

**EFFECT OF IRRADIATION ON THE SHELF LIFE AND NUTRITIONAL
QUALITY OF TOMATO (*Solanum lycopersicon* L.) POWDER**

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RADIATION PROCESSING DEGREE

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DECLARATION

I do hereby declare that, except for other people's work which have been cited and acknowledged, this work is my original research and this thesis has not been presented for another degree elsewhere, either in part or as a whole.

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DEDICATION

This thesis is dedicated to the Lord Almighty for fulfilling His promise, for divine favour, love, protection and guidance through this period, and to my entire family especially my Mum and Dad for their support and belief in education and knowledge acquisition.



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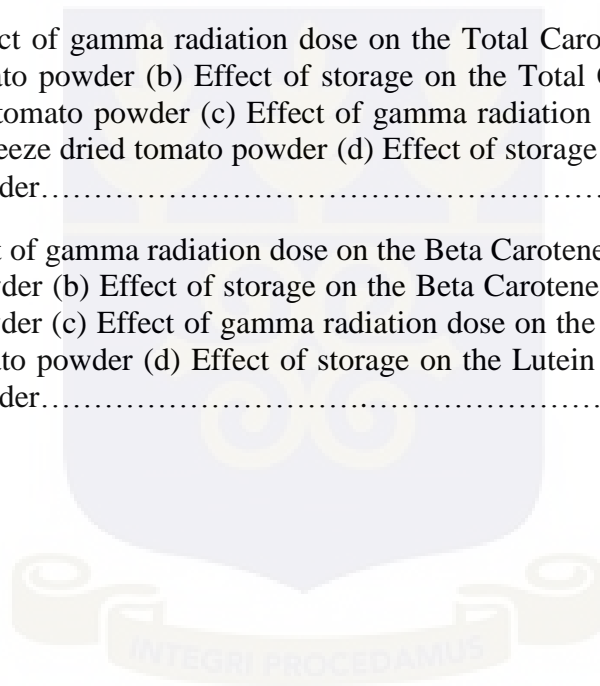
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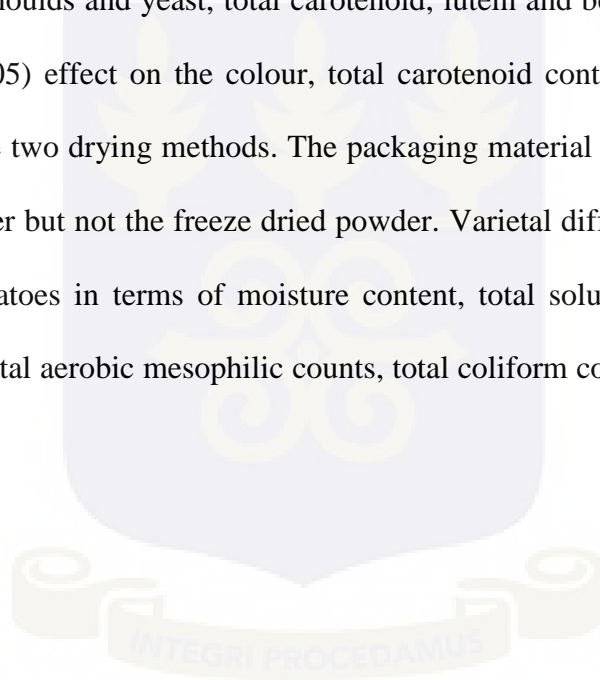
LIST OF ABBREVIATIONS

AOAC	-	Association of Official Analytical Chemists
ANOVA	-	Analysis of Variance
ARBC	-	Applied Radiation Biology Centre
BNARI	-	Biotechnology and Nuclear Agriculture Research Institute
CRD	-	Completely Randomized Design
DNA	-	Deoxyribonucleic acid
FAO	-	Food and Agriculture Organisation
GAEC	-	Ghana Atomic Energy Commission
HPLC	-	High Performance Liquid Chromatography
IAEA	-	International Atomic Energy Agency
ICBN	-	International Code on Botanical Nomenclature
IJECFI	-	International Joint Expert Committee on Food Irradiation
MoFA	-	Ministry of Food and Agriculture
NNRI	-	National Nuclear Radiation Institute
NMIMR	-	Nonguchi Memorial Institute of Medical Research
RAMSRI	-	Radiological and Medical Sciences Research Institute
TSS	-	Total Soluble Solids
TTA	-	Total Titratable Acids
WHO	-	World Health Organization

ABSTRACT

Tomato (*Solanum lycopersicon* L.) is a major horticultural crop with an estimated global production of over 153 million metric tons. It is the most important fruit vegetable and the second most widely cultivated crop in the world after potato, with a total production of about 141 million tons. In 2009, the average total yield in Ghana was 7.5 Mt ha⁻¹ compared to the achievable yield of 15.0 Mt ha⁻¹. The tomato industry in Ghana for the past decade has been bedevilled by a myriad of problems of which post-harvest losses range between 30% and 70% in the major seasons of production, hence a study was conducted into the preservation of *S. lycopersicon* L. through drying and packaging to reduce post-harvest losses. Two drying methods comprising of solar and freeze drying were employed for three varieties of tomato which are cultivated locally. The methods were compared to determine the more efficient for the three varieties used in the study and the impact of drying and radiation on some physico-chemical properties, microbial load as well as shelf-life of the samples. Evaluation of the packaging material for the dried samples was also carried out. The samples were exposed to gamma irradiation at 0 kGy, 1 kGy, 2 kGy and 3 kGy. The parameters determined included moisture content, pH, titratable acidity; total soluble solids total carotenoids, lycopene, lutein and beta carotene. Microbial analysis carried out included total aerobic mesophilic bacteria count, total coliform count and moulds and yeasts using standard methods. Data were analyzed using ANOVA. Storage had significant effect ($p < 0.05$) on the pH, TSS, TTA, colour and microbial load of the various varieties used. Irradiation had a significant effect ($p < 0.05$) on pH, colour, microbial quality, lycopene content, beta carotene, and total carotenoid content of the varieties used; however irradiation had no significant ($p > 0.05$) effect on

moisture content, total soluble solids and microbial quality of the varieties used. Comparing powders obtained from freeze dried and solar dried tomatoes (Akoma), solar drying emerged as a more efficient method of drying. In Akoma, significant differences ($p < 0.05$) were observed in all the parameters due to the difference in drying methods. Gamma irradiation did not affect ($p > 0.05$) the moisture content, total soluble solids, of the Akoma variety irrespective of the drying method used. However, gamma irradiation had a significant effect ($p < 0.05$) effect on pH, colour, total aerobic mesophilic counts, total coliforms; moulds and yeast, total carotenoid, lutein and beta carotene. Storage had significant ($p < 0.05$) effect on the colour, total carotenoid content, and lycopene of the powders from the two drying methods. The packaging material used was suitable for the solar dried powder but not the freeze dried powder. Varietal differences ($p < 0.05$) existed between the tomatoes in terms of moisture content, total soluble solids, pH, titratable acidity, colour, total aerobic mesophilic counts, total coliform count and total moulds and yeast counts.



CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

Tomato (*Solanum lycopersicon*) is a major horticultural crop with an estimated global production of over 153 million metric tons. It is the most important fruit vegetable and the second most widely cultivated crop in the world after potato, with a total production of about 141 million tons (FAOSTAT, 2009).

Taxonomically, cultivated tomato (*Solanum lycopersicon*) belongs to the family *Solanaceae* (also known as the night shade family) and genus *Lycopersicon* (Taylor, 1986). The family *Solanaceae* also includes other important vegetable crops such as chilli and bell peppers (*Capsicum* spp.), potato (*Solanum tuberosum*), aubergine (*Solanum melongena*), tomatillo (*Physalis ixocarpa*) and tobacco (*Nicotiana tabacum*).

Tomato is highly perishable and one of the most widely produced and consumed fresh vegetables in the world for fresh fruit market and the processed food industry (Costa and Heuvelink, 2006). Tomato is an essential vegetable in the Ghanaian diet and consumed by every household (Horna *et al.*, 2006). It is used in the preparation of sauces, stews, soups, salads and other dishes which are taken with most staple food crops (Issahaku, 2012; Adu-Dapaah and Oppong Konadu, 2002). It is also the most common vegetable in the Mediterranean diet and is known to be beneficial for health, especially with regards to

the prevention of chronic degenerative diseases (Herna'ndez Sua'rez *et al.*, 2007; Leonardi *et al.*, 2000).

Due to its nutritive properties and versatility, it is widely used in the food industries as raw material for products such as purees, paste, pickles, juices, dehydrated and whole peeled tomatoes, ketchup as well as salads (Rashid *et al.*, 2008). It is also used extensively in the cosmetic and pharmaceutical industries as a corrective measure for some sicknesses as a result of its health benefits (Youyan *et al.*, 2008; Prasad, 2005). Tomato is also seen as a model crop in plant genetic, physiological and pathological studies (Heuvelink, 2005).

Tomato has high nutritive value. It is rich in minerals such as potassium, magnesium and manganese; vitamins A, E and C (Wilcox *et al.*, 2003; Smith, 1994) and major carotenoids such beta-carotene and lycopene (Asare-Bediako *et al.*, 2007; Bull, 1989; Purseglove, 1979). Lycopene is an effective and potent antioxidant as well as free radical scavenger and has been suggested to prevent carcinogenesis (Agarwal and Rao, 2000) and atherogenesis by protecting critical cellular biomolecules such as lipids, proteins, lipoproteins and DNA (Olaniyi *et al.*, 2010; Proestos *et al.*, 2006; Miller *et al.*, 1996).

Annual worldwide production of tomato was 152,956,115 tons in 2009 and 110,017,091 tons in 2000 (<http://www.unctad.info/en/Infocomm/AACP-Products/COMMODITY-PROFILE---Tomato/>). This implies that there has been an increase in world tomato production. Tomato production is a source of employment and income to both rural and

urban dwellers in Ghana (Asare-Bediako *et al.*, 2007). It contributes significantly to the economic growth of the country and a source of foreign exchange. In 2003, 4368 metric tonnes of tomatoes were exported, accruing a foreign exchange of \$427000 to Ghana (FAO, 2005). Tomato production is one of the most important farming activities in the world, believed to reduce food and cash insecurity. Tomato is one of the most important income-generating vegetables cultivated in Ghana. In Ghana, its cultivation covers an acreage of 441,000 sq.km as compared to all other vegetables (194,000 sq.km); however total production does not meet the national demand for this vegetable (MoFA, 2010). The total cultivated area and production of tomato in Ghana has however increased gradually over the last few years although productivity is still low, averaging 5.46 t ha⁻¹ compared to the world average of 34.82 t ha⁻¹ (FAOSTAT, 2009). The total tomato cultivated in 2008 was 16,130 hectares; besides the estimated production of 284,000 metric tons as a consequence the crop yield was 17.6 metric tons (FAO, 2010). The production level of tomato however rose slightly to 35,000 metric tons in 2010 valued at \$129,347 (FAOSTAT, 2010). In 2009, the average total yield in Ghana was 7.5 Mt ha⁻¹ compared to the achievable yield of 15.0 Mt ha⁻¹ (MoFA, 2010). This resulted in a high yield gap of 50% (MOFA, 2011). The crop has therefore failed to reach its potential in attaining yields comparable to other countries, to sustain processing plants, and improve the livelihoods of household involved in tomato production and the tomato commodity chain (Robinson *et al.*, 2010b). As a result, Ghana is currently a net importer of fresh and processed tomato.

Despite government interventions to support the tomato industry through the establishment of three processing factories in the country to produce paste and puree, tomatoes of the right quality and quantity for commercial agro processing are not being grown in Ghana to any extent. These were located in the Nsawam in the Eastern Region, Pwalugu in the Upper East Region and Wenchi in the Brong Ahafo Region. Most farmers nonetheless prefer to plant local varieties, characterized by low yield and poor fruit quality such as high water content, high seed content, poor fruit colour and low brix (Donkor *et al.*, 2013; Robinson *et al.*, 2010a). As a result, the requirement and quantities for the industries are not met and operation is below capability; hence the factories have been shut down for a while (Robinson *et al.*, 2010a).

1.2 Statement of problem and justification of the study

The tomato industry in Ghana for the past decade has been bedevilled by a myriad of problems of which post-harvest losses comprise a significant proportion. Due to production seasonality, high perishability, poor market access and competition from imports, some farmers are unable to sell their tomatoes which are left to rot in the fields after harvesting, during peak harvest periods resulting in postharvest losses (Amikuzuno and Ihle, 2010; Robinson *et al.*, 2010a). Although tomato cultivation has been inundated with many problems in Ghana, farmers choose to cultivate tomatoes over other crops perhaps due to its early in maturity and adaptability to wide range of soils (Robinson *et al.*, 2010a). The rate and extent of spoilage is very startling and depends on a number of factors which include mechanical damage during harvesting, improper postharvest

sanitation, unstable purchasing outlets, poor storage, distribution system, poor handling and transportation systems (Olayemi *et al.*, 2010; Idah *et al.*, 2007; Ellis *et al.*, 1998).

The most important and crucial challenge to ensuring food security in most developing countries is making food available all year round (Habou *et al.*, 2003). Most agricultural products including tomatoes are highly perishable, spoiling within 4-6 days after harvest, depending on the variety, leading to huge economic losses for farmers. It is estimated that losses in Ghana range between 30% and 70% in major season. However tomatoes tend to become scarce in the dry season making food preservation an important activity in households and communities (Ellis *et al.*, 1998).

One key means of preserving tomato fruit is drying. It is the oldest method of preserving agricultural products. Drying is a form of processing that ensures the availability of perishable products all year round (Grabowski *et al.*, 2003; Habou *et al.*, 2003). Drying is a process of food preservation and management which appears to be suitable and satisfactory under most conditions in developing economies (Idah and Aderibigbe, 2007; Ali and Sakr, 1981). Dehydration of perishable commodities like tomatoes with very high moisture content results in substantial reduction in weight with consequent savings in storage and distribution (Mepba *et al.*, 2007). Conventional drying has been used in most developing countries including Nigeria to preserve most food stuffs (Kolawole *et al.*, 2010). Food drying preserves nutrients and protects it by removing the moisture that bacteria, yeasts, and moulds need for growth and survival. Hassan *et al.* (2007) reported that drying has been used in Nigeria for preserving leafy vegetables such as the leaf of

Gynandropsis gynandra for which their shelf life increased upon storage (Eklou *et al.*, 2006).

Although the nutritional and medicinal importance of tomato is known, little work has been done in Ghana in relation to drying as a postharvest storage method. Most of the tomatoes produced in Ghana are sold unprocessed.

Sun, solar and oven drying are the popular methods of drying food crops and alternative ways of processing tomatoes (Agoreyo *et al.*, 2011; Matazu and Haroun, 2004). Sun drying of agricultural produce is the most common, economical and widely drying method used in most developing countries of the tropical region (Muhammad *et al.*, 2011; Olorunda *et al.*, 1990). Other modern drying methods include spray, vacuum and freeze drying. Spray drying is a process of drying by mixing heated gas with an atomized liquid stream within a vessel (drying chamber) to accomplish evaporation and produce free flowing dry powder with a controlled average particle size (http://www.spray_drysys.com). Vacuum drying is also a process in which materials are dried in a reduced pressure environment which lowers the heat needed for rapid drying (<http://www.wisegeek.com>). Examples are nucha filter dryer, spiral dryer, conical dryer and bicuum (<http://www.bachiller.com>). Freeze drying also known as lyophilisation is a method that uses strong vacuum and a freezing process and tends to have less effect on a food's taste. It is used to preserve highly perishable foods (<http://www.wisegeek.com>).

Dried tomatoes have several applications in food nutrition and medicine thus sun-dried tomatoes are considered a “gourmet” ingredient (Sloan, 1999). Drying of tomatoes have

several advantages which include longer storage periods, little or no problems with microbes; easier packaging, ambient storage temperature conditions as well as handling, cheap drying method compared to other forms of processing (Holdsworth, 1971).

It is important to note that much is being dedicated to cultivation of the crop with much resources being spent on irrigation and fertilizer application and crop protection measures only to be wasted in a short while after harvest (Olayemi *et al.*, 2010). This project therefore aimed at preservation through drying to reduce post-harvest losses especially during the glut seasons. In Ghana, not much has been done in the processing and preservation of tomato using drying method hence the need for more work to develop a simple, cost-effective and easily adaptable preservation technique for farmers and industrialists.

1.3 Objectives of study

The principal objective of this study was to reduce postharvest losses associated with tomato (*Solanum lycopersicon* L.) through drying and irradiation. The research work had the following specific objectives, to;

- i. compare and determine the most efficient method of drying tomatoes using solar and freeze drying techniques in a tomato variety.
- ii. evaluate the effect of drying method on three tomato varieties
- iii. determine the effects of radiation on the physico-chemical properties of tomato powder.
- iv. assess the effect of radiation on the phytochemical properties of tomato powder.

- v. evaluate a packaging material for dried tomato powder.
- vi. study the effect of radiation on microbial load in dried tomato powder.
- vii. use radiation to extend the shelf life of dried tomato powder.



1.4 REFERENCES

The references for Chapter One are merged with that for Chapter Two as directed by the thesis guideline provided by University of Ghana, Legon.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution

The tomato (*Solanum lycopersicon*) plant is a native of Southern America, where it developed into a large variety of cultivated types, suitable to different environments (Rick, 1976). Cultivated tomatoes originate from the coastal strip of western South America. The species is especially native to Peru and the Galápagos Islands; however it was first domesticated in Mexico (Harvey *et al.*, 2002; Papadopoulos, 1991; Jenkins, 1948). The tomato plant was introduced into Europe from Peru in the mid-16th century and featured primarily in early herbals (Luckwill, 1943; Müller, 1940; De Candolle, 1884).

In the 18th century, it was introduced back into America from Europe, even though its importance as a vegetable had occurred only in that century. It is however believed that the American Indians ate the tomato a long time ago (Jones, 1999). The wild tomatoes (*Solanum pimpinellifolium*) are also native of western South America, distributed from Ecuador to northern Chile, with two endemic species in the Galapagos Islands (Peralta and Spooner, 2005).

Tomato is a short-lived perennial in the tropical regions and an annual in the temperate climates. It grows as a bushy creeping plant, requiring long periods of sunshine and warm

temperatures. The plant originally had an indeterminate plant habit however determinate varieties have been bred with a bush like form where the plant produces side shoots. The fruit and plant characteristics have changed substantially over the past fifty years as a result of breeding (Waterman, 1994; Stevens and Rick, 1986). More than 1000 different varieties of tomatoes exist for commercial and home gardening, with wide range of plant characteristics, resistance to wilt diseases and are adapted to a set of growing conditions, which include field and greenhouse conditions, fresh market as well as processing tomato and high tropical temperatures which include cherry tomato and the plum (Stevens and Rick, 1986; Villareal and Lai, 1978). Tomato fruit with improved characteristics have been developed through genetic engineering techniques (Baisden, 1994).

2.2 Fruit Nutrition

Tomato is a store house of essential vitamins. These include Vitamin A [red fruits contains an average 100 International Units (IU) per 100g], Vitamin B1, B2, B6, Vitamin E (Alpha Tocopherol), Ascorbic acid (Vitamin C). Tomato is also rich in minerals such as Magnesium, Potassium, Zinc, Manganese, Phosphorus, Copper, Iron, Sodium, Calcium (Rahman *et al.*, 2010) and high nutritive value due to the presence of carbohydrate, fibre, folic acid, niacin, thiamin, salicylic acid, tartaric acid and succinic acid. It also contains large amounts of water (93.5%), calcium (0.07%) and niacin, which are of ordinate importance in the metabolic activities of human beings (Olaniyi *et al.*, 2010; Sgherri *et al.*, 2008; Jaramillo *et al.*, 2007).

