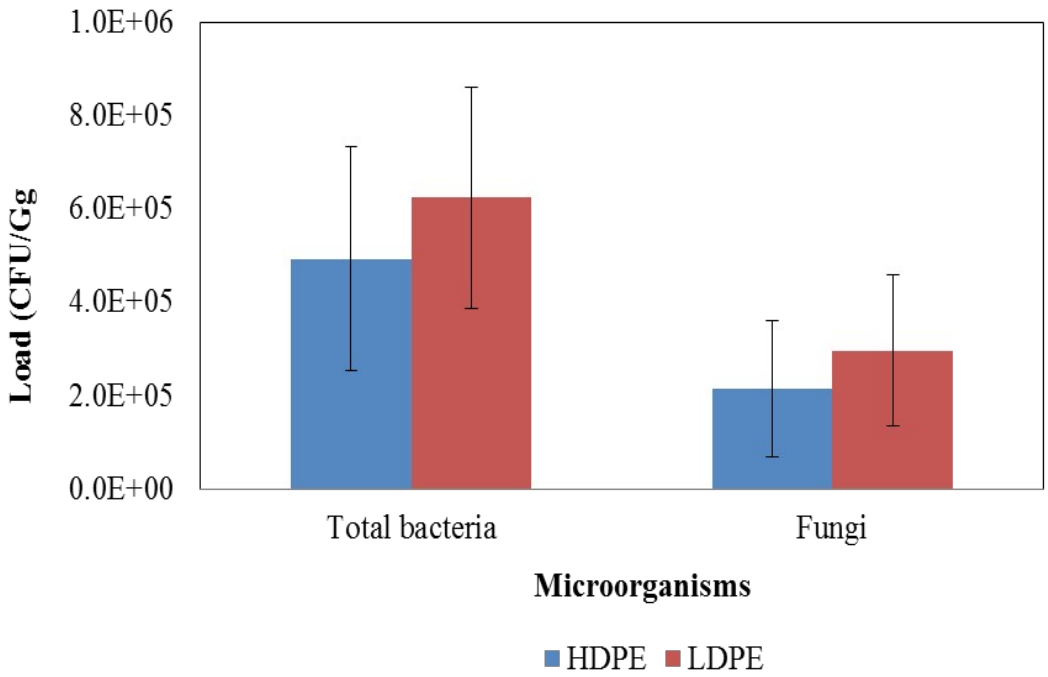

Figure : Effect of packaging materials on microbial load (cfu/g) of tomato cv *Tanya* for six month storage time.

The observed microbial loads in all fruits and vegetables samples lie within the maximum allowable limits set by TBS (2009; 2010) of zero coliform counts in cfu/g, 1x 10^5 total plate count and 1x10^3 cfu/g yeast and moulds counts implying that, solar drying produces microbiologically safe products. Removal of water increases the solute concentration of the food system and thus reduces the availability of water for microorganisms to grow. Lower limit of water activity for specific microorganisms to grow has been set where most fungi are inhibited below a_w= 0.7 (<20% moisture content) while most yeast are inhibited below a_w= 0.8 and most bacteria below a_w=0.9 (Perumal, 2007). For complete microbiological stability, water activity of the system should be below 0.6, where below this value, most microbial growth, especially bacterial, is impeded with the exception of xerophillic moulds and osmophillic yeasts which can thrive at water activity of 0.61 (Jayaraman and Das-Gupta, 2006).

It was found that, the moisture content values obtained for all the dried samples in this study fall within the range of 14-18% which is safe for storage of dried products (Food Standards' Agency, 2002). Fruit products with moisture content of 13-25% have water activity less than 0.8 (Jay, 1992). However, the survival, number and type of microorganisms during and after drying depends on the initial microbial quality of fresh produce, pH and composition, pre-treatments, drying time, methods of drying, moisture content of the finished product, good manufacturing practices and general level of hygienic practices during processing and drying (Sagar and Suresh, 2010). The interaction of some factors such as water activity, temperature-time combination, pH, oxygen and carbon dioxide or chemical preservatives has an important effect on the inhibition of microbial growth during drying (Fellows, 2009).