Tomato is a major source of lycopene, a potent and effective antioxidant which gives the vegetable its characteristic red colour and glutathione an antioxidant which aids in

cleansing the body of toxic products and prevents the accumulation of heavy metals (Jaramillo *et al.*, 2007). In fact tomato is ranked first as a source of lycopene (71.6%), second source of vitamin C (12%), provitamin A carotenoids (14.6%) and third as a source of vitamin E (6.0%) (Garcia-closas *et al.*, 2004). Table 2.1 shows the nutritional composition of 100mg fresh tomato.

The wild variety, *Solanum pimpinellifolium* is also known to be a good source of dietary fibre and has also been documented to contain about forty times as much lycopene as in domesticated tomatoes *Solanum lycopersicon* L. (Foolad, 2009; Cox, 2000).

The tomato crop is also very essential because the fruit can be eaten raw, cooked and can also be dried for later use (Facciola, 1990). The pulped fruit is extremely beneficial as skin-wash for people with oily skin, the sliced fruits are a quick and easy first aid treatment for burns, scalds and sunburn (Allardice, 1993). Edible oil can be obtained from the seed which is only viable if large quantities of the plant are grown for their fruits and the seed is not needed for storage or cultivation (Uphof, 1959). Riotte. (1978) reported that tomato has strong aroma which is said to repel insects from nearby plants. A decoction of the root is ingested in the treatment of toothache (Duke and Ayensu, 1985) and a homeopathic remedy is also made from the plant and used in the treatment of rheumatism and severe headaches (Chiej, 1984).

Table 2.1: Nutritional composition per 100g of fresh tomato

Element	Quantity
Water%	93.5
Protein (g)	0.9
Fat (g)	0.1
Calories	23
Carbohydrates (g)	3.3
Fibre (g)	0.8
Phosphorus (mg)	19
Calcium (mg)	7
Iron (mg)	0.7
Vitamin A(UI)	1.100
Vitamin B1(mg)	0.05
Vitamin B2(mg)	0.02
Vitamin C(mg)	20
Niacin(mg)	0.6

Source: Jaramillo *et al.*, 2007

2.2.1 Lycopene

Tomato has attracted significant attention as the red pigment in its fruit, known as lycopene, is an antioxidant. Lycopene (derived from the species name *lycopersicon*) is a bright red carotene and carotenoid pigment and phytochemical found in tomatoes and other red fruits and vegetables such as red bell peppers, watermelons, pink papaya and

red carrot (Rao and Agarwal, 2000). Thus lycopene is the key colouring agent for the red colour of tomatoes (Lavelli and Scarafoni, 2011; D'Sousa *et al.*, 2008). Lycopene is the most abundant carotenoid in tomatoes and represents about 83% of the total pigments present (Gould, 1992). Lycopene is a carotenoid of interest to Scientists and Researchers because of its potent and effective antioxidant activities, which have been found to be twice that of beta carotene (Van Breemen *et al.*, 2002; Paiva and Russell, 1999).

Lycopene is especially effective at quenching a free radical known as singlet oxygen. It is 100 times more efficient in test tube studies of singlet-oxygen quenching action than vitamin E, which in turn has 125 times the quenching action of glutathione (water soluble) and has therefore been described as the “world’s most powerful antioxidant” and may be the most powerful carotenoid of singlet oxygen (Di Mascio *et al.*, 1989). Singlet oxygen is a highly reactive free radical formed during normal metabolic processes that reacts with polyunsaturated fatty acids, which are major constituents of cell membranes (Clinton, 1998). Singlet oxygen produced during exposure to ultraviolet light is a primary cause of skin aging (Berneburg *et al.*, 1999). Given its antioxidant properties, substantial scientific and clinical research has been devoted to a possible correlation between lycopene consumption and general health.

Early research suggested its use in amelioration of cardiovascular disease, arteriosclerosis, diabetes, osteoporosis and even male infertility (Agarwal and Rao, 2000; Giovannucci *et al.*, 1995). High levels of lycopene have been found to starve off cancers of the cervix, rectum, colon, prostate, stomach, oesophagus, mouth and pharynx

(Agarwal and Rao, 2000; Gann *et al.*, 1999). Introduction of lycopene into pre-existing cancer cell cultures led to reduction in growth of these cultures. Research indicates that there is about 5mg of lycopene per 100gm of ripe tomato fruit and it takes as little as 540 millilitres of liquid tomato product to get the full benefits of lycopene. Thus a glass of tomato juice a day has the potential to keep a person healthy for life (Di Mascio *et al.*, 1989). Hence increasing levels of dietary lycopene through the consumption of fresh tomatoes and tomato products has been recommended by health experts (Giovannucci, 1999; Tonucci *et al.*, 1995).

Lycopene in tomato paste is four times more bioavailable than in fresh tomatoes. While most green leafy vegetables and other sources of lycopene are low in fats and oils, lycopene is insoluble in water and is tightly bound to vegetable fiber. Cooking and crushing tomatoes (as in the canning process) and serving in oil-rich dishes (such as spaghetti sauce or pizza) greatly increases assimilation from the digestive tract into the bloodstream. Lycopene is fat-soluble, so the oil is said to help absorption (Simpson and Chichester, 1981).

2.3 Tomato Production

Tomato plants thrive and survive in numerous environments in the world, however certain particular areas do not support the development of the crop in the open fields because of extreme climatic conditions (Northern Europe and Netherlands), and whiles selected zones are possible, but only in specific seasons (Mexico). The current trend of tomato production is in the direction of fruit production in environmentally controlled

greenhouses (Rico-Garcia *et al.*, 2009; Janes, 1994). This is rapidly increasing worldwide because this permits the production of fruits all year round (Wither and Castilla, 1995), precisely in Canada (Carrier, 1997; Mirza and Younus, 1997) and in the United States (Curry, 1997; Naegely, 1997). In Western Europe, primarily in The Netherlands, greenhouse tomato production is big business (Ammerlaan, 1994).

2.3.1 Worldwide Tomato Production

In the last four decades, global production of tomatoes (fresh and processed) increased by roughly 300%. Global trade of tomatoes and tomato products reached US\$ 4.2 billion, representing a 33% growth in production, relative to the beginning of the 1990s (FAS/USDA, 2003). Total world production was 152.9 million tons with a value of US\$ 74.1 billion (FAOSTAT, 2009). China, the USA and Turkey are the three leading producers of tomato. China accounts for 25% of the world's total production and cultivated area (Table 1.0). It is also the largest consumer of tomato (Wijnands, 2003). The world's processing tomato industry is however dominated by the USA, Italy, Spain and Turkey (Table 2.2).

Table 2.2 Top ten producers of tomatoes by volume in 2008 and 2009.

Country	Tomato production 2008 (metric tons)	Tomato production 2009 (metric tons)
China	39,938,708	45,365,543
United States	13,718,200	14,141,900
Turkey	10,985,400	10,745,600
India	10,303,300	11,148,800
Egypt	9,204,100	10,000,000
Italy	5,976,910	6,877,400
Islamic Republic of Iran	4,826,400	5,887,710
Spain	4,049,750	4,603,600
Brazil	3,867,660	2,591,400
Mexico	2,936,770	2,591,400

Source: <http://www.unctad.info/en/Infocomm/AACP-Products/COMMODITY-PROFILE---Tomato/>

2.3.2 Tomato Production in Ghana

Tomato production in Ghana is a very vital economic activity. In Ghana, average yields of tomatoes are usually lower than 10 t/ha and not encouraging compared to other African countries (Robinson *et al.*, 2010b). Tomato production seems to be falling as a result of crop failure due to a number of factors which include farmers agronomic practices, agro climatic conditions, diseases especially fungal diseases, pest incidence to insecticides and varietal choices; thus the recycling and use of seeds that are not well

suited for the soil and environment (Robinson *et al.*, 2010b; Horna *et al.*, 2006). Current surveys conducted in three regions of Ghana projected an average yield of 10.6 tons per hectare designating that the current average yield of tomato in Ghana is slightly above those from 1970s and 1980s but are lower than the estimates reported by Wolff (1999). This simply implies that Ghana's production has remained insignificant over the past two decades hence not able to meet even the basic domestic demand. Ghana is therefore a net importer of fresh tomato fruits from neighbouring countries like Burkina Faso and Ivory Coast in the dry seasons and processed tomato products, mainly canned tomato paste from China and Italy (Monney *et al.*, 2009; Horna *et al.*, 2006). Thus Ghana's imports of processed tomato from the EU increased by 628% from 3,713 tons to 27,015 tons between 1993 and 2003 (Donkor *et al.*, 2013).

Tomato production in Ghana is done either as rain-fed or with supplementary irrigation from different sources of water which could be a river, pipe borne, tube well or dam. Irrigation could also be furrow, sprinkler or manual watering. Irrigation farming permits the growth of tomatoes all year round. Tomato is produced all over the country. Some areas include Akomadan and Afrancho of the Offinso District of the Ashanti Region; Techiman, Wenchi and Dormaa-Ahenkro Districts of the Brong Ahafo Region; Ga West, Dangme East and Dangme West District of the Greater Accra Region; Fanteakwa, Kwahu South and Yilo Krobo District of the Eastern Region and Bolgatanga, Kasena Nankana and Talensi Nabdam Districts of the Upper East Region (Monney *et al.*, 2009). Greater Accra Region is however the only region in which tomato is grown under both rain-fed and irrigation conditions (Robinson *et al.*, 2010b).

Numerous tomato varieties are currently under cultivation across the nation. These include Pectomech (also known as Burkina), Pectomech VF, Power Rano, Heinz, Paul, “five-five”, Pectofake, Wosowoso, Techiman, Ada Lorry Tyre, Nimagent F1, Deca 1, Meenagiant, and Rasta (Clottey *et al.*, 2009; Monney *et al.*, 2009). Two exotic varieties namely Power Rano, a hybrid between the Power and Lurano varieties is grown extensively in the Brong Ahafo Region under rain-fed conditions and Pectomech, a variety appropriate for processing is grown widely in the Upper East Region and its neighbour Burkina Faso, outperform other varieties under most conditions. However the Nimagent F1, an expensive variety provided by Trusty Foods which is grown in Greater Accra Region is low yielding (Robinson *et al.*, 2010b). The variety chosen also depends on the demand of the market, high yield; disease tolerance and long shelf life. The longer the shelf life, the more preferred the variety (Monney *et al.*, 2009). Rio-Grande, Tropimech, Rio Vf and Tropimech are other varieties presently under cultivation in the country. These are provided by the Agriseed Ghana Limited. Kwadaso, Afrancho, local and Derma are found in Ashanti and Brong Ahafo Regions. Technisem is also supplied by Agrimat Services while Navrongo and Wosowoso are supplied by other seed companies in the nation.

2.3.3 Constraints of Tomato Production

The tomato industry is confronted with numerous challenges from production through harvesting to consumption. However tomato production is an affluent farming activity in the savanna and forest-savanna transitional belt of Ghana. A major challenge is the unavailability of good quality certified seeds. Thus some farmers obtain seed either from

neighbours and friends, from their own fields or from groups that maintain and distribute varieties that are in high demand in the market place. This recycling drives down seed price, but has negative effect on seed quality (Horna *et al.*, 2006). Some farmers also acquire their seeds from local markets and Agro-stores. Most of these Agro-stores are however not government registered and facilities for pure seeds processing are lacking and inadequate. Seeds obtained from open markets and farmers' farms are also most likely mixed and infested with diseases (Asare Bediako *et al.*, 2007). Thus there is poor seed delivery system (Adu-Dapaah and Oppong-Konadu, 2002).

A wide range of seed varieties used in commercial production is mainly of foreign origin hence there is poor adaption of these varieties to the Ghanaian environment. This, alongside the seasonality of tomato production results in periods of great quantities and scarcity which in turn affects availability and market prices (Robinson *et al.*, 2010b; Adu-Dapaah and Oppong- Konadu, 2002).

2.4 Economic Importance

Tomato is a very important crop because it is the second most consumed vegetable after potato and the most popular garden crop (FAO, 2005). It is also the vegetable with the highest consumption worldwide, hence under extensive production across the globe. It has unique nutritive worth and versatile in its uses. Due to this, it is used as raw material in the industries for products like canned, whole tomato, puree, ketchup, juices and pastes (Olayemi *et al.*, 2010; Sgherri *et al.*, 2008; Ellis *et al.*, 1998).

Tomato production has invaluable significance in that it plays a crucial role by serving as a source of employment and hence income generation, as food, nutritional use, medicinal and pharmaceutical purposes as well as a model plant for research. In Ghana it is usually consumed on daily basis by every household (Issahaku, 2012; Horna *et al.*, 2006; Ellis *et al.*, 1998).

Tomato is a highly seasonal crop therefore limiting its availability to specific seasons (Robinson *et al.*, 2010a). It is a food security crop hence the most cultivated vegetable in Ghana (Horna *et al.*, 2006).

2.5 Postharvest losses

Post-harvest problems are one of the key constraints that bedevil the tomato industry. Post-harvest loss is defined as a measurable quantitative and qualitative loss of a given product at any moment along the post-harvest chain (DeLucia and Assennato, 1994) and includes the “change in the availability, edibility, wholesomeness or quality of the food that prevents it from being consumed” (FAO and UNEP, 1981). In spite of the remarkable progress made in increasing food production at the global level, approximately half of the population in the third world does not have access to adequate food supplies. There are many reasons for this, one of which is food losses occurring in the post-harvest and market system (FAO, 2002). After production, proximity of processing facilities to farms and inaccessibility to markets are major post-harvest challenges (GOG, 2003).

The major factors responsible for post-harvest losses especially in tomatoes include poor pre-harvest measures, adoption of poor production techniques (varieties with low shelf life, imbalance use of nutrients, insect pest and disease infestation and abiotic stresses), non-application of pre-harvest recommended treatments and practices, harvesting at improper stage, improper care at harvest, damping produce, moisture condensation resulting in pathogenic infestation, packaging in bulk without sorting and grading of tomatoes, improper transportation and storage and long periods of market distribution (Adubofour *et al.*, 2010; Mujib ur Rehman *et al.*, 2007; Ellis *et al.*, 1998).

The principal factors leading to postharvest losses are as a result of level of education of the farmers, land tenure system, tomato variety grown as well as the type and number of labour used for picking the mature tomatoes. The others are the harvesting time, packaging and processing of produce.

Literacy is one of the significant characteristics that influence farmers' decisions about adoption of new technologies. Thus, most farmers find it difficult to comprehend and adapt to the new skills, technologies, improvements and developments that are made. A number of farmers have however acquired basic education hence their ability to put the new innovations into practice. The low literacy rate of the farmers may be due to their involvement in livelihood activities and less opportunities for education (Mujib ur Rehman *et al.*, 2007).

The major challenge for the farmers is the tenure of the land. Mode of land acquisition is rent, freehold, leasehold or free occupation. This is because most farmers are not land

owners but are rather tenants (Mujib ur Rehman *et al.*, 2007). Tomato production is mainly on family land and/or rented land of relatively small sizes ranging from one to three acres. Thus the productivity per unit area is more important than the size of the farm to the farmer. Farmers do not give serious consideration to the crop history of the site and its possible effects on the intended investment before renting the land. Consequently where land is rented out on yearly basis; farmers are unwilling to make long term investments to improve productivity. Moreover the continuous use of the same land over a long period results in pest and disease build-up which can still affect yields negatively (Monney *et al.*, 2009). This is because recommended period for rotation in tomato production is between three to four years (Mujib ur Rehman *et al.*, 2007).

Choice of variety to cultivate is dependent on market preference, high yield, disease tolerance and length of shelf life; the longer the shelf life the more preferred. Most of the farmers are only able to identify the varieties they grew as “local”. The local variety in one district however could be entirely different from the local variety in another district (Robinson *et al.*, 2010a; Clottey *et al.*, 2009; Monney *et al.*, 2009; Mujib ur Rehman *et al.*, 2007). The type and number of labour play a vital role in the post-harvest losses. Skilled labourers pick and handle the produce with care hence do little damage to the crop. In most farms, about 89% of the labourers have no formal training but had picked up skills on the job. These labourers normally work under the supervision of the farmers who hire them (Mujib ur Rehman *et al.*, 2007).

The time of picking or harvesting is the most important factor in post-harvest losses. Picking of tomatoes is normally done at the red ripe stage of the fruit, usually early in the

morning, two or three times in a week, depending on the variety and yield (Monney *et al.*, 2009). Picking can also be done in the afternoon or evening (Mujib ur Rehman *et al.*, 2007).

The ways and means of packing can affect the stability of products in a truck during transportation, and influence how much the container protects their quality. Prepackaging or consumer packaging generally provides additional protection for the products (McGregor, 1987). Most farmers use the wooden crates which usually crush the tomatoes leading to postharvest loss. During transportation the tomatoes should be immobilized by proper packaging and stacking, to avoid excessive movement or vibration. Vibration during transportation may result in severe bruising or other types of mechanical injury (McGregor, 1987). Farmers routinely transport their tomatoes by trucks or pickups depending on where the produce is needed or marketed. To reduce the post-harvest losses and glut supply to the markets, the surplus or over ripe produce must be processed. Many forms of processing exist, these include drying, freezing, pickling etc.

Evidence indicates that post-harvest losses tend to be highest in those countries where the need for food is greater; some authorities put post-harvest losses of sweet potatoes, tomatoes, bananas and citrus fruit sometimes as high as fifty percent (Babalola *et al.*, 2008; Oyewole and Oloko, 2006; FAO, 2002). Post-harvest losses are also believed to be higher in less industrialised countries; this is because of lack or un-availability of good facilities and technologies. These losses may however be lower in developed areas where there is shorter duration between harvesting and consumption and the produce need to be transported over shorter distances to the market (Mujib ur Rehman *et al.*, 2007).

Vegetables are usually harvested when the plant is fresh and high in moisture and are consequently distinguished from field crops, which are harvested at the mature stage of grains, oil seeds, fibre and pulses. The high moisture content of vegetables makes their handling, transport and marketing a special problem especially in the tropics (Babalola *et al.*, 2010). The nutritional value, taste, flavour and quality of these fresh produce like tomato is affected by postharvest handling and storage condition (Sablani *et al.*, 2006; Shankara *et al.*, 2005). Tomato is a vegetable which is highly perishable, spoiling within 4 to 6 days after harvest depending on the variety leading to huge economic losses to growers (Ellis *et al.*, 1998).

Tomato losses in Ghana are estimated to be in the range of 30% to 70% (Ellis *et al.*, 1998). According to the Ministry of Food and Agriculture in Ghana, postharvest losses of fruits, vegetables and roots and tubers are estimated to be 20-50% (Fiamor, 2009). Osei *et al.*, (2010) reported that the postharvest loss for tomatoes is 19%. Several reports cited by Zaldivar (1991) indicate that worldwide losses of tomato are between 25% or 28-42% and 15-60% or 15-50% in less industrialized countries. Raja and Khokar (1993) however stated that post-harvest losses in fruits and vegetables range from 25-40% or even greater (Mujib ur Rehman *et al.*, 2007; Iqbal, 1996).

Generally about 50% of fruits and vegetables produced are lost after harvesting (FAO, 1989). This then implies that the effort and money required to produce the crop are lost forever and half of what is produced on no occasion reaches the consumer for whom it was grown. These postharvest losses result in low return to the producers, processors, traders and country as a whole since foreign exchange earnings are also affected (Kader,

1992). In the year 2003, Ghana exported 4,368 metric tons of tomatoes, accumulating a foreign exchange of \$427,000 to the country; however this earning dwindled to \$56,000 in 2004 as a result of post-harvest losses. Thus only 607 metric tons of tomatoes were exported in 2004 hence the low foreign exchange (MoFA, 2005). This implies that post-harvest losses are very important hence require a lot of effort to curb the menace.

In most developing countries such as Ghana and Nigeria, transport, storage, handling techniques and packaging are essentially non-existent with perishable crops, hence this result in considerable losses of produce. This is because more fresh fruits are needed to supply the growing population in developing countries, as more produce is transported to non-producing areas and as more commodities are stored longer to obtain a year round supply, post-harvest loss prevention technology measures become paramount (Babalola *et al.*, 2010; Oyekanmi, 2007). Post-harvest losses have therefore been highlighted as one of the factors of the food problem in most developing countries including Ghana and Nigeria (Babalola *et al.*, 2008; Ojo, 1991).

Food supply can be improved either by increase in production or reduction in loss. Many researches also indicate that great effort is being made in the area of food production especially in the developing countries. The decline in food production therefore can be traced to food losses. This implies that reduction in post-harvest losses increases food availability, therefore alleviation of food problems. The effect of post-harvest losses reduces the effect of the efforts put into production henceforth lowering marketing efficiency (Babalola *et al.*, 2010; Okunmadewa, 1999).

To reduce these post-harvest losses in Ghana, farmers need to be trained about the latest techniques of preservation, processing, packaging and good storage facilities to preserve the produce that are harvested before being taken to the market. Roads linking farms to market should be improved to reduce transit losses. Farmers must also be trained on advanced techniques and methods of post-harvest handling of perishables such as tomatoes and processing of tomato. Therefore development of low cost processing and packaging methodologies to produce shelf stable and convenience products are the prime requirement of present competitive market. Post-harvest loss does not equal food loss necessarily and consequently, the reduction of post-harvest losses of perishables is of major importance when striving for improved food security in developing countries (Kader, 2005). With the reduction of post-harvest losses, food availability would be increased profoundly and significantly without automatically cultivating an additional hectare of land. This is very crucial to achieve food and nutrition security in the country and the world at large.

2.6 Food Preservation

Food preservation is a science, an act or a technique of maintaining foods at a desired level of properties or nature for as long as possible for their maximum benefits. Each step of handling, processing, storage, and distribution affects the characteristics of food, which may be desirable or undesirable (Rahman, 2007). Food preservation techniques are designed to reduce deterioration in quality which inevitably occurs in unprocessed foods and to increase the shelf life of the food beyond that of the raw material. Food preservation originated with traditional methods such as drying, curing, smoking, salting

and fermenting. However a number of new preservation techniques are being developed to satisfy current demands of economic preservation and consumer satisfaction in nutritional and sensory aspects, convenience, absence of preservatives, low demand of energy, and environmental safety. These innovative and modern technologies include canning, pasteurization, freezing, addition of chemicals, baking and irradiation (Desrosier and Singh, 2011; Tucker 2008).

In food processing and preservation, the important points that need to be considered are the desired level of quality, the preservation length and the individuals for whom the products are preserved. The product quality attributes can be quite varied, such as appearance, sensory, or microbial characteristics (Singh, 1994). Food safety is the first priority of the food production and preservation industry, incorporating innovation and sustainability. The industry can compromise on some qualities such as colour to some extent, but not with safety (Rahman, 2007). Processing is an operation that costs money but also a means of reducing post-harvest losses by packing and storing greater quantities of produce for lean seasons. Thus it is a way of generating extra income, ensuring availability of tomatoes all year round and providing more value-added products and offers to the buyer and consumers by providing variation in diet (Rahman, 1999). The most common methods of preservation of tomatoes in Ghana are refrigeration, freezing, storage at ambient and drying mainly in the Upper East Region of Ghana (Adimabuno, 2010).

Very little quantity of tomato is processed in Ghana because domestic tomato processing in Ghana has been introduced to “buy up the glut” and to add value to fresh tomatoes.

This is not a good strategy for the processors because tomatoes for processing is characterized by higher percentage of soluble solids (improved varieties) however most of the tomatoes (local varieties) grown are not of processing quality, characterized by low brix, high liquid content that are only suitable for the fresh market and thus farmers often prefer to grow these because they are more resilient and adapted to local conditions. The glut is usually made up of the latter local varieties that the processors will not purchase (Robinson *et al.*, 2010a).

Well preserved tomato products can be kept for very long periods, up to a year or more, depending on the processing technique, packaging material and storage conditions (Shankara *et al.*, 2005). Storage and handling are convenient and easier when tomatoes are processed. Marketing of tomatoes is also improved through processing therefore making them more suitable for use (Shankara *et al.*, 2005). Consequently there is a need to develop suitable technology for processing and preservation of this valuable commodity in a way that would check losses and generate additional revenue for the country (Ghavidel and Davoodi, 2010).

2.7 Drying

Drying is one of the oldest methods of food preservation and an important process for food preservation (Esehaghbeygi and Basiry, 2011) from microbiological spoilage as well as pathogens (Tucker, 2008). Drying or dehydrating is a process of slowly removing moisture from a produce in order to preserve it. It allows food to be preserved by a

reduction in water activity hence inhibit the growth of microbes that cause spoilage and to reduce enzymatic activities (Mukhtar, 2009).

This process is normally used to extend the shelf life of highly perishable commodities like vegetables and food crops, after harvesting. Examples of vegetables that are usually processed through drying include tomato, pepper, okra, garden eggs and food crops such as plantain. This makes such food crops available throughout the year (Eklou *et al.*, 2006; Habou *et al.*, 2003).

Drying is mostly used in the hot regions, semi-tropic and tropical regions. Drying agricultural produce by sun drying is widely used in most of the developing countries of the tropical region (Bala and Woods, 1994). Many regions of the world do not offer the appropriate climate for sun-drying however in hot regions; sun drying is a cheap and relatively easy way of preserving produce. Dried products require little space and are thus easy to store and very appropriate for soups, stews, sauces, pizzas etc. Completely dried tomatoes can be stored in plastic bags, air tight jars or other suitable containers. Dehydrated tomatoes are packed tightly by squeezing out all excess air. They may be stored at room temperature in a cool, dark place (Tucker, 2008; Rahman, 2007; Holdsworth, 1971).

Sun, oven and solar drying are the prevalent drying methods used in drying food crops and vegetables; nonetheless, sun drying is the most common practice (Agoreyo *et al.*, 2011; Matazu and Haroun, 2004). The sun, solar and oven drying methods utilise heat to

remove water from food by evaporation. Removal of water by heat has been stated to affect the nutrient contents of food in various ways. Consequently this results in increase of some nutrients by making them readily available or decrease the concentration of some nutrients (Hassan *et al.*, 2007; Morris *et al.*, 2004; Ladan *et al.*, 1997).

In Nigeria sun drying is used for preserving leafy vegetables such as *Gynandropsis gynandra* and food crops such as yam and plantain (Agoreyo *et al.*, 2011; Mestres *et al.*, 2004; Hounhouigan *et al.*, 2003; Akissoe *et al.*, 2001). Drying leafy vegetables increases their shelf life upon storage (Eklou *et al.*, 2006). The demand for dehydrated tomato is increasing rapidly both in domestic and in international market with major portion of it being used for preparation of convenience food (Ghavidel and Davoodi, 2010).

The amount of time taken for tomatoes to dry and the quality of the dehydrated product depends on the variety of the tomato, total soluble solid content of the fresh product, the humidity in the air during drying process, the thickness of the slices or pieces, and the efficiency of the dehydrator or the oven. The rate of drying affects the final quality of dehydrated product (Ghavidel and Davoodi, 2010). Additional heat is usually required to accelerate the drying process. The heat for drying can be supplied in many ways, such as solar energy, microwave/ radio-frequency radiation, hot gas stream etc. The dryers are often named according to how heat is supplied or what the drying or heating medium is. Examples are solar dryer, superheated steam dryer, microwave dryer (Kerry, 1992).

Drying may cause deterioration of both the eating quality and the nutritional value of the food hence the design and operation of dehydration equipment aim at minimizing these changes by selection of appropriate drying conditions for individual foods. Some

commercially important dried foods include pasta, pulses, raisins, coffee, spices, nuts, beans and milk (Karabacak and Atalay, 2010; Rahman, 2007). Tomato as other fruits and vegetables can be dried using various methods which include sun or open air drying, solar-drying, oven-drying, freeze-drying, spray drying, etc.

2.7.1 Sun or Open air drying

Sun drying is the most widely practiced agricultural processing operation in the world (Lapati and Barrett, 2006; Matazu and Haroun, 2004). Sun drying is dependent on air humidity and presence of wind. If the dried tomatoes are to be ground, the end product must be a hard and brittle product so that a powdery end product would be obtained (Shankara *et al.*, 2005).

The main disadvantages of this type of drying are contamination from the environment, product losses and contamination by insects and birds, floor space requirements, difficulty in controlling the process, and bad odour (Adesina *et al.*, 2010; Idah and Aderibigbe, 2007; Lapati and Barrett, 2006; Bansal 1999). When the climate is not particularly suitable for air drying or better quality is desired, mechanical air drying is used. However, sun drying is the cheapest method of drying foods. Nowadays, solar and mechanical air drying is widely used commercially.

2.7.2 Solar drying

Solar drying is a more refined method of drying (Doymaz, 2007); it collects solar energy and heated air which is used for drying (Hawllader and Jahangeer, 2006; David and

Whitfield, 2000). More than 250, 000 000 tons of fruits and grains are dried by solar energy per annum (Rahman, 2007; Olurunda *et al.*, 1990). Solar drying combines the advantages of traditional open-air drying and industrial methods (Eze, 2012) and is sometimes known as artificial drying. Solar drying uses equipment known as a solar dryer to achieve this process. Solar drying is also an elaboration of sun drying and a sterile method of drying (Hassan *et al.*, 2007; Bala and Woods, 1994). In solar drying, temperatures can exceed 65°C so care must be taken since the taste of the end product may be affected. Solar driers come in many designs to suit each purpose. The main setbacks of sun and solar drying are relatively poor control over drying conditions and lower drying rates than those found in artificial driers, which results in products that have lower quality and greater variability; drying is mainly dependent on the weather and the time of day (Karabacak and Atalay, 2010; Barbosa-Canovas and Vega Mercades, 1996).

2.7.3 Freeze drying

Freeze drying is one of the drying methods used widely today. Freeze-drying, also known as lyophilization or freeze sublimation dehydration, employs the principle that under high vacuum (4.58torr, or 0.61kPa), frozen water in food changes into vapour without going through a liquid phase (Al Laipis and Bruttini, 1995). This occurrence is known as sublimation and consequently responsible for giving freeze dried foods the physical characteristics that are exceptional among dried food products. It is a technique that results in high-quality dehydrated products due to the absence of liquid water and the low temperatures required in the process. The solid state of water during freeze-drying protects the primary structure and minimizes changes in the product shape, with minimal

reduction of volume, providing a dry product with porous structure (Mujumdar, 2006; Ratti, 2001; Lozano and Saca, 1992)

Foods are freeze dried in two stages: first by sublimation to approximately 15% moisture content and then by evaporative drying (desorption) of unfrozen water to 2% moisture content (Al Laipis and Bruttini, 1995). Under a high vacuum condition, ice is converted (sublimed) to water vapour and removed therefore drying the materials (Vega-Mercado *et al.*, 2001). Freeze-dried foods are of high quality because they have a very high retention of original flavours, sensory characteristics and nutritional qualities and a shelf life longer than 12 months when properly packaged. This is as a result of the low drying temperature. Volatile aromatic compounds are not entrained in the water vapour produced by sublimation and are trapped in the food matrix. Consequently, aroma retention of 80–100% is possible (Marques *et al.*, 2007; Hawlader *et al.*, 2006).

Generally freeze-dried products are much more expensive than other dried products (Khalloufi and Ratti, 2003; Chou and Chua, 2001; Ratti, 2001). As a result, freeze-drying is suitable for products that can be sold at a premium price such as functional foods or foods that can withstand only a small amount of sensory deterioration, or to impart certain desired characteristics (Sablani *et al.*, 2007b). Oxidative reactions take place very rapidly in freeze-dried products as a result of the porous and open structures in the products. Freeze-dried products require packaging materials with good oxidation barriers for storage (Abascal *et al.*, 2005; Nijhuis *et al.*, 1996). Currently, a number of foods undergo freeze drying and these include carrots, peas, corn, green pepper, broccoli, green beans, cauliflower, peppers, potatoes and cabbage, dairy products, fruits and meats (Nindo, 2008; Ratti, 2001). Examples of freeze driers include contact freeze driers,

accelerated freeze driers, radiation freeze driers, microwave freeze driers and dielectric freeze.

2.8 Microbiological contamination

Food contamination is mostly caused by microbiological organisms. Food borne illness is an ubiquitous threat which can be avoided with good care and handling of food products. Microbes responsible for illness include bacteria, fungi, parasites and viruses. Most microorganisms are however found in the environment (Mead, 2010). Contamination of tomatoes occurs at various levels, from their journey of harvest to the final consumer and the probable source of the contamination is very important. Consumption of contaminated tomatoes has led to the outbreaks of diseases including gastroenteritis which is associated with pathogens such as *Salmonella javiana* and *Listeria monocytogenes* (Wood *et al.*, 1991; Ho *et al.*, 1986). Tomatoes are widely consumed either in the fresh or processed state, because it is the main source of carotenoids for the populace (Watzl *et al.*, 2000).

Draughon *et al.* (1988) reported that food poisoning as a result of botulism was associated with tomatoes contaminated with mould. The tomato fruit contains 90–95% moisture content and is capable of supporting bacterial growth. The pH of tomato varies considerably, depending on important factors such as cultivar, maturity, and seasonal variation. Nonetheless, tomato is not considered a high-risk food, as the pH of the fruit generally ranges from pH 4.2 to 4.9 with an average of about 4.5. At this pH, most pathogens are unlikely to grow. Studies suggests that the presence of moulds causes the destruction of acid, and the pH of tomato rises above the minimum required for growth

and toxin production of *Clostridium botulinum* (Wei *et al.*, 1995; Draughon *et al.*, 1988). Work done by Robinson *et al.* (1994) also demonstrated that *Clostridium* only grew when mould was present. Mould contamination is an important indicator of low quality raw product in the tomato processing industry. Mould infestation also reduces the quality of dried tomato powder by making it unacceptable (Idah and Aderibige (2007). The species most frequently associated with spoiled tomatoes are *Alternaria alternata*, *Botrytis cinerea*, *Fusarium oxysporum*, *Geotrichum candidum*, *Phoma lycopersici*, *Rhizoctonia solani*, and *Rhizopus nigricans* (Battilani *et al.*, 1995).

Dry foods are believed to be free from dangerous microorganisms and safe for human consumption, because microorganisms cannot grow and multiply in properly processed dehydrated foods since the free water they require is unavailable (Adams and Moss, 2000). Dried foods if safe in terms of pathogenic microbial count, would receive acceptance depending on the flavour or aroma, colour, appetizing appearance, texture, taste, and nutritional value of the product. Microorganisms can grow over a broad range of temperatures. Nonetheless, the optimum temperature of growth for most foodborne pathogens is between 30 and 37°C. Microorganisms can also grow at low temperatures but slowly. Many food spoilage microorganisms are psychrotrophs. Examples of psychrotrophs are moulds, yeasts, *Pseudomonas*, *Yersinia*, *Serratia*, *Aeromonas* and *Listeria*. The type of processing a food undergoes is one factor that determines the microbiological safety of the product. Thus canned foods are processed to a temperature high enough to inactivate vegetative cells as well as spores of pathogens and most spoilage bacteria and thus can be stored at room temperature for a long period of time (Adams and Moss, 2000). Contrariwise, minimally processed foods have a shorter shelf

life. Packaging after processing is important since recontamination of processed foods needs to be prevented. A good package should be able to prevent microbial entry. Handling of products after processing and prior to packaging should be done carefully to avoid recontamination of the product.

Yeasts and moulds can spoil a wide variety of food products including those with low pH, high sugar or salt content, or low water activity. Yeasts and moulds cause spoilage of fruits, vegetables, and bakery products (Forsythe, 2000). Spoilage by yeasts and moulds is most visible either in the form of spores or slime, often pigmented usually on the surface (Brackett, 1997).

The principal spoilage organism in dried foods and vegetables are bacteria, moulds and yeast. Bacteria multiply very rapidly when food is kept in an environment favourable for their growth. They may be gram-negative or gram-positive. Moulds usually appear dry and fuzzy. They may be white, green or pink in colour and can cause an unpleasant flavour and smell in tomato powder. The quality, shelf life and microbial load of dried tomato are affected by the packaging material used in packaging (Idah and Aderibigbe, 2007). Microbial quality of dried tomato powder is also influenced by storage condition as well as packaging material during storage (Davoodi *et al.*, 2007).

Kolawole *et al.* (2010) discovered that microorganisms associated with tomato fruit during tray drying were *Erwinia carotovora*, *Proteus sp*, *Bacillus sp*, *Micrococcus luteus*, *Aspergillus sp*, *Aspergillus niger*, *Rhizopus stolonifer* and *Penicillium chrysogenum*. Idah and Aderibigbe (2007) conducted a study on sun dried tomato powder and realized

that prior to storage; the microbial load was 3.6.10³ cfu/g, however upon storage in HDPF and open systems, for a period of three (3) months, the counts increased to 5.4.10³ cfu/g and 7.2.10³ cfu/g respectively. Moulds such as *Aspergillus niger*, *Aspergillus flavus*, *Penicillium*, and *Mucor hemalis* were isolated from dried tomato (Oyebanji *et al.*, 2011). Microbial standards are usually based on the total number of indicator organisms or number of pathogens (Wheeler *et al.*, 1986). The microbial load and its changes during drying and storage are important for establishing a standard that will ensure food safety (Rillo *et al.*, 1988).

2.9 Food Irradiation

Food irradiation has been the focus of intense and deep research for more than 40 years. Irradiation is the process of exposing an object or individual to some form of radiation. Food irradiation is the exposure of food, either pre-packaged or in bulk to a predetermined level of ionization radiation or to high energy particles from one of three types of ionizing energy: gamma rays (emitted from radioactive sources such as Cobalt-60 or Caesium-137), machine generated high electrons or X-rays from accelerators (Rahman, 2007; ICGFI, 1991).

It is a technology that can be used to control contamination by destroying microorganisms such as bacteria, viruses, insects as well as moulds and yeast which may be present in food by causing lesions in genetic material of the cell (Murano, 1995). It reduces food losses due to deterioration by sprout inhibition and delay in ripening (Anon,

1991). Irradiation can be done in any state of the food (thawed or frozen, raw or cooked, solid or liquid) making it economical to use.

Food irradiation is also referred to as cold, non-chemical processing of food such as canning or freezing and has durable and resilient advantages over traditional methods such as drying, cold storage and fumigation since it does not lead to loss of texture, flavour, quality or odour (Diehl, 1995) if carried out under optimum condition.

Radiation doses administered to products are generally characterized as low, medium, high and higher doses. Low dose (less than 1kGy) for delay of ripening in mango, insect and parasite disinfestation and sprout inhibition in potatoes, ginger, onion, garlic and yam (IAEA, 2002); medium (1–10 kGy) for reduction of spoilage microorganisms, microbial reduction in dry products, reduction of non-spore pathogens and high (10-50 kGy) for sterilisation purposes and (10-500 kGy) for reduction in viral contamination (Lund *et al.*, 2004). Different levels of radiation dose are required to achieve desired results for the products (Willemoti *et al.*, 1996). The amount of radiation dose a product receives during irradiation is measured with a dosimeter; examples are ceri-cerous, fricke, alanine and dichromate (IAEA, 2002). The radiosensitivity of microorganism to radiation is dependent on certain factors such as presence of oxygen, irradiation temperature, food composition and vegetative form (Jo *et al.*, 2004).

A joint FAO/IAEA/WHO Expert Committee on Food Irradiation (IJEFCFI) concluded that irradiation of food up to an overall average dose of 10 kGy causes no toxicological hazards and introduces no special nutritional or microbiological problems (WHO, 1994;

WHO, 1988; WHO, 1980). Furthermore, organizations including Health Canada, the FDA, the Codex Alimentarius Commission, and European Commission's Scientific Committee on Food have also supported this limit (Smith and Pillai, 2004). The American Medical Association's Council on Scientific Affairs in 1993 endorsed food irradiation as a safe and effective tool to increase food safety and reduce the incidence of foodborne illness, a view expressed earlier by the U.S. Department of Agriculture (Loaharanu and Murrell, 1994). Irradiation of food and agricultural products is currently allowed in about 40 countries and approximately 60 commercial irradiation facilities are operating in the United States (Sommers, 2004).