The findings have shown the significant effects of drying methods on the microbial quality of the final dried products. The greatest effect in minimizing microbial load observed in tunnel dryer could be associated to its relatively high temperature-short drying time combination which resulted into products with lower final moisture contents than cabinet dryers. Good tunnel dryer design and mode of operations such as material interconnection and airflow modes could have also contributed to its low microbial load. The effect of drying methods on microbial load of the dried products were also reported in dried mango slices (Tettey, 2008), tomato (Babarinde *et al*., 2009) and silverside fish (Selmi, 2010). Packaging materials properties greatly affect the shelf life of the dried products and depend on permeability and transparency (Siah and Tahir, 2011). The high microbial load in LDPE could be attributed to their higher water vapour permeability than in HDPE package. Lack of proper barrier increases the moisture content levels inside the package and favours the microbial growth. Studies in cooked oggtt (Arzoo *et al*., 2013), dried okra (Babarinde and Fabunmi, 2009) and cassava based product (pupuru) (Idowu *et*

al., 2009) have similarly shown more microbial load in LDPE package than HDPE package which shows the importance of selecting proper packaging to enhance quality and shelf life.

Coliform are commonly used as indicators of unsanitary conditions in food processing (Jayaraman and Das-Gupta, 2006). Lack of these organisms in all dried samples used in under this study indicates that good sanitary conditions were followed during preparation and drying. The microbial contamination of food products may be a result of lack of good manufacturing practices (GMP) and good hygienic practices at the whole food chain; that is from the farm through processing plant and storage facilities to the consumers table (Ofor *et al*., 2009). Therefore, adequate training on GMPs and GHP to food handler and processors coupled with effective application of hazard analysis critical control point (HACCP) in all food chain values is still highly advocated for microbiologically safe products.

The findings have generally shown the potential of solar drying in extending shelf life of fruits and vegetables and thus minimize the post-harvest losses. However, the higher microbial loads in tomato approaching maximum limit values set by TBS (2009; 2010) predict a shorter shelf life than fruits. This findings goes in line with reports by Harisson and Andress (2000) and Jayaraman and Das-Gupta (2006) that, dried vegetables have about half the shelf-life of fruits and the variation may be attributed to naturally high sugar and acid contents in fruits that allow them to dry well and store for longer periods of time than vegetables. Nevertheless, further studies to determine shelf life of fruits above six months is recommended.

4.4 Solar Drying and Opportunity for Employment Creation

The main objective of this study was to generate information knowledge which in turn will provide a basis for establishment of an enterprise within the food processing industry for solar drying of fruits and vegetables and thus lay the foundation for youths and women to engage in small-scale processing enterprises for employment creation. Tanzania's economy is predominantly based on agriculture which accounts for about half of the national income, three quarters of merchandise exports, is source of food, and provides employment opportunities to about 80 percent of Tanzanians (URT, 2004). Nevertheless, in 2011, the unemployment rate in Tanzania was estimated to be 10.7 of the labour force population (National Bureau of Statistics, 2011).

The information obtained from this study offers an opportunity for more engagement by youth and women in solar drying of fruits and vegetables sub sector. It has been observed that, solar drying is simple and affordable method of food processing which retains substantial amount of biochemical and sensory parameters of the dried products. In addition, products are prepared in hygienic manner resulting in quality product that can penetrate both local and international markets. Among the drying methods, tunnel dryer was observed to perfume better than cabinet dryers in terms of its heat generation, coupled with moisture reduction, nutrient and sensory quality retention as well as microbial load reduction. The dryer is best for commercial purposes. However, the tunnel dryer is expensive than cabinet dryers which may act as stumbling block for self-employment in this sub sector to individual or/and groups of poor rural youth and women.

Considering the importance of agriculture in national economy against high post-harvest losses of agriculture produces and unemployment rate, solar drying seems to offer hopes for solution. It is high time for unemployed youth and women be empowered on

individual or group basis to establish small and medium enterprises in this sub sector. The obtained information will serve as guide, but more importantly is for government, Non-Governmental Organisation and farmer friendly loan facilities to offer resources assistances such as training, dryers, finances, land, market channels etc. More employment in the sub sector, will not only generate income to the actors coupled with poverty reduction, but also, will reduce the post-harvest loss and enhances food security in Tanzania.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In a view of the findings it can be concluded that, the performance of solar dryers depends on weather conditions which also varies within a drying day, between drying methods and seasons. The performance is better during dry season than wet seasons and among the drying methods, tunnel dryer performs better than cabinet dryers Moreover, solar drying has varied significant effects on quality of dried fruits and vegetable; It reduce or enhance antioxidant activity, reduces proteins,

fat, vitamin C and colour and it enhances flavor (sweetness and aroma). With exception of vitamin C which suffered greater loss, substantial amount of biochemical and sensory parameters were retained in concentrated form, more pronounced in tunnel dried samples. On the other hand, solar drying was observed to have no significant effect on ash, crude fibre, minerals and sugars contents of dried fruits and vegetables except for sugars in tunnel dried samples.