A study conducted by Prakash *et al.* (2002) revealed that a dose of 3.07 kGy eliminated microorganisms such as moulds and yeast and mesophilic bacteria contaminated in diced tomatoes to no detectable counts. Youssef *et al.* (2011) reported that radiation dose of 3.0 kGy was also effective in improving microbial load counts of organisms such as moulds and yeast and lactic acid bacteria in tomato juice to acceptable levels and hence extend the shelf life, however, irradiation dose of 4.5 kGy affected sensory properties of tomato juice.

A dose of 2.5 kGy has been found to reduce the *Clostridium*, *Staphylococcus*, *Bacillus*, *Aspergillus* and *Fusarium* species by 2 log cycles and 7.5 kGy eliminated the fungal population of whole and ground pepper (Rahman *et al.*, 2007). For fruits such as cherries and blue berries, low radiation doses have been found to extend the post-harvest shelf life. Blue berries irradiated at 0.25, 0.5, 0.75, or 1.0 kGy stored for 1, 3 and 7 days at 1°C respectively (Miller and McDonald, 1994).

Akamine and Moy, (1983) also revealed that the optimum radiation dose for three-quarter ripe fruits, stored at room temperature is 0.75 kGy. Diop *et al.* (1997) stated that the shelf life of cowpeas can be extended by storing in polyethylene bags after ionizing treatment at doses less than 0.01kGy without causing unfavourable nutritional consequence. Sommers, (2004) also discovered that irradiation was able to inactivate pathogenic bacteria such as *Eschericia coli* 0157:H7, *Salmonella*, *Staphylococcus aureus* and *Listeria monocytogenes* that are normally found in ground beef.

Rahman *et al.* (2007) outlined the main advantages of radiation processing as follows:

- It is highly effective and efficient and environmentally friendly.
- Gamma radiation is highly penetrating and reaches all deep places.
- Fresh or frozen products can be treated on line in their final packaging materials.
- Little or no heating of the food and therefore negligible change to sensory characteristics.
- Processing is automatically controlled and has low operating costs.
- Changes in nutritional value of foods are comparable with other methods of food preservation.
- It has considerable potential to increase international trade in agricultural commodities.

It is very important to note that irradiation does not make irradiated food radioactive and does not introduce any chemical residues or toxicity to the treated product. Irradiated foods must be handled properly to thwart loss of nutrients, deterioration and spoilage (Graham, 1980). The storage material after irradiation is crucial in preserving the integrity of the product from recontamination.

2.10 Food Packaging

Packaging plays a key and essential role in the whole food chain “from field to consumer’s table. It is constantly changing with the introduction of new materials, technology and processes and may be due to the need for improved product quality, productivity, profitability and environmental performance.

Packaging contributes to the preservation of the world’s resources through the prevention of product spoilage and wastage, and by protecting products until they have performed their function (Coles *et al.*, 2003). The primary roles of packaging are to provide product containment, preservation by maintaining quality, presentation and convenience, protection and to provide information to the user. Thus food waste is curtailed, the integrity of the product is maintained and the health of the consumer safeguarded (Rahman, 2007). Robertson (2010) defined packaging as an essential part of a long-term incremental development process to reduce losses that will have to employ a blend of technologies and processes.

Materials that can be used as packaging include paper and board (35%), glass (10%), metal (20%), ceramic, plastics (30%) and regenerated cellulose films. Food is generally packaged prior to irradiation to avoid recontamination; consequently the effects of radiation on the packaging material must be of prime importance to enhance the safety of irradiated foods. This is because the process of radiation can affect different types packaging materials in different ways. The effects of radiation on plastic film depend on the nature of the packaging films, additives in formulation, layers of packaging films, oxygen and temperature content during treatment and treatment dose (Graham, 1980).

El-Makhzoumi, (1994) stated that some food packaging materials produce volatile compounds under certain conditions. These volatile compounds are formed in polyethylene, oriented polypropylene and polyester terephthalate after exposure to radiation doses from 5 to 50 kGy. These compounds are able to leach into packaged food products and affect its quality.

Radiation doses above 30 kGy cause brittleness in cellophanes, plioform and saran while 20 kGy and more can cause inconsequential physical changes and polyethylene plastic films and polyethane (Graham, 1980). Food packaging techniques include vacuum packaging, modified atmosphere packaging, moderate vacuum packaging, aseptic packaging, active packaging, edible coatings and films, primary, secondary and tertiary packaging. The benefits of packaging may include the prevention of product damage and food spoilage, thereby saving vital nutrients, reduces or eliminates the risk of tampering and adulteration and presents food in a hygienic and often aesthetically attractive way (Manalili *et al.*, 2011). In order to help abate food waste and save cost, appropriate packaging is required at each level of the food supply chain; that is production, post-harvest, distribution, processing, whole sale, retail and consumption.

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CHAPTER THREE

3.0 EFFECT OF DRYING AND RADIATION ON THE PHYSICO-CHEMICAL PROPERTIES OF TOMATO (*Solanum lycopersicon* L.) POWDER

3.1 INTRODUCTION

Tomato is an important fruit vegetable cultivated all over the world. It is a seasonal and highly perishable vegetable, deteriorating few days after harvest, affecting their nutritional and qualitative characteristics (Nakhasi *et al.*, 1991). The shelf life of tomato is within 4 to 6 days after harvest, and this is dependent on the variety and storage conditions (Ellis *et al.*, 1998). The short shelf-life of tomato, coupled with improper packaging and storage equipment, as well as lack of effective transport means has been one of the bottlenecks affecting the tomato industry (Babalola *et al.*, 2010; Idah *et al.*, 2007).

To extend the shelf life of tomatoes, they are processed into puree, ketchup, paste, powder, juice and canned whole (Alam *et al.*, 2009). These processing methods preserve the nutritional qualities of fresh tomatoes although some may be lost during processing. The predominant method of preservation of fresh tomato in most homes is by storing at low temperatures. This, however, often results in poor and uneven ripening, and in some instances, high fungal spoilage (Ryall and Lipton, 1972; Tomkins, 1963).

Dehydration is one of the most widely used methods for fruits and vegetables preservation. It is well known that during drying, vegetables undergo physical, structural, chemical and nutritional changes that can affect quality indicators like texture, colour,

flavour, and nutritional value (Di Scala & Crapiste, 2008). Increasing demand for dehydrated tomato in domestic and international markets is growing, with greater portion of it being used in the catering industry (Ghavidel and Davoodi, 2010). It is therefore important to develop suitable technology for drying and preservation of this valuable crop to reduce the losses and increase productivity.

Like other fruits and vegetables, tomato can be dried using several drying methods such as sun, solar, spray and freeze drying techniques. The quality of the dehydrated product depends on factors such as tomato variety, the total soluble solid content of the fresh product, air humidity, air temperature and velocity, the size of the tomato segments and the efficiency of the drying system. The rate of drying also affects the quality of the dehydrated product (Ghavidel and Davoodi, 2010).

The objective of the study was to determine the effect of radiation and storage on the physico-chemical properties of solar dried and freeze dried tomato powder. The study had the following sub-objectives. To determine the:

- i. moisture content of irradiated tomato powder.
- ii. total soluble solids (TSS) of irradiated tomato powder.
- iii. total titratable acidity (TTA) of irradiated tomato powder.
- iv. pH of irradiated tomato powder.
- v. colour changes in irradiated tomato powder.
- vi. methods of drying in Akoma tomato variety

3.2 MATERIALS AND METHODS

3.2.1. Sample Collection and Preparation

Sixty kilogrammes (60 kg) each of fresh and matured Akoma, Pectofake and Chibli varieties of tomato (*Solanum lycopersicon* L.) fruits were purchased from Akomadan in the Offinso North District of the Ashanti Region of Ghana, and transported in plastic crates to the laboratory. This location was chosen because it is a major producing area of tomato for the local market. Each variety was sorted to eliminate the injured and damaged fruits. The samples were washed in brine and rinsed in distilled water. They were then divided into groups for solar and freeze drying. For the solar drying samples, the fruits were cut into two, the seeds removed and each half further chopped into four with an alcohol-sterilized stainless knife to aid drying. The chopped tomatoes were then arranged on alcohol-sterilized aluminium sheets. Drying was done for six days in a Solar dryer (2.78 x 5.45 x 16.46 m) (Plate 1), after which the dried samples (Plate 2) were ground into powder with a blender (Philips Pengisar HR 2021 model) with stainless steel blades.

Samples for freeze drying were similarly prepared. The blended tomatoes were kept in new plain polyethylene bags and packed in a freezer till they were frozen. After freezing, samples were dried in a freeze-dryer (Vertis Consul 24 model) (Plate 3).



Plate 1: Sliced tomatoes in a solar drier



Plate 2: Solar dried tomato



Plate 3: Blended tomatoes being arranged in a freeze drier



Plate 4: (a) Freeze dried tomato (b) Solar dried tomato

3.2.2 Irradiation of samples

Thirty grammes of each solar dried and freeze dried powdered samples was weighed into polyethylene zip lock bags for irradiation and storage (Plate 4). For each dose, samples were bagged in triplicates and each set was further kept in a large zip lock bag for storage. Samples of the solar and freeze dried tomato powder were then irradiated in air at doses of 0, 1, 2 and 3 kGy at a dose rate of 2.6 kGy/h using Cobalt-60 source at the Gamma Irradiation Facility of the Ghana Atomic Energy Commission. The Lithium fluoride photo-flourescent film (SUNNA Dosimeter System, UK) was used to determine the absorbed dose.

3.2.3 Storage of tomato powder

The irradiated tomato powder and their controls were kept in zip lock plastic bag and further stored in a clean box at $(30\pm 2^{\circ}\text{C})$ room temperature. Solar dried samples were stored for 90 days whilst freeze dried samples were stored for 60 days. A laboratory thermometer was kept in the box to observe the temperature throughout the storage period.

3.3.1 Determination of moisture content of irradiated tomato powder

The moisture contents of the irradiated and non-irradiated (control) tomato powder were determined according to the method of AOAC (2000) on monthly basis. Two grammes (2g) of the powder were weighed into petri dishes in triplicates. The samples were dried for 2 hours at 130°C in an oven (Gallenkamp, United Kingdom). The dish, covered while

still in the oven, was transferred into a desiccator and allowed to cool to room temperature before being weighed. The percentage moisture content was calculated using the formulas:

$$\% \text{ Moisture} = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100$$

Where W_1 is the weight of the empty petri dish, W_2 is the weight of petri glass and wet sample and W_3 is the weight of the petri dish and dry sample respectively (Neilson, 2010).

3.3.2 Determination of total soluble solids (TSS) of irradiated tomato powder

The total soluble solids of the tomato powder were determined every month using the method described in AOAC (2000) by weighing. 5 grammes each of the irradiated and unirradiated tomato powder were weighed and mixed with fifty (50) ml of distilled water in a clean beaker. Each was filtered through a sieve of 1mm pore size to facilitate the removal of the seed coats. The TSS was measured using a Westover Model RHB-32ATC Hand Held Brix Refractometer. Readings were taken in triplicates after the refractometer had been calibrated (Neilson, 2010).

3.3.3 Determination of total titratable acidity (TTA) of the irradiated tomato powder

The titratable acidity of the tomato powder was determined every month using the method described in AOAC (2000). Ten (10) grammes of the irradiated and unirradiated powder was mixed with 100ml of distilled water and filtered. Ten (10) ml of the extract was pipetted into a 25ml conical flask. The aliquot was diluted with fifty (50) ml distilled water to minimize interference from colour. Three drops of 1% phenolphthalein was added and titrated with 0.1M NaOH to the end point (pH=8.1±0.1). TTA was analyzed in triplicate and expressed as citric acid equivalent. Acidity was computed and expressed as percent citric acid (Neilson, 2010)

$$\% \text{ acid} = \frac{\text{Titre value} \times \text{Normality} \times \text{M.eq.wt of Acid} \times 100}{\text{Volume of Sample}} \times 100$$

Milli-equivalent weight of citric acid = 0.06404

3.3.4 Determination of pH of irradiated tomato powder

The pH of the tomato powder was determined every month according to the AOAC (2000). Ten (10) grammes of irradiated and unirradiated powder were weighed and mixed with 100ml distilled water and filtered. The pH of the filtrate was measured using a standard pH meter (Mettler Toledo Model) after it had been calibrated.

3.3.5 Determination of colour changes of irradiated tomato powder

Colour changes were measured every month. It was done using a Minolta Camera (CR-300 with a D65 light source; Minolta Camera Co., Osaka Japan) based on the CIELAB color parameters L^* , a^* and b^* where L^* defines the lightness and a^* and b^* are the chromatic components, a^* defines the redness and b^* defines yellowness respectively. A standard white calibration curve plate was used to calibrate the calorimeter before taking the measurements in triplicates (Plate 5).



Plate 5: Colorimeter used in determining changes in tomato colour

3.4 Data analysis

Data were analyzed using STATGRAPHICS Centurion software and GenStat version 12. Means were separated using the least significant difference and the chosen level of significance was $P < 0.05$. Graphs were drawn using Microsoft Excel on the Microsoft Office 2010 package.

3.5 RESULTS

3.5.1 Effect of gamma radiation and storage on the Moisture Content (%) of solar dried tomato powder

The moisture content in the tomato powders used for the study is shown in Table 3.1 and Figs. 3.1 (a) and (b). Significant differences ($p < 0.05$) were observed in all the parameters and their interactions (Appendix 1.1). The moisture content in the powders varied between 12.54 and 23.09%. Pectofake recorded the largest % moisture at all storage times whilst Akoma recorded the least. Pectofake recorded high moisture contents ranging from 16.24% at 2 kGy in month 2 to 23.09 % at 1 kGy in month 3 while Akoma recorded values between 12.54% at 2 kGy in month 0 to 15.09% at 2 kGy in the third month (Table 3.1). Chibli's moisture content also varied between 12.98% at 3 kGy in month 2 to 14.77% at 0 kGy in month 3. There were no significant differences ($p < 0.05$) between the control and irradiated samples at the various doses in Akoma and Chubli. In Pectofake, there were significant differences ($p < 0.05$) between 0 and 1 kGy, and 1 and 2 kGy (Fig. 3.1a). As storage period increased, moisture content fluctuated resulting in significant differences ($p < 0.05$) within and between the varieties (Fig. 3.1 b) (Appendices 1.2 and 1.3).

3.5.2 Effect of gamma radiation and storage on the Total Soluble Solids (TSS, %) of solar dried tomato powder

The percent total soluble solids content in the various tomato powders is shown in Table 3.1 and Fig.3.1 (c) and (d). Generally there were significant differences ($p < 0.05$) between all the factors and their interactions (Appendix 1.10). Total soluble solids in the powders ranged from 4.53 to 6.00% (Table 3.1). Pectoke powder recorded higher total soluble solids at all doses in months 0 and 1 as compared to Akoma and Chibli. Total soluble solids in Pectofake varied from 5.00% at 2 kGy in months 2 and 3 to 6.00% at 0 kGy in month 0. Akoma also recorded values ranging from 4.53% at 1 kGy in month 3 to 5.07% at 0 kGy in month 0. Total soluble solids in Chibli were in the range of 4.80% at 3 kGy in month 0 to 5.40% at 0 kGy in month 3. There were no significant differences ($p > 0.05$) between the control and irradiated powder (Fig. 3.1c). TSS reduced slightly as storage months increased (Fig. 3.1d) (Appendices 1.11 and 1.12).

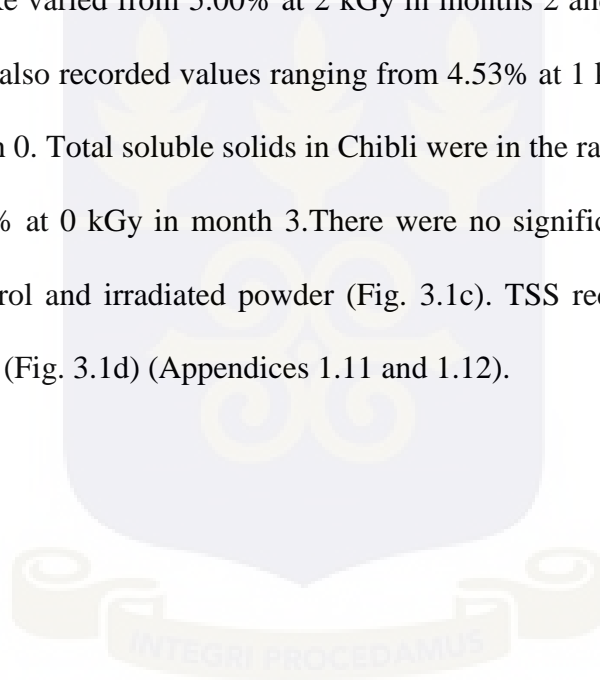
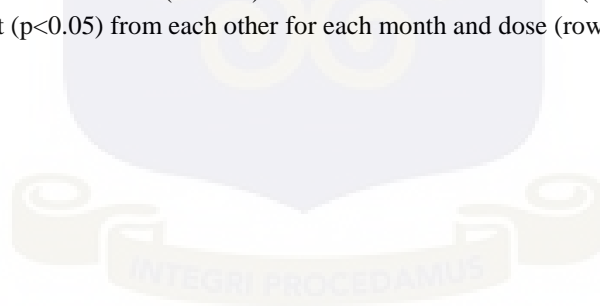


Table 3.1 Effect of gamma radiation dose and storage on the Moisture Content (%) and Total Soluble Solids of solar dried tomato powder

Month	Dose (kGy)	Moisture Content			Total Soluble solids		
		Varieties			Varieties		
		Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli
0	0	18.17 ^{cdB}	12.55 ^{aA}	13.19 ^{aA}	6.00 ^{dB}	5.07 ^{CA}	5.00 ^{aA}
	1	18.56 ^{cdB}	12.65 ^{aA}	13.26 ^{aA}	6.00 ^{dB}	5.00 ^{CA}	5.00 ^{aA}
	2	18.06 ^{2CB}	12.54 ^{aA}	13.50 ^{abA}	6.00 ^{dB}	5.00 ^{CA}	5.00 ^{aA}
	3	17.58 ^{bcB}	12.63 ^{aA}	13.22 ^{aA}	6.00 ^{dB}	5.00 ^{CA}	4.80 ^{aA}
1	0	19.99 ^{efC}	13.22 ^{abcA}	14.58 ^{cdB}	5.87 ^{cdB}	5.00 ^{CA}	5.00 ^{aA}
	1	21.24 ^{ghB}	13.84 ^{bcdA}	14.55 ^{cdA}	6.00 ^{dB}	5.00 ^{CA}	5.00 ^{aA}
	2	21.34 ^{ghB}	14.23 ^{deA}	14.57 ^{cdA}	6.00 ^{dB}	5.00 ^{CA}	5.00 ^{aA}
	3	20.65 ^{fgB}	14.31 ^{deA}	14.41 ^{bcdA}	6.00 ^{dB}	5.00 ^{CA}	5.00 ^{aA}
2	0	19.07 ^{deB}	12.94 ^{aA}	13.72 ^{abcA}	5.27 ^{bb}	4.80 ^{bcA}	5.00 ^{aA}
	1	19.15 ^{deB}	12.74 ^{aA}	13.35 ^{aA}	5.20 ^{abA}	5.00 ^{CA}	5.00 ^{aA}
	2	16.24 ^{abB}	12.98 ^{abA}	13.91 ^{abcdA}	5.00 ^{aA}	5.00 ^{CA}	5.00 ^{aA}
	3	16.89 ^{abB}	12.94 ^{aA}	12.98 ^{aA}	5.00 ^{aA}	5.00 ^{CA}	5.00 ^{aA}
3	0	22.01 ^{hB}	14.47 ^{deA}	14.77 ^{dA}	5.00 ^{aA}	5.00 ^{CA}	5.40 ^{bb}
	1	23.09 ^{iB}	14.11 ^{cdeA}	14.52 ^{cdA}	5.00 ^{ab}	4.53 ^{aA}	5.00 ^{ab}
	2	22.21 ^{hiB}	15.09 ^{eA}	14.86 ^{dA}	5.00 ^{ab}	4.73 ^{abA}	5.00 ^{ab}
	3	21.31 ^{ghB}	14.15 ^{cdeA}	14.54 ^{cdA}	5.40 ^{bcC}	4.73 ^{abA}	5.00 ^{ab}

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). Means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose (row).