It can further be concluded that, solar drying has potential to extend shelf life of dried fruits and vegetables for six month and more than six month for vegetables and fruits respectively. Drying methods, packaging materials and storages times have pronounced effects on microbial load and overall shelf life of dried fruit and vegetable products. Tunnel dryer, shorter storage time and high density polyethylene (HDPE) package minimize microbial load than their counterparts.

Therefore, this information is expected to cover to a large extent the existing information gap pertaining solar drying technology and if well utilized may serve as a guide for engagement of more people in the sub sector. This will not only enhance the employment opportunities and income generation, but also will enlarge the food processing industry and reduces the alarming post-harvest losses in fruits and vegetables in Tanzania.

5.2 Recommendations

Based on the objective and findings of this study, the following are recommended;

(i) Advocacy of solar drying technology for product development and reducing post-harvest losses.

Since solar drying is simple in operation, cheap in cost compared to modern industrial machine, and the study has shown it retains substantial amount of biochemical and sensory parameters during drying, then there is a need to advocate its application in the country for development of solar dried based products and reducing post-harvest losses which is currently amounting to 30-40%. The advocacy should begin at family levels through SMEs to the large companies.

(ii) Fabrication and more researches on Tunnel dryers

In this study, it was observed that tunnel dryer was observed to perform better than cabinet dryers in almost all aspects tested. This suggest that, for successful and commercialization of solar drying, tunnel dryer is recommended over local cabinet dryers. However, the dryer is too expensive for low income people and SMEs who need the dryer most. Therefore, it is recommended for fabrication of local and affordable tunnel dryer comparable to the industrial ones, using local available materials followed by researches/experiments to ascertain their performance comparative to the modern ones. If this succeeds, the solar drying activities and quality of the dried products will be enhanced many folds.

(iii) Drying activities and weather conditions

It is strongly advised to conduct solar drying activities when weather conditions are conducive, especially when humidity is low (Below 45%). As observed in the study, temperature and humidity are the main factors affecting drying, so drying activity when humidity is high will lead to loss due reduced moisture removal capacity of the dryer. It is recommended to have simple equipment for measuring temperature and humidity. If the values are found to be out of range, then drying activity should be stopped.

(iv) Supplementation with fresh fruits for vitamin C

Vitamin C is adversely affected during drying, especially with cabinet dryers, so it is not advisable to solely depend on dried fruits and vegetables for vitamin C and thus recommended to supplement with fresh fruits or other sources rich in this vitamin.

(v) Further studies

Further studies to ascertain some parameters which could not be covered by this study due to some resources constraints such as time and equipment are worthy to be done. These include:

(i) Vitamin A

One of the objectives of this study was to determine the effect of drying on vitamin A. Regrettably, due to resource constraints this objective was left out and thus a study to for its determination is worth

to be done when resources are available. Vitamin A is an important antioxidant scavenge free radicals in the body and it helps proper vision.

ii) Shelf life

Due to time constraint, a shelf life of more than six month could not be done and only six month has been reported in this study. A further shelf life study to ascertain shell life of more than six month including more parameters such as vacuum pack, coloured packaging materials, different storage temperatures and nutrient loss is recommended.

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APPENDICES

Appendix 1: Sample size and experimental units plan

1. **Mangoes**

40 fresh pieces of mangoes gives 1 kg of dried product

So, 40 x 4 (1 control + 3 dryers) x 3 varieties x 2 seasons = 960 pieces

2. **Pineapples**

20 fresh pieces of pineapples gives 1 kg of dried product

So, 20 x 4 (1 control + 3 dryers) x 3 varieties x 2 seasons = 480 pieces

3. **Banana**

60 fresh pieces of banana gives 1 kg of dried product

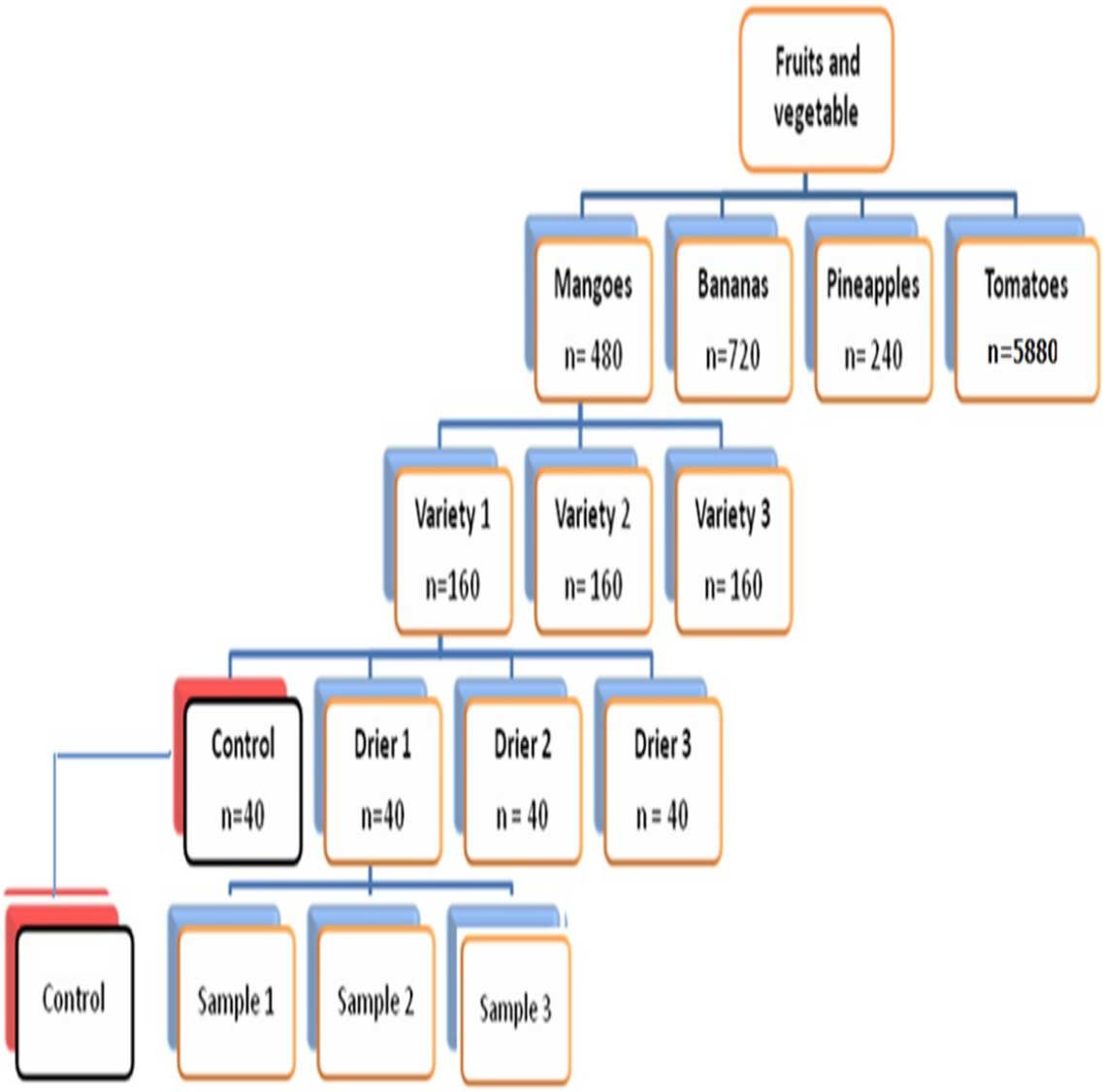
So, 60 x 4 (1 conrol+ 3 dryers) x 3 varieties x 2 seasons = 1440 pieces

4. Tomatoes

245 fresh pieces of tomatoes gives 1 kg of dried product

So, 245 x 4 (1 control + 3 dryers) x 3 varieties x 2 seasons = 5880 pieces

The whole plan has been summarized in Appendix 1



Experimental units = (4 x 3 x 3) x 2 seasons = 72

Appendix : Performance evaluation sheet for mango

Product:	**Mango**		
Initial moisture content (% wb)	79	79	79
Global radiation on the plane of solar collector for day1/day2/day 3	625	629	629
Average ambient temperature for day 1/day2/day3	31	31	33
Average ambient relative humidity for day 1/day2/day3	34.1	35	31
Parameters	CDD	CMD	TD
Quantity loaded. kg	9.6	8	58.
Loading density, kg/m2 of solar aperture	2.91	2.91	2 2.9
Collector Area, m2	2.75	2.23	1 15.
Collector tilt	7.5	7.6	4 0
Solar aperture, m2	3.3	2.7	20
Airflow rate, m3/h	0.72	0.62	2.4
Drying time up to 16% mc (hr)	57	58	33
Drying rate kg/hour	0.13	0.11	1.3
Collector efficiency	32.4	34.2	6 57