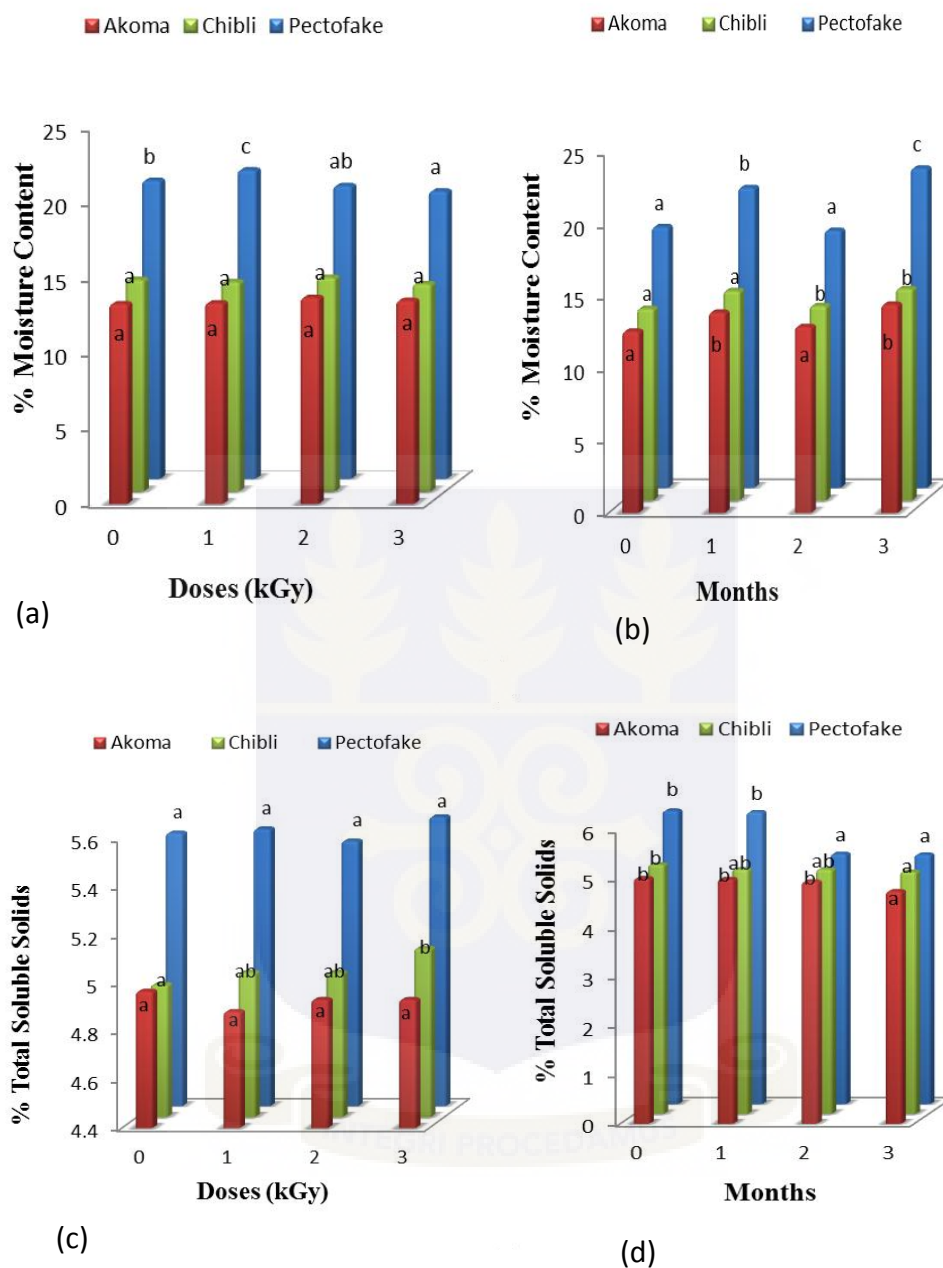


Fig. 3.1 (a) Effect of gamma radiation on the Moisture Content (%) of solar dried tomato powder (b) Effect of storage on the Moisture content (%) of solar dried tomato powder (c) Effect of gamma radiation dose on the Total Soluble Solids (%) of solar dried tomato powder (d) Effect of storage on the Total Soluble Solids (%) of solar dried tomato

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

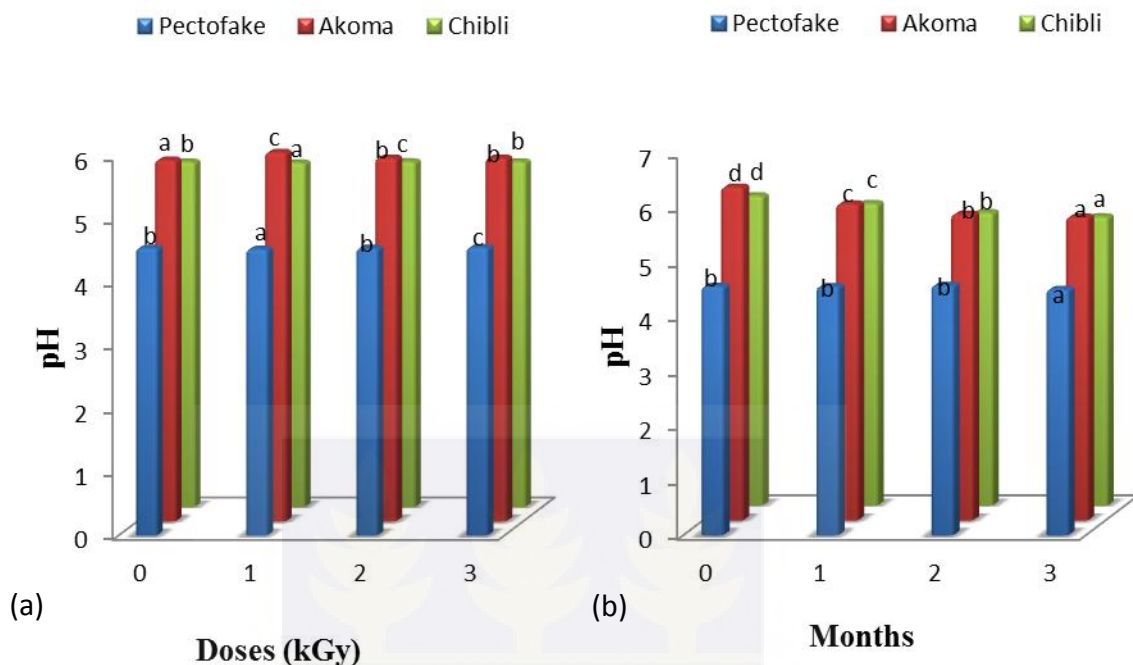


Fig. 3.2 (a) Effect of gamma radiation on the pH of solar dried tomato powder **(b)** Effect of storage on the pH of solar dried tomato powder.

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

3.5.3 Effect of gamma radiation and storage on the pH of solar dried tomato powder

The pH of the solar dried powder after irradiation and storage is shown in Table 3.2 and Fig. 3.2 (a) and (b). Significant differences ($p < 0.05$) were observed within and between all varieties, doses and storage months as well as all their interactions (Appendix 1.4). The pH of tomato powders ranged between 4.51 and 6.18. Akoma recorded the highest pH values while Pectofake recorded the lowest values (Fig 3.2 (a) and (b)). The pH values in Pectofake varied between 4.51 at 2 kGy in month 3 to 4.60 at 2 and 3 kGy in the second month. Akoma recorded values between 5.46 at 2 kGy in month 3 to 6.18 at 2

kGy in month 0. Chibli also logged pH values ranging between 5.27 at 1 kGy in month 3 and 5.68 at 2 and 3 kGy in month 0. A sinusoidal pattern was observed in each variety as radiation dose increased (Fig. 3.2a). The pH in all the varieties reduced significantly ($p < 0.05$) with storage (Fig. 3.2b) (Appendices 1.5 and 1.6).

3.5.4 Effect of gamma radiation and storage on the Total Titratable Acidity (TTA) of solar dried tomato powder

Table 3.2 and Fig 3.3 (a) and (b) show the total titratable acidity of the tomato powders used for the project. Generally significant differences ($p < 0.05$) were observed in all the factors and their interactions (Appendix 1.7). TTA of the powders ranged between 0.11% and 0.45%. Larger TTA were recorded in Pectofake as compared to Akoma and Chibli. Pectofake recorded values varying between 0.34% at 0 kGy in 3rd month and 0.45% at 1 and 2 kGy in month 1. Akoma logged TTA values varying from 0.11% at 1 and 2 kGy in month 0 to 0.24% at 0, 1 and 2 kGy in month 2. Pectofake had the largest percent TTA followed by Chibli and Akoma throughout the storage period (Fig 3.3 a and b). There were no significant differences ($p > 0.05$) between the control and irradiated samples (Fig. 3.3a). As storage months increased, TTA increased significantly ($p < 0.05$) in Akoma and Chibli while Pectofake observed significant ($p < 0.05$) decreases (Fig. 3.3b) (Appendices 1.8 and 1.9).

Table 3.2: Effect of gamma radiation dose and storage on the pH and Total Titratable Acidity (%) of solar dried tomato powder

Months	Doses (kGy)	pH			Total Titratable Acidity		
		Varieties			Varieties		
		Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli
0	0	4.57 ^{efA}	6.09 ^{kC}	5.68 ^{hB}	0.43 ^{cdeC}	0.12 ^{aA}	0.17 ^{aB}
	1	4.55 ^{dA}	6.15 ^{lC}	5.64 ^{gB}	0.43 ^{cdeC}	0.11 ^{aA}	0.17 ^{aB}
	2	4.56 ^{deA}	6.18 ^{mC}	5.68 ^{hB}	0.42 ^{bcdeC}	0.11 ^{aA}	0.17 ^{aB}
	3	4.58 ^{fA}	6.03 ^{jC}	5.68 ^{hB}	0.41 ^{bcdB}	0.13 ^{aA}	0.16 ^{aA}
1	0	4.56 ^{deA}	5.74 ^{fC}	5.53 ^{fB}	0.42 ^{bcdeB}	0.15 ^{aA}	0.18 ^{aA}
	1	4.56 ^{deA}	5.88 ^{iC}	5.53 ^{fB}	0.45 ^{eC}	0.12 ^{aA}	0.19 ^{aB}
	2	4.56 ^{deA}	5.79 ^{gC}	5.54 ^{fB}	0.45 ^{eC}	0.13 ^{aA}	0.24 ^{cdB}
	3	4.57 ^{efA}	5.81 ^{hC}	5.54 ^{fB}	0.44 ^{deC}	0.14 ^{aA}	0.18 ^{aB}
2	0	4.57 ^{efA}	5.56 ^{cC}	5.37 ^{dB}	0.41 ^{bcdB}	0.24 ^{cA}	0.27 ^{dA}
	1	4.57 ^{efA}	5.64 ^{eC}	5.38 ^{eB}	0.40 ^{eB}	0.24 ^{cA}	0.21 ^{bA}
	2	4.60 ^{gA}	5.61 ^{dC}	5.38 ^{eB}	0.39 ^{bB}	0.24 ^{cA}	0.21 ^{bA}
	3	4.60 ^{gA}	5.65 ^{eC}	5.35 ^{cB}	0.39 ^{bB}	0.23 ^{cA}	0.22 ^{bcA}
3	0	4.53 ^{cA}	5.52 ^{bC}	5.30 ^{bB}	0.34 ^{aB}	0.22 ^{bcA}	0.24 ^{cdA}
	1	4.48 ^{aA}	5.73 ^{fC}	5.27 ^{aB}	0.35 ^{aC}	0.19 ^{bA}	0.26 ^{dB}
	2	4.51 ^{bA}	5.46 ^{aC}	5.30 ^{bB}	0.39 ^{bB}	0.22 ^{bcA}	0.24 ^{cdA}
	3	4.52 ^{bcA}	5.55 ^{cC}	5.30 ^{bB}	0.41 ^{bcdC}	0.21 ^{bcA}	0.25 ^{cdB}

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). Means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose

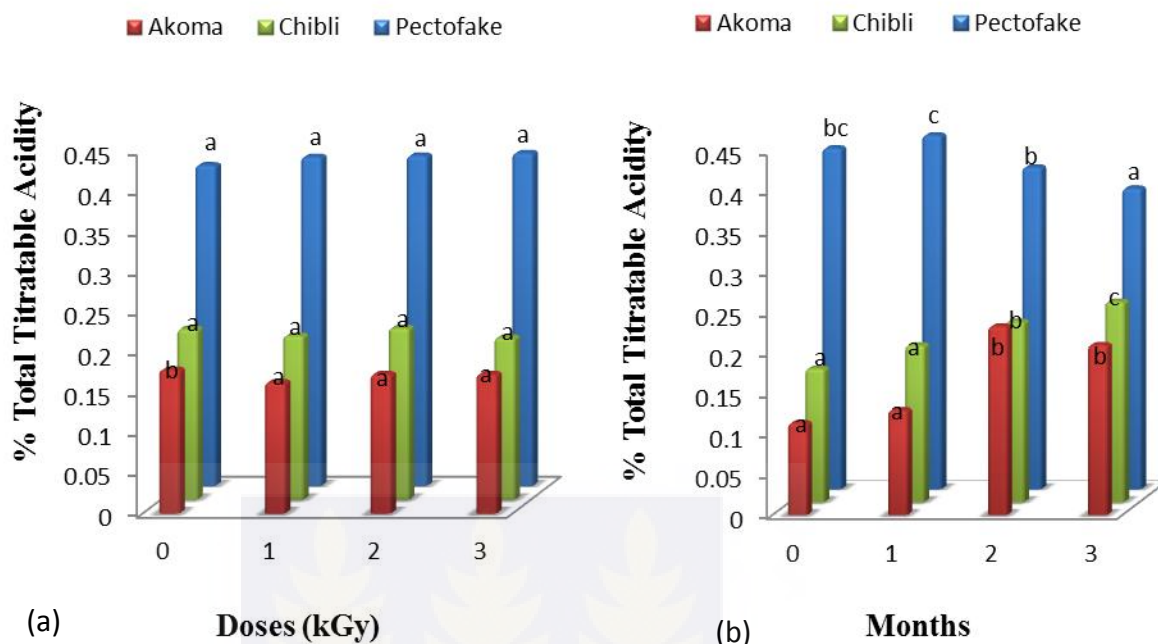


Fig 3.3 (a) Effect of gamma radiation the Total Titratable Acidity (%) of solar dried tomato powder **(b)** Effect of storage on the Total Titratable Acidity (%) of solar dried tomato powder

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

3.5.5 Effect of gamma radiation on storage on the Colour of solar dried tomato powder

The colour changes observed in the solar dried powder after irradiation and storage is shown in Table 3.3. Generally there were significant differences ($p < 0.05$) between and within all the parameters and their interactions for colour parameters (Appendices 1.13, 1.14 and 1.15). The colour of a sample is determined by the L^* , a^* and b^* values. The L^* values in the tomato powder ranged between 22.06 and 35.87. Pectofake had lower L^* values while Akoma and Chibli recorded higher L^* values. Pectofake recorded L^* values

varying from 22.06 at 2 kGy in month 3 to 29.05 at 3 kGy in month 0; 311.53 at 0 kGy in month 3 to 35.87 at 3 kGy in month 1 and 31.17 at 2 kGy in month 3 to 36.05 at 2 kGy in month 0.

The a^* values of the tomato powder varied between 4.59 and 8.95. The lowest was observed in Pectofake while the highest was in Akoma. The a^* values in Pectofake, Akoma and Chibli varied between 45.9 at 2 kGy in month 2 to 7.45 at 3 kGy in month 0; 6.69 at 3 kGy in month 2 to 8.95 at 1 kGy in month 0 and 5.61 at 2 and 3 kGy in month 3 to 7.16 at 2 kGy in month 0. The b^* values of the tomato powder ranged between 7.48 and 22.91. Here also the least value was recorded in Pectofake while the largest was in Akoma. The b^* values in Pectofake ranged from 7.48 at 0 kGy in month 3 to 15.65 at 3 kGy in month 0. Akoma and Chibli recorded b^* values ranging between 18.09 at 0 kGy in month 3 to 22.91 at 3 kGy in month 0 and 17.10 at 2 kGy in month 3 to 22.64 at 2 kGy in month 0.

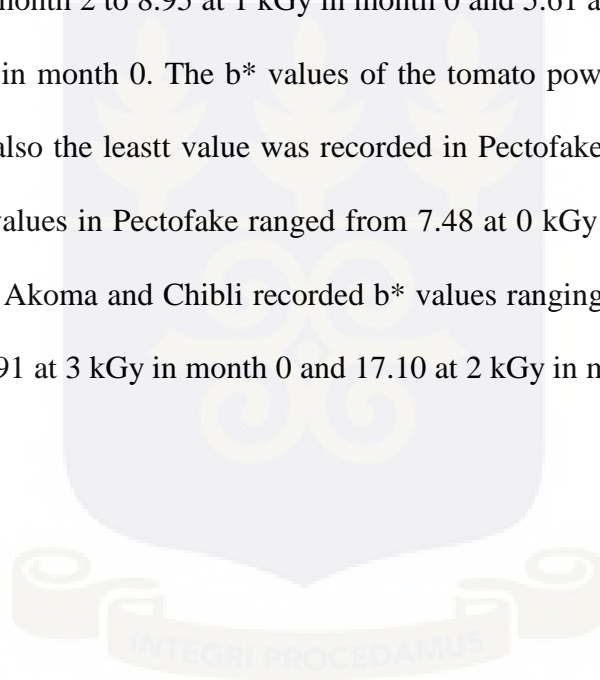


Table 3.3 Effect of gamma radiation dose and storage on the colour of solar dried tomato powder