Appendix : Performance evaluation sheet for banana

Product:	**Banana**		
Initial moisture content (% wb)	72	72	72
Global radiation on the plane of solar collector for day1/day2/day 3	627	628	625
Average ambient temperature for day 1/day2/day3	31	29	30
Average ambient relative humidity for day 1/day2/day3	36.6	37	34
Parameters	CDD	CMD	TD
Quantity loaded. kg	9.6	8	58.2
Loading density, kg/m2 of solar aperture	2.91	2.91	2.91
Collector Area, m2	2.75	2.23	15.1
Collector tilt	7.5	7.6	40
Solar aperture, m2	3.3	2.7	20
Airflow rate, m3/h	0.72	0.62	2.4
Drying time up to 17% mc (hr)	57	58	33
Drying rate kg/hour	0.11	0.09	1.1
Collector efficiency	32.4	34.2	75.7

Appendix : Performance evaluation sheet for pineapple

Product:	**Pineapple**		
Initial moisture content (% wb)	80.6	80.6	80.6
Global radiation on the plane of solar collector for day1/day2/day 3	628	627	626
Average ambient temperature for day 1/day2/day3	31	30	31
Average ambient relative humidity for day 1/day2/day3	35.2	38	35
Parameters	**CDD**	**CMD**	**TD**
Quantity loaded. kg	9.6	8	58.2
Loading density, kg/m^2 of solar aperture	2.91	2.91	2.91
Collector Area, m^2	2.75	2.23	15.4
Collector tilt	7.5	7.6	0
Solar aperture, m^2	3.3	2.7	20
Airflow rate, m^3/h	0.72	0.62	2.4
Drying time up to 16% mc (hr)	31	32	26
Drying rate kg/hour	0.13	0.11	1.35
Collector efficiency	32.4	34.2	57

Appendix : Performance evaluation sheet for tomato

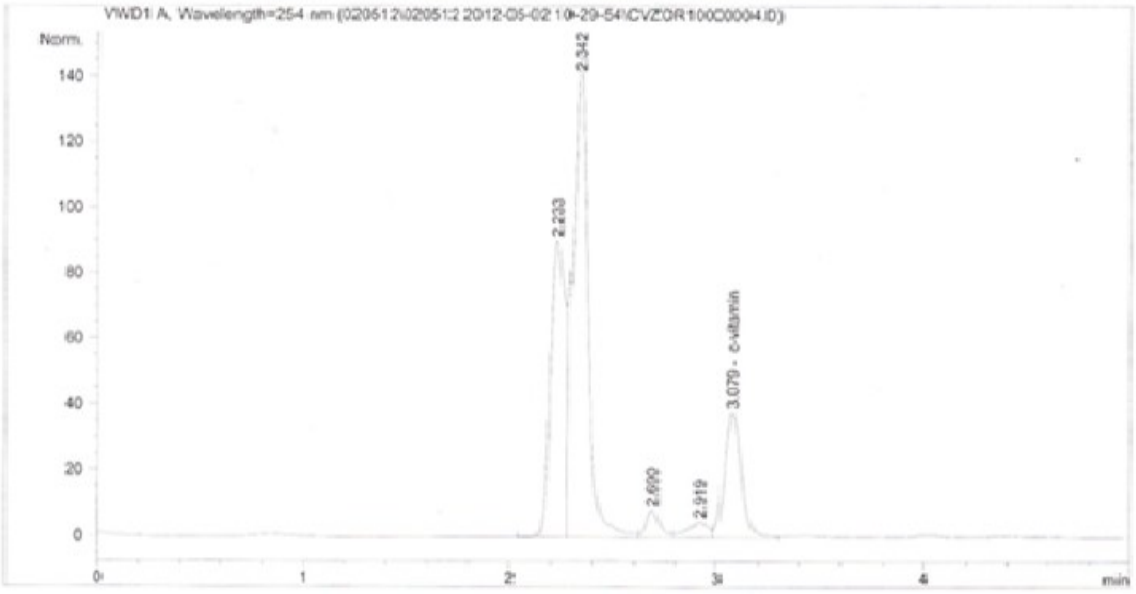
Product:	**Tomato**		
Initial moisture content (% wb)	93.18	93.1	93.1
		8	8
Global radiation on the plane of solar	627	628	625
collector for day1/day2/day 3			
Average ambient temperature for day	31	29	30
1/day2/day3			
Average ambient relative humidity for day	36.6	37	34
1/day2/day3			
Parameters	**CDD**	**CMD**	**TD**
Quantity loaded. kg	9.6	8	58.2
Loading density, kg/m^2 of solar aperture	2.91	2.91	2.91
Collector Area, m^2	2.75	2.23	15.4
Collector tilt	7.5	7.6	0
Solar aperture, m^2	3.3	2.7	20
Airflow rate, m^3/h	0.72	0.62	2.4
Drying time up to 14% mc (hr)	31	32	26
Drying rate kg/hour	0.22	0.17	1.57
Collector efficiency	32.4	34.2	57

Appendix : Sample chromatogram from HPLC showing the detector signals against retention time of solution containing vitamin C

```
Data File C:\CHEM32\1\DATA\020512\020512 2012-05-02 10-29-54\CVZOR10000004.D
Sample Name: banana

Acq. Operator    : KS                                  Seq. Line :   3
Acq. Instrument  : Instrument 1                         Location : Vial 3
Injection Date   : 5/2/2012 10:48:24 AM                      Inj :   1
                                                      Inj Volume : 5 µl
Acq. Method      : C:\Chem32\1\DATA\020512\020512 2012-05-02 10-29-54\CVZOR10.M
Last changed     : 8/19/2011 2:04:18 PM by ks
Analysis Method  : C:\CHEM32\1\DATA\020512\020512 2012-05-02 10-29-54\CVZOR10000004.D\
                   DA.M (CVZOR10.M)
Last changed     : 5/2/2012 10:54:03 AM by KS
                   (modified after loading)
Method Info      : Analyse av l-ascorbinsyre
                   Gammel Zorbax 2001 og Zorbax fra 2009
                   Ny standardkurve 21,06,2010
```

1052




```
            External Standard Report (Sample Amount is 01)

Sorted By             :      Signal
Calib. Data Modified  :      5/2/2012 10:54:03 AM
Multiplier            :      1.0000
Dilution              :      1.0000
Do not use Multiplier & Dilution Factor with ISTDs

Signal 1: VWD1 A, Wavelength=254 nm

RetTime  Type     Area      Amt/Area    Amount    Grp   Name
 [min]         mAU   *s                [mg/100 g]
-------|------|----------|----------|----------|--|------------------
  3.079 VB      218.33934 1.83201e-2    4.00001     c-vitamin

Totals :                                4.00001 X2 = 8,10

                      *** End of Report ***
```

Appendix : Mean percentage vitamin C recoveries (%) for dried fruit and vegetable samples

FruitVeg.	Var.	Drying method		
		CDD	CMD	TD
Banana	*Dodo*	18[a]	20[a]	54[b]
	Viringe	18[a]	20[a]	54[b]
	Kent	22[a]	24[a]	56[b]
Pineapple	*Kisukari*	22[a]	19[a]	32[b]
	Kimalindi	14[a]	16[a]	29[b]
	Mtwike	14[a]	13[a]	29[b]
Tomato	*Smooth cayenne*	30[a]	28[a]	51[b]
	Tanya	21[a]	23[a]	29[b]
	Cal J	24[a]	23[a]	31[b]
	Onyx	23[a]	21[a]	29[b]

Data presented as arithmetic means ± SD (n = 3).

Means in row with different small letter are significantly different ($p<0.05$) between drying methods.

Appendix : Quantitative Descriptive Sensory Evaluation Form

Sensory Evaluation Form

Quantitative descriptive Analysis (QDA) of fresh and dried dried fruits and vegetables

Sex……Age……Time……

Please evaluate each coded ample in the order they are listed. Choose appropriate number in a scale from 1 to 9, where 1 is low intensity and 9 is high intensity. How do you find the following characteristics for different fruit and vegetable. Put the appropriate number against each characteristic.

Sample number

Whiteness

Grey Very white	1	2	3	4	5	6	7	8	9

Colour

Faint Very concentrated	1	2	3	4	5	6	7	8	9

Hardness

Not hard Very hard	1	2	3	4	5	6	7	8	9

Sweetness

Not sweet Very sweet	1	2	3	4	5	6	7	8	9

Acidity

Not acidic Very acidic	1	2	3	4	5	6	7	8	9

Aroma

Not aromatic Very aromatic	1	2	3	4	5	6	7	8	9

What is your total liking of the product?