Month	Dose (kGy)	L			a			B		
		Variety			Variety			Variety		
		Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli
0	0	28.68 ^{lA}	34.60 ^{kB}	34.93 ^{kC}	7.18 ^{hB}	8.70 ^{jC}	7.00 ^{gA}	15.25 ^{fA}	21.58 ^{bcdefB}	21.97 ^{fgB}
	1	28.90 ^{mA}	35.07 ^{mC}	34.38 ^{iB}	6.97 ^{gA}	8.95 ^{kB}	7.04 ^{gA}	15.25 ^{fA}	22.42 ^{defB}	21.23 ^{d^{efgB}}
	2	28.14 ^{kA}	35.64 ^{pB}	36.05 ^{lC}	6.52 ^{fA}	7.88 ^{gC}	7.16 ^{hB}	14.38 ^{efA}	22.62 ^{efB}	22.64 ^{gB}
	3	29.05 ^{nA}	35.49 ^{oC}	34.73 ^{iB}	7.45 ^{iB}	7.91 ^{gC}	7.05 ^{ghA}	15.65 ^{fA}	22.91 ^{fB}	21.35 ^{efgB}
1	0	27.39 ^{hA}	33.91 ^{iC}	33.67 ^{hB}	5.73 ^{eA}	8.25 ^{iC}	6.70 ^{gB}	12.73 ^{cdeA}	20.09 ^{abcdB}	20.25 ^{cdefgB}
	1	27.54 ^{iA}	33.52 ^{eC}	33.28 ^{eB}	5.72 ^{eA}	8.08 ^{hC}	6.70 ^{gB}	13.21 ^{cdefA}	19.22 ^{abB}	19.47 ^{abcdeB}
	2	27.88 ^{iA}	34.83 ^{lC}	33.29 ^{eB}	5.74 ^{eA}	7.97 ^{hC}	6.84 ^{fB}	13.46 ^{defA}	20.31 ^{abcdeB}	19.68 ^{bcdefB}
	3	28.17 ^{kA}	35.87 ^{qC}	33.55 ^{gB}	6.42 ^{fA}	7.46 ^{dC}	6.86 ^{fB}	13.83 ^{defA}	21.81 ^{cdefB}	19.64 ^{bcdefB}
2	0	24.56 ^{eA}	32.71 ^{cB}	33.48 ^{iC}	4.76 ^{bA}	7.12 ^{cC}	6.57 ^{eB}	10.95 ^{bcA}	19.55 ^{abcB}	18.8 ^{abcdB}
	1	25.06 ^{gA}	33.86 ^{hC}	33.13 ^{dB}	5.42 ^{dA}	7.60 ^{eC}	5.74 ^{bB}	11.92 ^{cdbcA}	21.12 ^{bcdefB}	18.76 ^{abcB}
	2	24.83 ^{fA}	35.20 ^{nC}	33.14 ^{dB}	4.59 ^{aA}	6.94 ^{bC}	6.40 ^{dB}	10.93 ^{bcA}	22.73 ^{efC}	18.29 ^{abcB}
	3	25.03 ^{gA}	34.03 ^{jC}	33.47 ^{fB}	5.18 ^{cA}	6.69 ^{ab}	6.77 ^{fB}	11.40 ^{cdA}	21.11 ^{bcdefB}	19.00 ^{abcdeB}
3	0	22.21 ^{bA}	31.53 ^{aB}	33.47 ^{fB}	5.44 ^{dA}	7.90 ^{gC}	5.94 ^{cB}	7.48 ^{aA}	18.09 ^{aB}	17.85 ^{abcB}
	1	22.93 ^{dA}	31.92 ^{bC}	31.50 ^{bB}	5.63 ^{eA}	8.08 ^{hB}	5.74 ^{bA}	8.64 ^{abA}	18.59 ^{aB}	17.45 ^{abB}
	2	22.06 ^{aA}	33.60 ^{fC}	31.17 ^{aB}	5.16 ^{cA}	7.74 ^{fC}	5.61 ^{aB}	7.86 ^{aA}	20.36 ^{abcdeC}	17.10 ^{aB}
	3	22.62 ^{cA}	33.47 ^{dC}	31.54 ^{bB}	5.70 ^{eA}	7.75 ^{fB}	5.61 ^{aA}	8.66 ^{abA}	20.49 ^{abcdefC}	18.00 ^{abcB}

LSD: Means with the different letters (within the same variety) are significantly different (p<0.05) from each other for each month (column). Means with different letters (between different varieties) are significantly different (p<0.05) from each other for each month and dose (row)



3.5.6 Comparison between Solar dried and Freeze dried tomato powder

3.5.6.1 Effect of gamma radiation and storage on the Moisture Content (%) of solar dried and freeze dried tomato powder

The moisture contents of the solar and freeze dried tomato powders used for the study are shown in Table 3.4 and Fig. 3.4 (a) and (b). Significant differences ($p < 0.05$) were observed between and within all factors and their interactions (Appendix 1.16). The freeze dried powder recorded higher values compared to the solar dried powder (Table 3.4). The moisture content of the solar dried samples varied between 12.55% at 0 kGy in month 0 and 14.31% at 3 kGy in month 1; the freeze dried samples recorded values between 23.47% at 1 kGy in month 0 and 25.36% at 0 kGy in month 2. There were no significant differences ($p > 0.05$) between the control and irradiated samples in the solar dried and freeze dried powder at the various doses used (Fig. 3.4a). The moisture content of the solar and freeze dried increased significantly ($p < 0.05$) with increasing storage period (Fig. 3.4b and Appendix 1.17 and 1.18).

3.5.6.2 Effect of gamma radiation and storage on the Total Soluble Solids (TSS, %) of solar dried and freeze dried tomato powder

The total soluble solids of the freeze and solar dried tomato powders are shown in Table 3.4 and Fig. 3.5 (a) and (b). Generally significant differences ($p < 0.05$) were observed between and within the drying methods and months (Appendix 1.25). Solar dried powder recorded lower total soluble solids as compared to the freeze dried powder (Table 3.4). The solar dried powder recorded total soluble solids varying between 4.80% at 0 kGy in

month 2 and 5.06% at 0 kGy in month 0. There were no significant differences ($p>0.05$) between the control and irradiated solar dried powders and a sinusoidal pattern was observed in the freeze dried powder as radiation dose increased (Fig. 3.5a). No significant difference ($p>0.05$) was observed between the control and irradiated powders within the solar dried and freeze dried powders as storage months increased (Fig. 3.5b and Appendices 1.26 and 1.27).

Table 3.4 Effect of gamma radiation and storage on the Moisture Content (%) and Total Soluble Solids of solar and freeze dried tomato powder

Month	Doses (kGy)	Moisture Content (%)		Total Soluble Solids (%)	
		Variety-Akoma		Variety-Akoma	
		Solar dried	Freeze dried	Solar dried	Freeze dried
0	0	12.55 ^{aA}	23.57 ^{aB}	5.06 ^{aA}	7.33 ^{bcB}
	1	12.65 ^{abA}	23.47 ^{aB}	5.00 ^{aA}	7.73 ^{dB}
	2	12.54 ^{aA}	23.94 ^{abB}	5.00 ^{aA}	6.80 ^{aB}
	3	12.63 ^{abA}	23.78 ^{abB}	5.00 ^{aA}	7.40 ^{cdB}
1	0	13.22 ^{bA}	23.73 ^{abB}	5.00 ^{aA}	7.13 ^{abcB}
	1	13.84 ^{cA}	23.89 ^{abB}	5.00 ^{aA}	7.07 ^{abcB}
	2	14.23 ^{cA}	24.18 ^{bB}	5.00 ^{aA}	7.00 ^{abB}
	3	14.31 ^{cA}	23.88 ^{abB}	5.00 ^{aA}	7.07 ^{abcB}
2	0	12.94 ^{abA}	25.36 ^{cb}	4.80 ^{aA}	7.07 ^{abcB}
	1	12.79 ^{abA}	25.24 ^{cb}	5.00 ^{aA}	7.00 ^{abB}
	2	12.98 ^{abA}	25.07 ^{cb}	5.00 ^{aA}	7.00 ^{abB}
	3	12.94 ^{abA}	25.38 ^{cb}	5.00 ^{aA}	7.00 ^{abB}

LSD: Means with the different letters (within the same variety) are significantly different ($p<0.05$) from each other for each month and dose (column). Means with different letters (between different varieties) are significantly different ($p<0.05$) from each other for each month and dose (row).

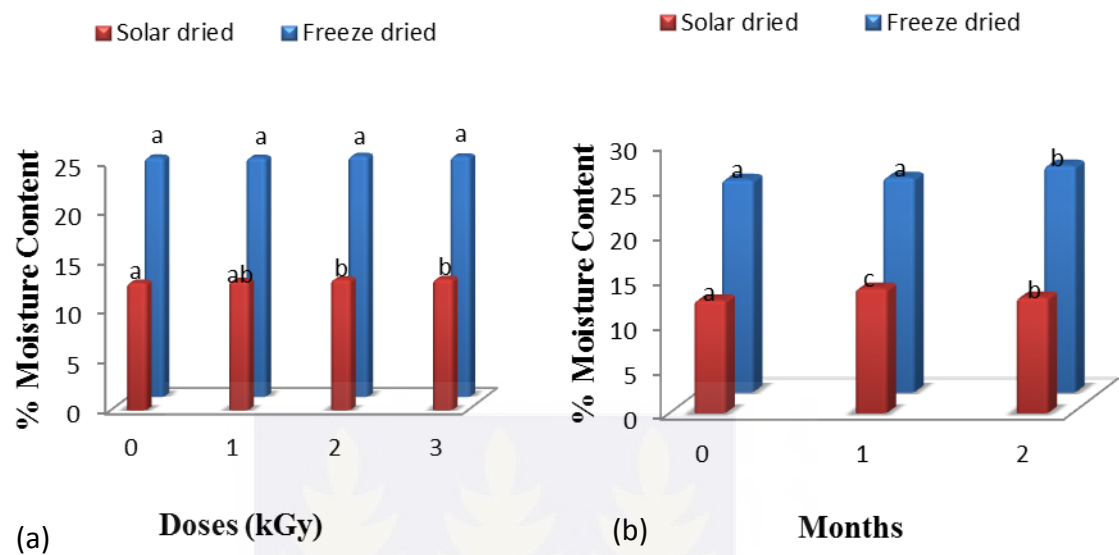


Fig 3.4 (a) Effect of dose on the Moisture Content (%) of solar and freeze dried tomato powder **(b)** Effect of storage on the Moisture Content (%) of solar and freeze dried tomato powder

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

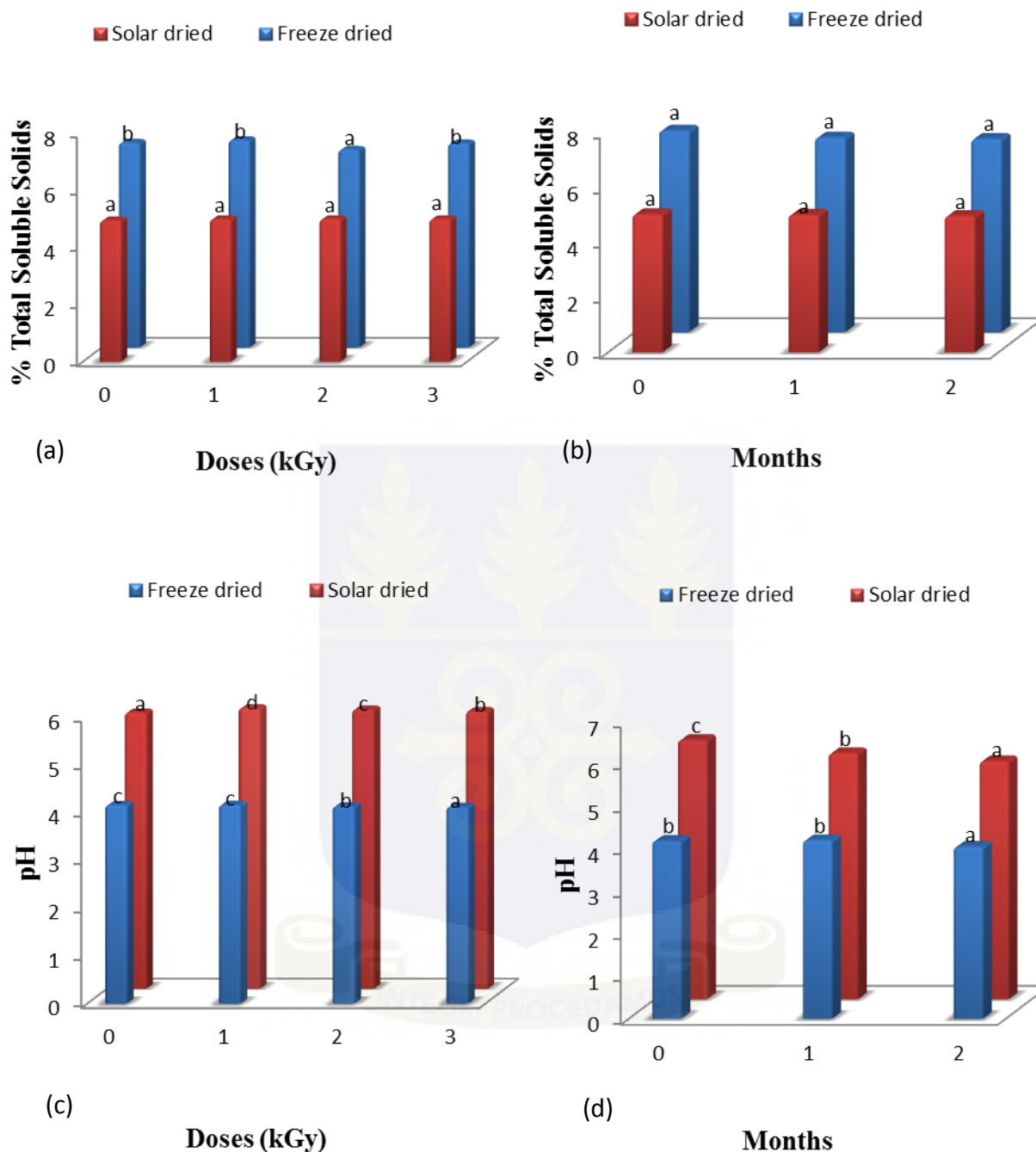


Fig. 3.5 (a) Effect of gamma radiation dose on the Total Soluble Solids (%) of solar and freeze dried tomato powder **(b)** Effect of storage on the Total Soluble Solids (%) of solar and freeze dried tomato powder **(c)** Effect of gamma radiation dose on the pH of solar and freeze dried tomato powder **(d)** Effect of storage on the pH of solar and freeze dried tomato powder

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

dried and freeze dried powder as storage months increased (Fig.3.6b and Appendices 1.23 and 1.24).

Table 3.5 Effect of gamma radiation dose and storage on the pH and Total Titratable Acidity (%) of solar and freeze dried tomato powder

Month	Doses(kGy)	pH		Total Titratable Acidity	
		Variety-Akoma		Variety-Akoma	
		Solar dried	Freeze dried	Solar dried	Freeze dried
0	0	6.09 ^{gB}	4.18 ^{cA}	0.12 ^{abA}	0.74 ^{bB}
	1	6.15 ^{hB}	4.23 ^{eA}	0.11 ^{aA}	0.72 ^{aB}
	2	6.18 ^{iB}	4.19 ^{cdA}	0.11 ^{aA}	0.71 ^{aB}
	3	6.03 ^{fB}	4.18 ^{cA}	0.13 ^{bcA}	0.72 ^{aB}
1	0	5.74 ^{cB}	4.22 ^{eA}	0.14 ^{cA}	0.81 ^{cB}
	1	5.88 ^{eB}	4.22 ^{eA}	0.12 ^{abA}	0.84 ^{dB}
	2	5.79 ^{dB}	4.21 ^{deA}	0.13 ^{cA}	0.82 ^{cB}
	3	5.81 ^{dB}	4.19 ^{cdA}	0.13 ^{bcA}	0.71 ^{aB}
2	0	5.56 ^{aB}	4.10 ^{bA}	0.24 ^{eA}	0.99 ^{eB}
	1	5.64 ^{bB}	4.08 ^{bA}	0.24 ^{deA}	0.98 ^{eB}
	2	6.18 ^{iB}	4.02 ^{aA}	0.24 ^{deA}	0.98 ^{eB}
	3	6.03 ^{fB}	4.02 ^{aA}	0.23 ^{deA}	0.98 ^{eB}

Note: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). Means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose (row).

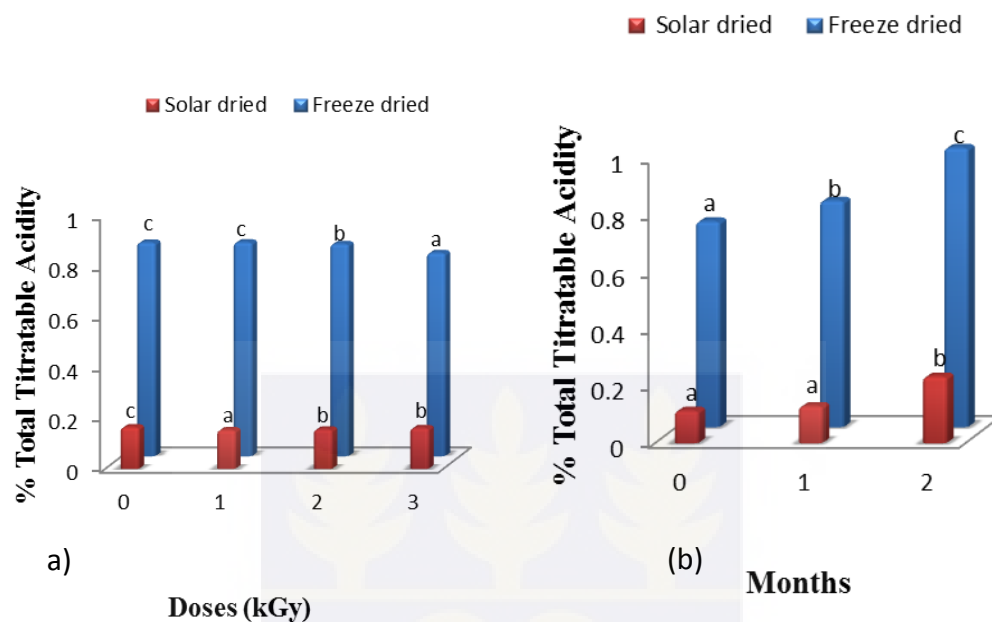


Fig 3.6 (a) Effect of gamma radiation dose on the Total Titratable Acidity (%) of solar and freeze dried tomato powder **(b)** Effect of storage on the Total Titratable Acidity (%) of solar and freeze dried tomato powder

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

3.5.6.5 Effect of gamma radiation and storage on the Colour of solar and freeze dried tomato powder

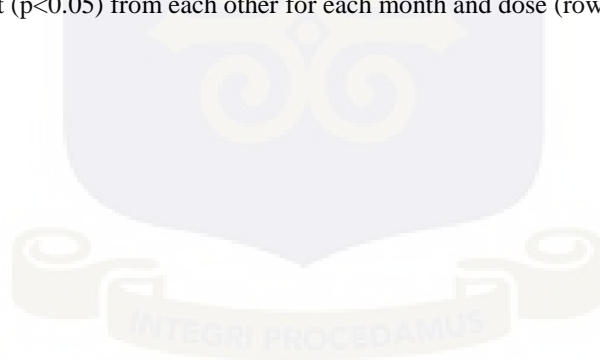
The colour changes detected in the solar dried and freeze dried powders after irradiation and storage are shown in Table 3.6. There were significant differences ($p < 0.05$) between and within all the factors (Appendices 1.28, 1.29 and 1.30). L^* , a^* and b^* values are used to denote the colour changes in a sample. The L^* values in the powders ranged from 32.71 at 0 kGy in month 2 to 35.87 at 3 kGy in month 1 in the solar dried powder and 31.02 at 1 kGy in month 1 to 36.97 at 3 kGy in month 0 in the freeze dried powder. Thus freeze dried samples recorded higher L^* values compared to solar dried samples.

The a^* values of the tomato powder varied between 6.69 and 22.02. The freeze dried powder recorded higher a^* values between 15.00 at 0 kGy in month 2 and 22.02 at 3 kGy in month 0 whereas the solar dried samples recorded lower values of 6.69 at 3 kGy in month 2 to 8.95 at 1 kGy in month 0. The b^* values recorded in the tomato powder ranged from 14.38 at 2 kGy in month 1 to 22.91 at 3 kGy in month 0 in the solar dried sample and 19.25 at 1 kGy in month 1 to 24.83 at 3 kGy in month 2 in the freeze dried samples. Thus the solar dried samples recorded lower values as compared to the freeze dried samples.

Table 3.6: Effect of gamma radiation and storage on the colour of solar and freeze dried tomato powder

Month	Dose (kGy)	L		a		b	
		Variety-Akoma		Variety-Akoma		Variety-Akoma	
		Solar dried	Freeze dried	Solar dried	Freeze dried	Solar dried	Freeze dried
0	0	34.60 ^{fA}	36.52 ^{iB}	8.70 ^{hA}	21.4 ^{hB}	21.58 ^{bcA}	24.46 ^{cdA}
	1	35.07 ^{haA}	35.17 ^{hB}	8.95 ^{iA}	20.64 ^{gB}	22.42 ^{bcA}	22.79 ^{bcdA}
	2	35.64 ^{kA}	36.49 ^{iB}	7.88 ^{eA}	20.51 ^{gB}	22.62 ^{bcA}	24.00 ^{bcdA}
	3	35.49 ^{jA}	36.97 ^{jB}	7.91 ^{efA}	22.02 ^{iB}	22.91 ^{cA}	25.70 ^{dA}
1	0	33.91 ^{dA}	34.94 ^{gB}	8.25 ^{gA}	19.35 ^{fB}	20.09 ^{bcA}	22.81 ^{bcdA}
	1	33.52 ^{bB}	31.02 ^{aA}	8.08 ^{fgA}	18.47 ^{dB}	19.22 ^{bA}	19.25 ^{aA}
	2	34.83 ^{gB}	32.70 ^{bA}	7.97 ^{efA}	18.91 ^{eB}	14.38 ^{aA}	20.72 ^{abB}
	3	35.87 ^{iB}	33.72 ^{dA}	7.46 ^{dA}	18.60 ^{dB}	21.81 ^{bcA}	22.14 ^{abcA}
2	0	32.71 ^{aA}	32.70 ^{bA}	7.12 ^{cA}	15.00 ^{aB}	19.55 ^{dcA}	22.79 ^{bcdA}
	1	33.86 ^{cB}	33.03 ^{cA}	7.60 ^{dA}	15.01 ^{aB}	21.12 ^{bcA}	23.85 ^{bcdA}
	2	35.20 ^{iB}	33.86 ^{eB}	6.94 ^{bA}	16.04 ^{cB}	22.73 ^{cA}	24.63 ^{cdA}
	3	34.03 ^{eA}	34.86 ^{fB}	6.69 ^{aA}	15.23 ^{bB}	21.11 ^{bcA}	24.83 ^{cdB}

Note: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). Means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose (row).



3.6 DISCUSSION

3.6.1 Effect of gamma radiation and storage on the moisture content of solar dried tomato powder

Immediately after irradiation, the moisture contents in Pectofake were significantly different from Akoma and Chibli. This was due to varietal differences (Gowda and Huddar, 2000). These authors documented that different varieties of a crop tend to have different characteristics, hence the observed phenomenon.

After the third month of storage of the tomato powder, the moisture content had increased significantly in all three varieties; however Pectofake was significantly different from Akoma and Chibli and recorded the highest moisture content during the study. This was due to varietal differences as reported by Gowda and Huddar, (2000). This observation was in accordance with earlier findings which observed that in irradiated dried apricots, moisture contents increased significantly with storage (Hussain *et al.*, 2011). The increase in moisture content during storage was as a result of environmental changes which led to changes in relative humidity outside the packaging system (Jayathunge *et al.*, 2012; Mir *et al.*, 2009; Taoukis *et al.*, 1988). The lower increase in moisture content in 2 and 3 kGy (irradiated powders) may be attributed to alterations caused in cellular integrity and pore size due to irradiation hence affecting the uptake of moisture from the surrounding atmosphere (Rastogi *et al.*, 2006; Rastogi, 2005). Earlier reports by Hussain *et al.* (2011) revealed a lower increase in moisture content of dried apricots irradiated at 3 kGy.

3.6.2 Effect of gamma radiation and storage on the total soluble solids of solar dried tomato powder

Upon 3 months storage, total soluble solids had reduced significantly in Akoma and Chibli with increasing radiation dose and storage. In Pectofake however the total soluble solids in the second and third months were not different. The findings in Pectofake are similar to reports made by Ajayi and Oderinde, (2013). They attributed the decrease in total soluble solids during storage to breakdown of solids as a result of increase in temperature (Bachman and Earles, 2000).

3.6.3 Effect of gamma radiation and storage on the pH and total titratable acid of solar dried tomato powder

Immediately after radiation treatment, Pectofake and Chibli, recorded significant reductions in pH as radiation dose increased. Similar findings were made by Hussain *et al.* (2011) in irradiated dried apricot and Ladaniya *et al.* (2003), who realized that pH reduced with increasing radiation dose.

After storage, there were significant increases in total titratable acidity in Akoma and Chibli while a significant decrease was observed in Pectofake. pH dropped significantly in all varieties but was not due to radiation dose. The increase in total titratable acidity with storage was similar to previous findings (Lui *et al.*, 2011). During storage of tomato powder, total titratable acidity increased as pH decreased hence total titratable acidity and pH were inversely related (Ajayi and Oderinde, 2013; Lui *et al.*, 2010). These increases in total titratable acidity and decreases in pH were due to reactions of basic amines to

form compounds of lower basicity and to the breakdown of sugars into acids during the Millard reaction (Beck *et al.*, 1990). The fluctuations in the pH implied that radiation treatment had no effect on pH. This was in accordance with Prakash *et al.* (2002) who documented that radiation dose of 3.07 kGy had no significant effect on diced tomatoes. The difference in acidity and total titratable acidity in the tomato powders was due to varietal difference (Gowda and Huddar, 2000)

3.6.4 Effect of gamma radiation and storage on the colour of solar dried tomato powder

Colour is a very essential quality factor in fruit and vegetable products; this is because it influences consumer criteria and acceptability. After storage, L* a* and b* reduced significantly in the first and second months irrespective of the radiation treatment administered. The decreases in colour were in consonance with previous studies (Abano *et al.*, 2012; Lui *et al.*, 2010; Anguelova and Warthesen, 2000). These authors documented that the colour (L*, a* and b*) of tomato powder decrease regardless of the storage temperature and time due to oxidation. The L values within and between solar dried tomato powders diminished significantly during storage, however, Pectofake had a faster reduction in the brightness compared to Chibli and Akoma which had slow reduction rates. This was due to biochemical interaction between the variety and the storage environment.

Reduction in a* values was due to general degradation of the red carotenoid pigment (lycopene) (Contreras *et al.*, 2008) due to oxidation (Shi *et al.*, 1999; Sharma and Le

Maguer, 1996) and to isomerization of lycopene (Anguelova and Warthesen, 2000) which plays a major role in the colour of tomato powders (Lui *et al.*, 2010). It was also due to the existence of non-enzymatic reaction between the amino acids and reducing sugars in the tomato (Cernișev, 2010; Contreras *et al.*, 2008). Lycopene is known to impact red colour to fruits and vegetables including tomatoes (Akdeniz *et al.*, 2012; Lavelli and Scarafoni, 2011; D'Souza *et al.*, 2008).

3.6.5 Comparison between solar dried and freeze dried tomato powder

Gamma radiation treatment did not significantly affect moisture content however storage had a significant effect on the moisture content. Freeze dried powder recorded higher moisture contents compared to solar dried samples. This was due to difference in drying methods since the freeze dried samples were porous in nature (Abascal *et al.*, 2005). Immediately after irradiation, the moisture contents of the treated and control were not significantly different in both drying methods. Upon 2 months storage, the moisture contents increased significantly in the solar and freeze dried samples. The findings in this study is similar to previous studies (Hussain *et al.*, 2011; Hossain and Gottschalk, 2009; Latapi and Barret, 2006). These authors documented that moisture content in a sample increases with storage due to changes in the environment which leads to changes in the relative humidity in the packaging material.

The total soluble solids in the solar dried powder were lower than that of the freeze dried powder. Radiation treatment had no effect on the total soluble solids in this study. This observation was in accordance with literature (Prakash *et al.*, 2002; Miller and

McDonald, 1996). Low gamma radiation doses are reported not to affect total soluble solids (Patil *et al.*, 2004; Hallman and Martinez, 2001).

Freeze dried powder recorded lower pH and higher total titratable acidity values compared to solar dried powder although they belong to the same variety. Two months after storage, the pH of the solar and freeze dried samples reduced significantly while the total titratable acidity increased significantly. This observation was in accordance with previous findings which revealed that total titratable acidity and pH were inversely related (Ajayi and Oderinde, 2013; Lui *et al.*, 2010; Beck *et al.*, 1990). Thus radiation treatment had no effect on the total titratable acidity and pH as reported by Prakash *et al.* (2002).

The L*, a* and b* values of the freeze dried samples were higher and significantly different from the solar dried samples. Similar observation was made by Nindo, (2008) who observed that freeze dried samples had better retention of colour in dried vegetables than solar dried samples. Immediately after radiation treatment, the L* (brightness) and a* (redness) values recorded did not follow a definite pattern; hence not dose dependent. Two months after storage, there were significant decreases within and between L*, a* and b* values in both drying methods. The behaviour of the two drying methods were similar to earlier reports (Abano *et al.*, 2012; Akdeniz *et al.*, 2012; Lui *et al.*, 2010; Contreras *et al.*, 2008; Sharma and Le Maguer, 1996). The freeze dried samples recorded higher a* values but this did not reflect in the lycopene content. Solar dried powder recorded higher a* lycopene values compared to the freeze dried powder. This implies that lycopene is not the only carotenoid responsible for the red colour observed in

tomatoes (Zeb and Mehmood, 2004). The reduction in yellowness, b^* , of solar and freeze dried samples was due to isomerization (Anguelova and Warthesen, 2000) and biochemical changes within the dried powder.



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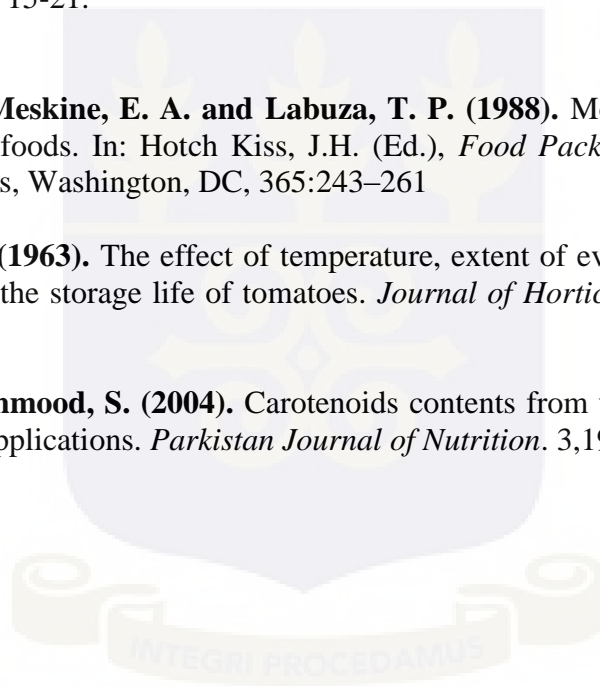
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CHAPTER FOUR

4.0 EFFECT OF RADIATION ON THE MICROBIOLOGICAL QUALITY OF SOLAR DRIED AND FREEZE DRIED TOMATO (*Solanum lycopersicon* L.) POWDER

4.1 INTRODUCTION

Food contamination is a serious issue because it results in food-borne diseases each year, affecting about seventy - six million people in the United States, resulting in hospitalization of 325,000 and 5,000 deaths (Mead *et al.*, 2010). Contamination of tomatoes occurs at various levels from their journey from harvest to the final consumer and the probable source of the contamination is very important. A number of outbreaks of diseases including gastroenteritis have been linked to the consumption of contaminated tomatoes associated with pathogens such as *Salmonella javiana* and *Listeria monocytogenes* (Wood *et al.*, 1991; Ho *et al.*, 1986). Tomatoes are widely consumed either in the fresh or processed state, because it is the main source of carotenoids for the populace (Watzl *et al.*, 2000).

Ionising radiation is now an alternative decontamination method of public health products and food (Hammad *et al.*, 2010). This is because ionising radiation has the ability to destroy viable cells of microorganisms without raising the temperature of the product thereby keeping the freshness, nutrients, physical and chemical properties (Tiwaria *et al.*, 2009). A study conducted by Song *et al.* (2007) revealed that irradiation treatment of fresh carrot was effective in eliminating coliforms. Prakash *et al.* (2002)

reported that gamma radiation was effective in eliminating all microorganism contaminating diced tomatoes to no measurable counts. Solar-dried and sun-dried tomatoes have gained great acceptance in the food service segment and food industry as an ingredient hence the need for radiation treatment to improve the microbial quality and hence increase the shelf life.

The main objective of this study was to ascertain the effect of gamma radiation on the microbial quality of solar and freeze dried tomato. The specific objectives were to determine the total

- i. aerobic mesophilic bacteria count in the irradiated powder.
- ii. coliform count in the irradiated powder.
- iii. mould and yeast count in the irradiated powder.

4.2 MATERIALS AND METHODS

4.2.1. Sample Collection and Preparation

Sixty kilogrammes (60 kg) each of fresh and matured Akoma, Pectofake and Chibli varieties of tomato (*Solanum lycopersicon* L.) fruits were purchased from Akomadan in the Offinso North District of the Ashanti Region of Ghana and transported in plastic crates to the laboratory. This location was chosen because it is a major producing area of tomato for the local market. Each variety was sorted to eliminate injured and damaged fruits before work commenced. The samples were washed in brine and rinsed in distilled water. They were then divided into groups for solar and freeze drying respectively. For the solar drying samples, the fruits were cut into two, the seeds removed and each half

was further chopped into four to aid drying. The chopped tomatoes were then arranged on aluminium sheets. The stainless steel knife and aluminium sheets were sterilized with alcohol before use. Drying was done for six days in a Solar dryer (2.78 x 5.45 x 16.46)m after which the dried samples were ground into powder with cleaned Philips blender (Pengisar HR 2021 model) with stainless steel blades.

Samples for freeze drying were similarly prepared. The blended tomatoes were packed into new plain polyethylene bags and kept in a freezer till they were frozen. After freezing, samples were dried in a freeze dryer (Vertis Consul 24 model).

4.2.2 Irradiation of Samples

Thirty grammes of each solar and freeze dried samples were weighed into polyethylene zip lock bags for irradiation and storage. For each dose, samples were bagged in triplicates and each set was further kept in a large zip-lock bag for storage. Samples of the solar and freeze dried tomato powder were then irradiated in air at doses of 0, 1, 2, and 3kGy at a dose rate of 2.6 kGy/h using Cobalt-60 source at the Gamma Irradiation Facility of the Ghana Atomic Energy Commission. The lithium fluoride photo-flourescent film (SUNNA Dosimeter System, UK) was used to determine the absorbed dose.

4.2.3 Storage of Tomato Powder

The irradiated tomato powder and their controls were kept in zip lock bags and further stored in a clean box at room temperature ($30\pm 2^{\circ}\text{C}$). Solar dried samples were stored for

90 days whilst freeze dried samples were stored for 60 days. A laboratory thermometer was kept in the box to record the temperature throughout the storage period.

4.3. Microbiological Analysis

4.3.1. Counting of Microorganisms

For Microbial enumeration, Total Aerobic Mesophilic Bacteria Count, Total Coliform Count, Moulds and Yeast Counts were used.

4.3.1.1. Total aerobic mesophilic bacteria count (TAMB)

For total aerobic mesophilic bacteria count (TAMB), the pour-plate method was used. One (1) g of tomato powder was added to 0.1% of sterile peptone water (Pw) to form the inoculum. This was incubated at 37°C for 15 minutes to allow for the organisms to be in solution. From the neat, one (1) mL was serially diluted using the 10-fold serial dilution into ten (10) other sterile MacCartney bottles containing 9 mL 0.1% sterile Pw. One (1) mL of the suspension (sample) was aseptically added to 9 mL molten standard plate count agar (SPCA) [Merck, Darmstadt-Germany] kept at 45°C-50°C (Collins and Lyne, 1983) in a water bath (Grant, OLS 200) . This was mixed by rotation and poured into 90 mm sterile Petri dish. It was allowed to set and incubated at 37°C for 18-24 hours in a Microbiological incubator (Westach, 2002). After overnight incubation, plates showing between 30 and 300 colonies were selected and counted using electronic colony counter (Stuart Scientific, 1999). The colonies were counted and multiplied by the dilution factor

and expressed as $x \cdot 10^y$ cfu/g where x is colony counted, y is the dilution factor and cfu/g as unit (Collins and Lyne, 1983).

4.3.1.2. Total coliform count (TCC)

Using the inoculum, one (1) mL of the suspension was serially diluted using the 10-fold serial dilution as stated above. TCC was identified using Violet Red Bile Agar (VRBA) (Merck, Darmstadt-Germany) and plates incubated 37°C for 48 hours in a microbiological incubator (Westach, 2002).

4.3.1.3. Moulds and Yeast Count

One (1) mL of the inoculum was serially diluted using the 10-fold serial dilution as already described. Moulds and Yeasts were determined using Malt Extract Dextrose Agar (MEDA) media and plates incubated at 25°C-30°C for 5-7 days in a microbiological incubator (Westach, 2002).

4.3.2. Culture and Identification techniques

4.3.2.1. Bacterial cultures:

Using the plate-out technique, cultures were made from the inoculum onto Blood Agar (Merck, Darmstadt-Germany), MacConkey Agar (Merck, Darmstadt-Germany) and de man, Rogosa, Sharpe Agar (MRS) (Merck, Darmstadt-Germany) as described by

Heritage *et al.* (1996). The samples were incubated at 37°C for 18-24 hours in a microbiological incubator. Examination of the colonial morphologies of organisms on the media was studied and the impure colonies purified on Blood Agar and Nutrient Agar.

4.3.2.2. Moulds and Yeast:

One (1) mL of the neat was spread to the surface of the solid Malt Extract Dextrose Agar (MEDA) media in 90mm sterile Petri dish. Using the spread-plate technique, the suspension was spread evenly to cover the whole surface of the plate and the excess discarded. Plates were incubated at 25°C for 5-7 days in a microbiological incubator (Westach, 2002). Cultures were observed daily for growth.

Colonial morphology of organisms was observed based on their physiological characteristics for size, shape, outline, colour and change on various media. Standard microbiological techniques including staining reaction, cellular morphology and biochemical test among others were used to isolate and identify the organisms. Bacteria were stained with Gram stain and examined for Gram reaction using light microscope at x100 with oil immersion; and identified using biochemical test such as catalase, motility, indole, urea and IMViC according to Bergey's manual of determinative bacteriology (Cowan, 1979).

Moulds and Yeast were stained with lactophenol cotton blue and examined at x10 magnification. They were identified using colonial and cell morphology.

4.4 Data Analysis

Data were analyzed using STATGRAPHICS Centurion software and GenStat version 12. Means were separated using the least significant difference and the chosen level of significance was $P < 0.05$. Graphs were drawn using Microsoft Excel on the Microsoft Office 2010 package.

4.5 RESULTS

4.5.1 Effect of gamma radiation and storage on the Total Aerobic Mesophilic Bacteria (TAMB) count (\log_{10} cfu/g) in solar dried tomato powder

The total aerobic mesophilic bacteria (TAMB) count in the tomato powders after irradiation and storage are shown in Table 4.1 and Fig.4.1 (a) and (b). Significant differences ($p < 0.05$) were observed within and between all the parameters their interactions (Appendix 3.1). The TAMB in the irradiated powders varied between 0.00 and 6.78 (\log_{10} Cfu/g, Table 4.1). Pectofake recorded TAMB ranging between 6.78 (\log_{10} Cfu/g) at 0 kGy in month 0 and 0.00 (\log_{10} Cfu/g) at 2 and 3 kGy in the second and third months. The TAMB recorded in Akoma varied between 5.82 (\log_{10} Cfu/g) at 3 kGy in month 3 and 6.77 (\log_{10} Cfu/g) at 0 kGy in month 0 while 6.77 (\log_{10} Cfu/g) at 0 kGy in month 0 to 5.88 (\log_{10} Cfu/g) at 3 kGy in the third month in Chibli. The counts for TAMB decreased significantly ($p < 0.05$) as radiation dose increased in all the varieties (Fig 4.1a). Figure 4.1b shows a decline in TAMB as storage months increased in Pectofake while in Akoma and Chibli, the irradiated and control recorded the same counts of TAMB, thus they were not significantly different ($p > 0.05$) (Appendices 3.2 and 3.3).