Don‟t like it Like it a lot	1	2	3	4	5	6	7	8	9

Appendix : Consumer test form

Sensory Evaluation Form

Consumer test of fresh and dried fruits and vegetables

Sex……Age……

Date…… Time……

Please evaluate each of the four (4) coded samples from left to right. Indicate how much you like or dislike each sample by checking the appropriate sample attribute and indicate your preference (9-1) in the column against each attribute. Put the appropriate number against each attribute.

Key: 9- Like extremely, 8-Like very much, 7- Like moderately, 6-Like slightly, 5-Neither like nor dislike 4-Dislike slightly, 3- Dislike moderately, 2-Dislike very much, 1-Dislike extremely.

	Sample code			
Attribute	**802**	**410**	**848**	**420**
Color				
Taste				
Aroma				
Texture				
Mouth feel				
Overall Acceptability.				
Would you be interested in buying/using this product?	Yes No	Yes No	Yes No	Yes No

Comments……

……

Appendix : Mean intensity rating for the fruit and vegetable samples

Fruit/Veg	Drying methods	Attributes					
		Whiteness	colour	Hardness	Sweetness	Aroma	Acidity
Mango		1.1±0.7[a]	8.1±1.0[a]	4.3±0.8[a]	6.5±0.9[a]	5.1±1.0[a]	3.9±1,0[a]
	Direct	2.0±1.0[b]	7.1±1.0[b]	6.3±0.9[b]	7.4±0.8[a]	5.3±0.7[a]	3.8±1.0[a]
	Mixed	2.1±0.9[b]	7.0±0.9[b]	6.5±0.6[b]	7.3±1.0[a]	5.3±1.3[a]	3.7±1.0[a]
	Tunnel	1.2±1.1[ab]	7.8±1.8[ab]	7.4±0.7[c]	7.5±1.1[b]	5.5±1.0[a]	3.9±0.7[a]
Banana							
	Fresh	7.8±1.0[a]	8.1±0.7[a]	2.3±0.8[a]	7.3±0.9[a]	6.0±0.8[a]	
	Direct	6.0±0.7[b]	6.5±0.6[bc]	5.4±0.9[b]	7.9±0.8[a]	6.3±0.7[a]	
	Mixed	6.1±0.6[bc]	6.3±0.7[b]	5.5±0.6[b]	8.1±0.8[a]	6.3±1.3[a]	
	Tunnel	6.9±0.9[c]	7.1±1.1[c]	7.4±0.7[c]	8.1±0.7[b]	6.4±0.9[a]	
Pineapple							
	Fresh	7.5±0.7[a]	8.1±0.7[a]	4.3±0.8[a]	6.5±0.9[a]	5.1±1.0[a]	5.5±0.5[a]
	Direct	7.3±0.7[a]	7.7±0.8[a]	6.3±0.9[b]	7.2±0.7[a]	5.3±0.7[a]	5.3±0.8[a]
	Mixed	7.3±0.7[a]	7.8±0.4[a]	6.5±0.6[b]	7.1±0.8[a]	5.3±1.3[a]	5.4±0.6[a]
	Tunnel	7.1±0.7[a]	7.7±0.8[a]	7.4±0.7[c]	7.5±1.1[b]	5.5±1.0[a]	3.9±0.7[b]
Tomato							
	Fresh	7.5±0.7[a]	8.1±0.7[a]	4.3±0.8[a]	6.5±0.9[a]	5.1±1.0[a]	5.5±0.5[a]

Direct	7.3±0.7[a]	7.7±0.8[a]	6.3±0.9[b]	7.2±0.7[a]	5.3±0.7[a]	5.3±0.8[a]
Mixed	7.3±0.7[a]	7.8±0.4[a]	6.5±0.6[b]	7.1±0.8[a]	5.3±1.3[a]	5.4±0.6[a]
Tunnel	7.1±0.7[a]	7.7±0.8[a]	7.4±0.7[c]	7.5±1.1[b]	5.5±1.0[a]	3.9±0.7[b]

Appendix : Analysis of Variance Table for total bacterial count (cfu/g) in mango

Source	DF	SS	MS	F Value	Prob
Dryer	2	98 182 800	49 091 400	37.8004	0.0025
Storage Time (ST)	2	84 113 100	2 056 550	32.3836	0.0034
Error	4	5 194 800	1 298 700		
Packaging Material (PM)	1	28 350 450	28 350 450	41.2310	0.0007
ST*PM	2	2 171 700	1 085 850	1.5792	0.2812
Error	6	4 125 600	687 600		
Total	**17**	**222 138 450**			

Appendix : Analysis of Variance Table for fungi count (cfu/g) in mango.

Source	**DF**	**SS**	**MS**	**F Value**	**Prob**
Dryer	2	21 212 100	10 606 050	9.8286	0.0286
Storage Time (ST)	2	29 047 500	14 523 750.	13.459 1	0.0167
Error	4	4 316 400	1079		
Packaging Material (PM)	1	9 073 800	100.0 9073800. 0	62.816 2	0.0002
ST*PM	2	87 300	43 650	0.3022	
Error	6	866 700	144450.0		
Total	**17**	**64 603 800**			

Appendix : Analysis of Variance Table for total bacterial count (cfu/g) in banana

Source	DF	SS	MS	F Value	Prob
Dryer	2	21213900	10606950	7.4651	0.0446
Storage Time (ST)	2	41588100	20794050	14.634	0.0145
Error	4	5683500	1420875		
Packaging Material(PM)	1	2020050	2020050	14.766	0.0085
S.T*PM	2	135900	67950	0.4967	
Error	6	820800	136800		
Total	**17**	**71462250**			

Appendix : Analysis of Variance Table for fungi count (cfu/g) in banana.

Source	DF	SS	MS	F Value	Prob
Dryer	2	6 038 100	3 019 050	32.7268	0.003 3
Storage Time (ST)	2	9 105 300	4 552 650	49.3512	0.001 5
Error	4	369 000	92 250		
Packaging Material (PM)	1	1 080 450	1 080 450	40.6949	0.000 7
ST*PM	2	27 900	13 950	0.5254	
Error	6	159 300	26 550		
Total	**17**	**16 780 050**			

Appendix : Analysis of Variance Table for total bacterial count (cfu/g) in pineapple.

Source	DF	SS	MS	F Value	Prob
Dryer	2	94 655 356	47327678.0	140.51 72	0.000 2
Storage Time (ST)	2	80 595 601	40297800.5	119.64 53	0.000 3
Error	4	1 347 242	336810.5		
Packaging Material (PM)	1	37 057 440	37057440.5	44.766 3	0.000 5
ST*PM	2	828 961	414480.5	0.5007	
Error	6	4 966 788	827798.0		
Total	**17**	**219 451 388**			

Appendix : Analysis of Variance Table for fungi count (cfu/g) in pineapple.

Source	**DF**	**SS**	**MS**	**F Value**	**Prob**
Dryer	2	67 041 900	3352095 0.0	39.739 1	20.00 23
Storage Time(ST)	2	97 053 075	4852653 7.5	57.528 3	20.00 11
Error	4	3 374 100	843525. 0		
Packaging Material (PM)	1	16 245 000	1624500 0.0	41.399 1	0.000 7
ST*PM	2	595 575	297787. 5	0.7589	
Error	6	2 354 400	392400. 0		
Total	**17**	**186 664 050**			

Appendix : Analysis of Variance Table for total bacterial count (cfu/g) in tomato.

Source	DF	SS	MS	F Value	Prob
Dryer	2	314165250000	157082625000	22.5937	0.0066
Storage Time (ST)	2	548174250000	274087125000	39.4228	0.0023
Error	4	27810000000	6952500000		
Packaging Material (PM)	1	772245000.00	772245000.00	36.5322	0.0009
ST*PM	2	696825000.00	348412500.00	1.6482	0.2688
Error	6	1268325000.0	211387500.00		
Total	**17**	**9870255000000**			

Appendix : Analysis of Variance Table for fungi count (cfu/g) in tomato.

Source	DF	SS	MS	F Value	Prob
Dryer	2	111789000	5589450000	13.3416	0.01
		000	0		70
Storage Time (ST)	2	251912250	1259561250	30.0647	0.00
		000	00		39
Error	4	167580000	4189500000		
		00			
Packaging Material	1	302580000	3025800000	74.7111	0.00
(PM)		00	0		01
ST*PM	2	906750000	453375000	1.1194	0.38
					62
Error	6	243000000	405000000		
		0			
Total	**1**	**41405400**			
	7	**0000**			

Appendix : Researcher at work and some equipment used in the study.






Call to me, and I will answer you, and show you great and mighty things, which you know not. [Jeremiah 33:3]

I can do all this through him who gives me strength [Philippians 4:13]