4.5.2 Effect of gamma radiation and storage on the Total Coliform Count (TCC) (\log_{10} cfu/g) in solar dried tomato powder

The total coliform count (TCC) in tomato powders after radiation treatment and storage are shown in Table 4.1 and Fig. 4.1 (c) and (d). There were significant differences ($p < 0.05$) in all the factors their interactions (Appendix 3.4). The TCC in the powders ranged between 0.00 and 6.53 (\log_{10} CfU/g) (Table 4.1). Pectofake recorded TCC varying between 0.00 (\log_{10} CfU/g) at 1, 2 and 3 kGy in the second and third months to 6.00 (\log_{10} CfU/g) at 0 kGy in month 0. TCC in Akoma varied between 3.77 (\log_{10} CfU/g) at 3 kGy in month 0 to 6.39 (\log_{10} CfU/g) at 0 kGy in month 3. Chibli also recorded counts between 5.00 at 3 kGy in month 3 and 6.53 at 0 kGy in month 3. A decrease in TCC was observed as radiation dose increased (Fig. 4.1c). A significant ($p < 0.05$) decline in TCC was noticed as storage months increased in Pectofake (Fig. 4.1d) (Appendices 3.5 and 3.6).

4.5.3 Effect of gamma radiation and storage on the Total Mould and Yeast Count (MYC) (\log_{10} cfu/g) in solar dried tomato powder

The total mould and yeast counts (MYC) in tomato powders after irradiation and storage are shown in Table 4.1 and Fig. 4.2 (a) and (b). There were significant differences ($p < 0.05$) between and within all the factors and their interactions (Appendix 3.7). Moulds and yeast counts in the powders varied between 3.77 and 7.39 (\log_{10} CfU/g) (Table 4.1). The MYC observed in Pectofake ranged from 3.77 at 3 kGy in month 3 to 7.30 at 0 kGy in month 0. MYC in Akoma varied between 3.92 (\log_{10} CfU/g) at 3 kGy in month 3 to 7.58 at 0 kGy in month 2 and Chibli recorded counts from 4.04 at 3 kGy in month 3 to 7.39 at 0 kGy in month 0. A reduction in counts of MYC was noticed in all varieties as radiation dose increased (Fig. 4.2a). Generally MYC reduced significantly ($p < 0.05$) as storage months increased in all the varieties (Fig 4.2b) (Appendices 4.7 and 4.8).

Table 4.1: Effect of gamma radiation and storage on the microbial count (TAMB, TCC, MYC) (\log_{10} cfu/g) of solar dried tomato powder

Months	Doses (kGy)	Total Aerobic Mesophilic Count (Cfu/g)			Total Coliform Counts (Cfu/g)			Moulds and Yeast Counts (Cfu/g)		
		Varieties			Varieties			Varieties		
		Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli
0	0	6.78 ^{jA}	6.77 ^{iA}	6.77 ^{hA}	6.00 ^{fA}	6.03 ^{hiA}	6.53 ^{hB}	6.62 ^{jA}	7.04 ^{iB}	7.39 ^{mC}
	1	6.65 ^{iB}	6.20 ^{eA}	6.68 ^{gB}	5.29 ^{eB}	4.84 ^{cA}	6.38 ^{gC}	6.70 ^{kA}	6.92 ^{hB}	6.92 ^{jB}
	2	6.48 ^{gB}	6.08 ^{cdA}	6.54 ^{efB}	4.01 ^{bA}	4.15 ^{bb}	6.31 ^{fgC}	6.31 ^{hA}	6.32 ^{eA}	6.30 ^{gA}
	3	5.92 ^{cB}	5.67 ^{aA}	6.48 ^{eC}	3.77 ^{aA}	3.84 ^{ab}	6.18 ^{eC}	6.04 ^{fA}	6.00 ^{cA}	6.04 ^{eA}
1	0	6.57 ^{hA}	6.59 ^{hB}	6.68 ^{gC}	4.48 ^{dA}	6.23 ^{jB}	6.40 ^{gC}	7.30 ^{iB}	7.29 ^{jB}	7.18 ^{lA}
	1	6.48 ^{gA}	6.45 ^{gA}	6.60 ^{fB}	4.08 ^{bA}	6.08 ^{iA}	6.26 ^{eB}	6.48 ^{iA}	6.45 ^{fA}	6.47 ^{iA}
	2	6.32 ^{fA}	6.30 ^{fA}	6.48 ^{eB}	0.00 ^{gC}	5.75 ^{gA}	6.17 ^{eB}	6.32 ^{hA}	6.56 ^{gC}	6.40 ^{hiB}
	3	6.08 ^{dA}	6.04 ^{cA}	6.36 ^{dB}	0.00 ^{gC}	5.37 ^{eB}	6.00 ^{dB}	5.20 ^{eB}	4.28 ^{bA}	5.90 ^{dC}
2	0	6.15 ^{eA}	6.42 ^{gB}	6.48 ^{eC}	4.32 ^{cA}	6.35 ^{kB}	6.29 ^{fB}	6.48 ^{iA}	7.58 ^{kC}	7.00 ^{kB}
	1	5.18 ^{bA}	6.12 ^{dB}	6.40 ^{dC}	0.00 ^{gB}	5.95 ^{hA}	6.00 ^{dA}	6.32 ^{hB}	6.25 ^{eA}	6.39 ^{hB}
	2	0.00 ^{kC}	6.04 ^{cA}	6.29 ^{cB}	0.00 ^{gC}	5.56 ^{fA}	6.00 ^{dB}	5.04 ^{dA}	5.95 ^{cB}	6.08 ^{fC}
	3	0.00 ^{kC}	5.82 ^{bA}	6.16 ^{bB}	0.00 ^{gC}	5.59 ^{fA}	5.69 ^{bB}	3.90 ^{bA}	3.95 ^{aA}	4.18 ^{bB}
3	0	6.33 ^{fA}	6.42 ^{gB}	6.48 ^{eB}	4.43 ^{dA}	6.39 ^{kC}	6.30 ^{fgB}	6.58 ^{jA}	6.60 ^{gA}	7.00 ^{kB}
	1	5.03 ^{aA}	6.12 ^{dB}	6.38 ^{dC}	0.00 ^{gC}	5.88 ^{hA}	6.00 ^{dB}	6.20 ^{gA}	6.17 ^{dA}	6.39 ^{hB}
	2	0.00 ^{kC}	6.04 ^{cA}	6.19 ^{bB}	0.00 ^{gC}	5.56 ^{fA}	5.86 ^{cB}	4.77 ^{cA}	5.97 ^{cC}	5.69 ^{cB}
	3	0.00 ^{kC}	5.82 ^{bA}	5.88 ^{aA}	0.00 ^{gC}	5.10 ^{dB}	5.00 ^{aA}	3.77 ^{aA}	3.92 ^{aB}	4.04 ^{aC}

LSD: means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose (row).

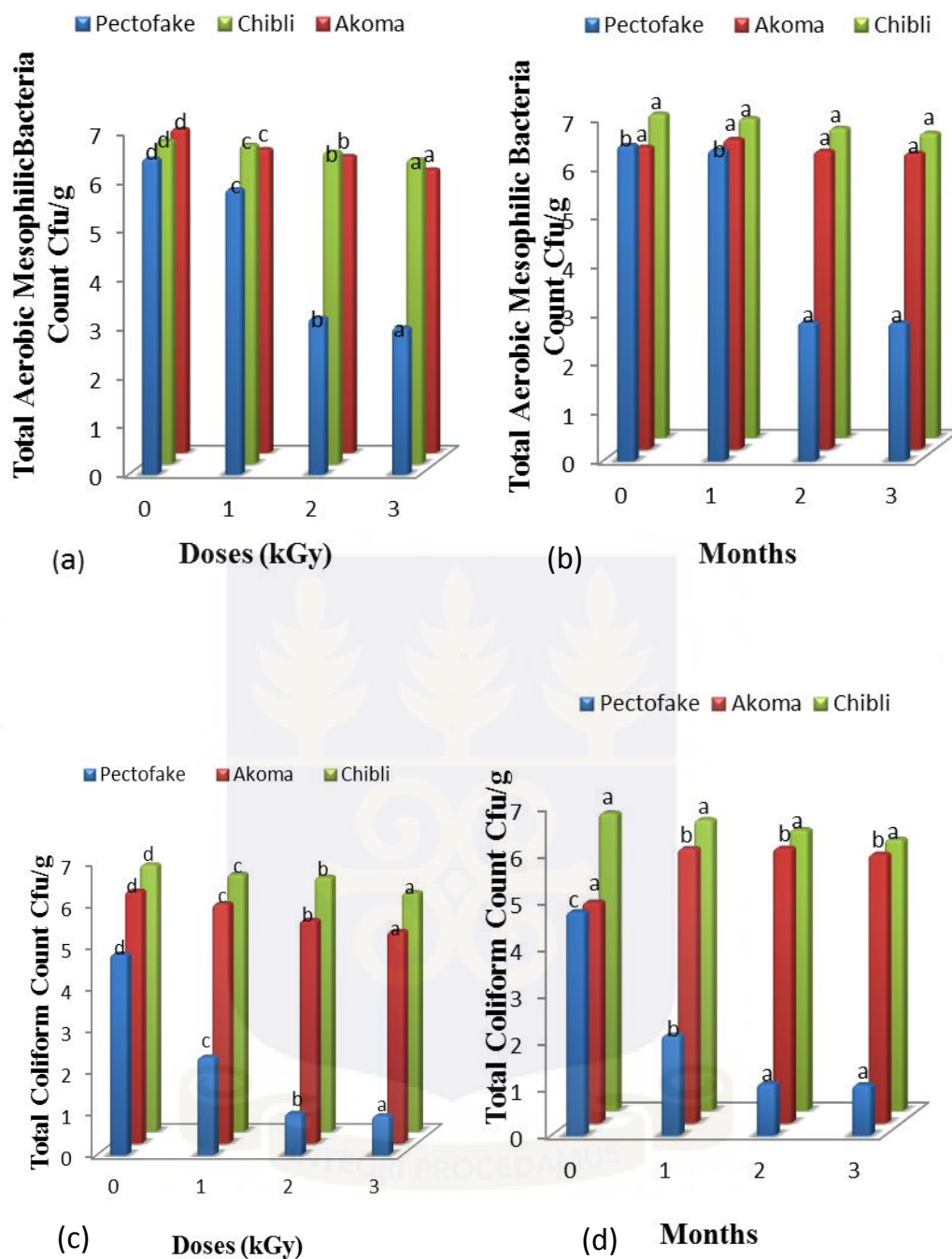


Fig. 4.1(a) Effect of gamma radiation on the Total Aerobic Mesophilic Bacteria count (log₁₀ CfU/g) in solar dried tomato powder **(b)** Effect of storage on the Total Aerobic Mesophilic Bacteria count (log₁₀ CfU/g) of solar dried tomato powder **(c)** Effect of gamma radiation on the Total Coliform Count (log₁₀ CfU/g) in solar dried tomato powder **(d)** Effect of storage on the Total Coliform Count (log₁₀ CfU/g) in solar dried tomato powder.

LSD: means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

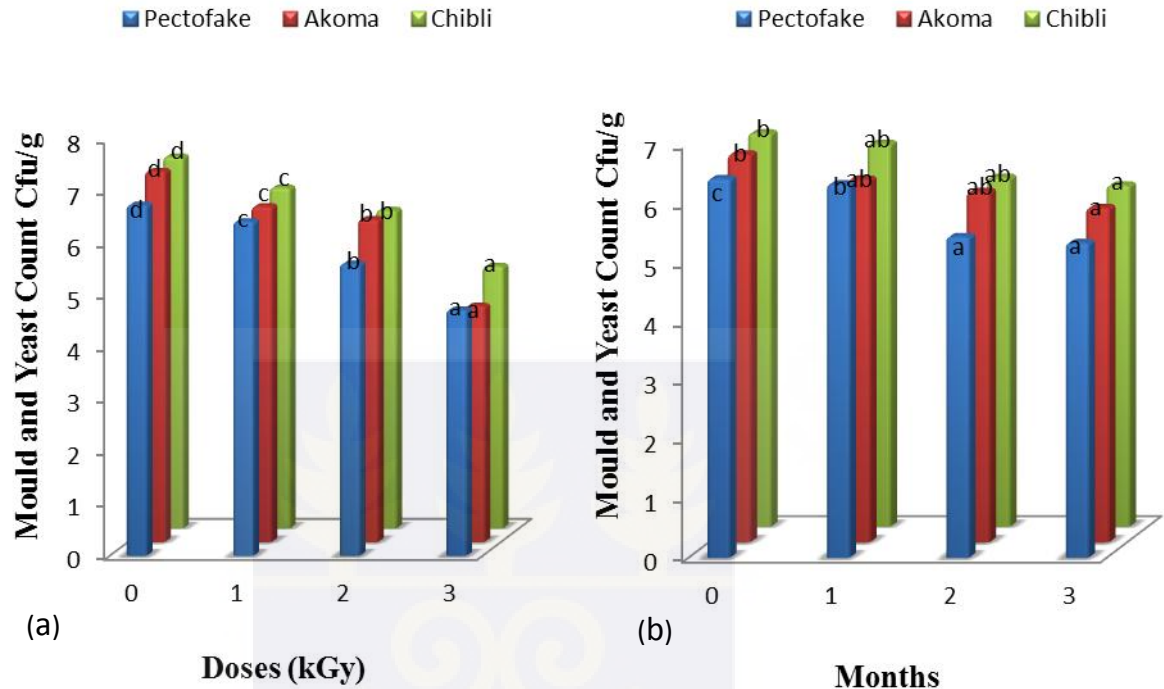


Fig. 4.2 (a) Effect of gamma radiation on the Mould and Yeast Count (log₁₀ CfU/g) in solar dried tomato powder **(b)** Effect of storage on the Mould and Yeast Count (log₁₀ CfU/g) in solar dried tomato powder

LSD: means with the different letters (within the same variety) are significantly different (p<0.05) from each other for each month and dose (column)

4.5.4 Comparison between solar dried and freeze dried Akoma

4.5.4.1 Effect of gamma radiation and storage on the Total Aerobic Mesophilic Bacteria count (TAMB) (log₁₀ CfU/g) in solar dried and freeze dried tomato powder

Total aerobic mesophilic bacteria counts in tomato powders after irradiation and storage are shown in Table 4.2 and Fig 4.3 (a) and (b). Significant differences (p<0.05) were

observed within and between the drying methods, doses, months and all their interactions (Appendix 3.10). The TAMB in the irradiated powders varied between 0.00 and 6.77 (\log_{10} Cfug) (Table 4.2). Solar dried Akoma recorded higher TAMB values ranging from 5.82 (\log_{10} Cfug) at 3 kGy in month 2 to 6.77 (\log_{10} Cfug) at 0 kGy in month 0 while the freeze dried Akoma varied between 0.00 (\log_{10} Cfug) at 2 and 3 kGy in month 0 and 3 kGy in the second month. TAMB reduced significantly ($p < 0.05$) as radiation dose increased in both drying methods (Fig 4.3a) however the higher moisture content of freeze dried powder made radiation more effective. Total aerobic mesophilic bacteria counts in control and irradiated solar dried powder were not significantly different ($p > 0.05$) while a sinusoidal trend was noticed in the freeze dried powder as storage months increased (Fig 4.3b, Appendices 3.11 and 3.12).

4.5.4.2 Effect of gamma radiation and storage on the Total Coliform Count (TCC) (\log_{10} Cfug) in solar dried and freeze dried tomato powder

Total coliform counts (TCC) in the tomato powders after irradiation and storage are shown in Table 4.2 and Fig. 4.3 (c) and (d). There were significant differences ($p < 0.05$) between and within all the factors and their interactions (Appendix 3.13). TCC in the powders ranged between 0.00 and 6.03 (\log_{10} Cfug) (Table 4.2). The freeze dried powder recorded no TCC at all doses in month 0 however in the first month, TCC of 3.33 (\log_{10} Cfug) was recorded at 0 kGy; and 4.0 and 3.36 (\log_{10} Cfug) at 0 and 1kGy in the second month respectively. Solar dried samples observed higher values of between 3.84 (\log_{10} Cfug) at 3 kGy in month 0 and 6.35 (\log_{10} Cfug) at 0 kGy in month 2. Generally

there were significant decreases ($p < 0.05$) in TCC as radiation dose increased in both the solar dried and freeze dried powder (Fig 4.3c). Significant increases ($p < 0.05$) in TCC were observed in freeze dried powders as storage months increased whereas the solar dried powder recorded insignificant increase as storage months increased (Fig 4.3 c and d, Appendices 3.14 and 3.15).

4.5.4.3 Effect of gamma radiation and storage on the total Mould and Yeast Count (MYC) (\log_{10} cfu/g) in solar dried and freeze dried tomato powder

The total mould and yeast count (MYC) in the tomato powders after irradiation and storage are shown in Table 4.2 and Fig. 4.4 (a) and (b). Significant differences ($p < 0.05$) were observed within and between the drying methods, doses, months and their interactions (Appendix 3.16). Moulds and yeast counts in the powders varied between 0.00 and 7.58 (\log_{10} Cfu/g) (Table 4.2). MYC observed in the solar dried powder ranged from 3.95 at 3 kGy in month 3 to 7.58 at 0 kGy in month 3, while the freeze dried powder recorded MYC of 0.00 (\log_{10} Cfu/g) in months 0 and 2. There were significant reductions ($p < 0.05$) in MYC as radiation dose increased (Fig 4.4a). Both irradiation and storage were less effective in reducing MYC in solar dried powder than freeze dried powder but it was still far lower than the level of 7.29 (\log_{10} Cfu/g) of solar dried powder. As storage period increased, a significant increase ($p < 0.05$) in MYC was noticed in the freeze dried powders whereas a decline in MYC was noticed in solar dried powder (Fig 4.4b, Appendices 3.17 and 3.18).

Table 4.2 Effect of gamma radiation and storage on the microbial count (TAMB, TCC, MYC) (\log_{10} cfu/g) of solar and freeze dried tomato powder.

Months	Doses (kGy)	Total Aerobic Mesophilic Bacteria count (Cfu/g)		Total Coliform Count (Cfu/g)		Moulds and Yeast Count (Cfu/g)	
		Variety- Akoma		Variety –Akoma		Variety- Akoma	
		Solar dried	Freeze dried	Solar dried	Freeze dried	Solar dried	Freeze dried
0	0	6.77 ^{eB}	4.99 ^{eA}	6.03 ^{deA}	0.00 ^{bB}	7.04 ^{iA}	0.00 ^{bB}
	1	6.20 ^{bcdB}	2.60 ^{aA}	4.84 ^{bcA}	0.00 ^{bB}	6.92 ^{iA}	0.00 ^{bB}
	2	6.08 ^{abcA}	0.00 ^{hB}	4.15 ^{abA}	0.00 ^{bB}	6.32 ^{fA}	0.00 ^{bB}
	3	5.67 ^{aA}	0.00 ^{hB}	3.84 ^{aA}	0.00 ^{bB}	6.00 ^{dA}	0.00 ^{bB}
1	0	6.59 ^{deB}	5.92 ^{hA}	5.37 ^{cdA}	3.33 ^{aB}	7.29 ^{kA}	5.56 ^{aB}
	1	6.45 ^{cdeB}	5.56 ^{fA}	6.23 ^{deA}	0.00 ^{bB}	6.45 ^{gA}	0.00 ^{bB}
	2	6.30 ^{cdB}	4.10 ^{cA}	5.56 ^{cdeA}	0.00 ^{bB}	6.56 ^{hA}	0.00 ^{bB}
	3	6.04 ^{abcB}	3.42 ^{bA}	5.59 ^{cdeA}	0.00 ^{bB}	4.28 ^{bA}	0.00 ^{bB}
2	0	6.42 ^{cdeB}	4.90 ^{dA}	6.35 ^{eA}	4.00 ^{aB}	7.58 ^{lA}	0.00 ^{bB}
	1	6.12 ^{bcB}	4.00 ^{cA}	5.95 ^{deA}	3.36 ^{aB}	6.25 ^{eA}	0.00 ^{bB}
	2	6.04 ^{abcB}	3.00 ^{abA}	5.56 ^{cdeA}	0.00 ^{bB}	5.95 ^{cA}	0.00 ^{bB}
	3	5.82 ^{abA}	0.00 ^{hB}	5.59 ^{cdeA}	0.00 ^{bB}	3.95 ^{aA}	0.00 ^{bB}

LSD: means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose (row).

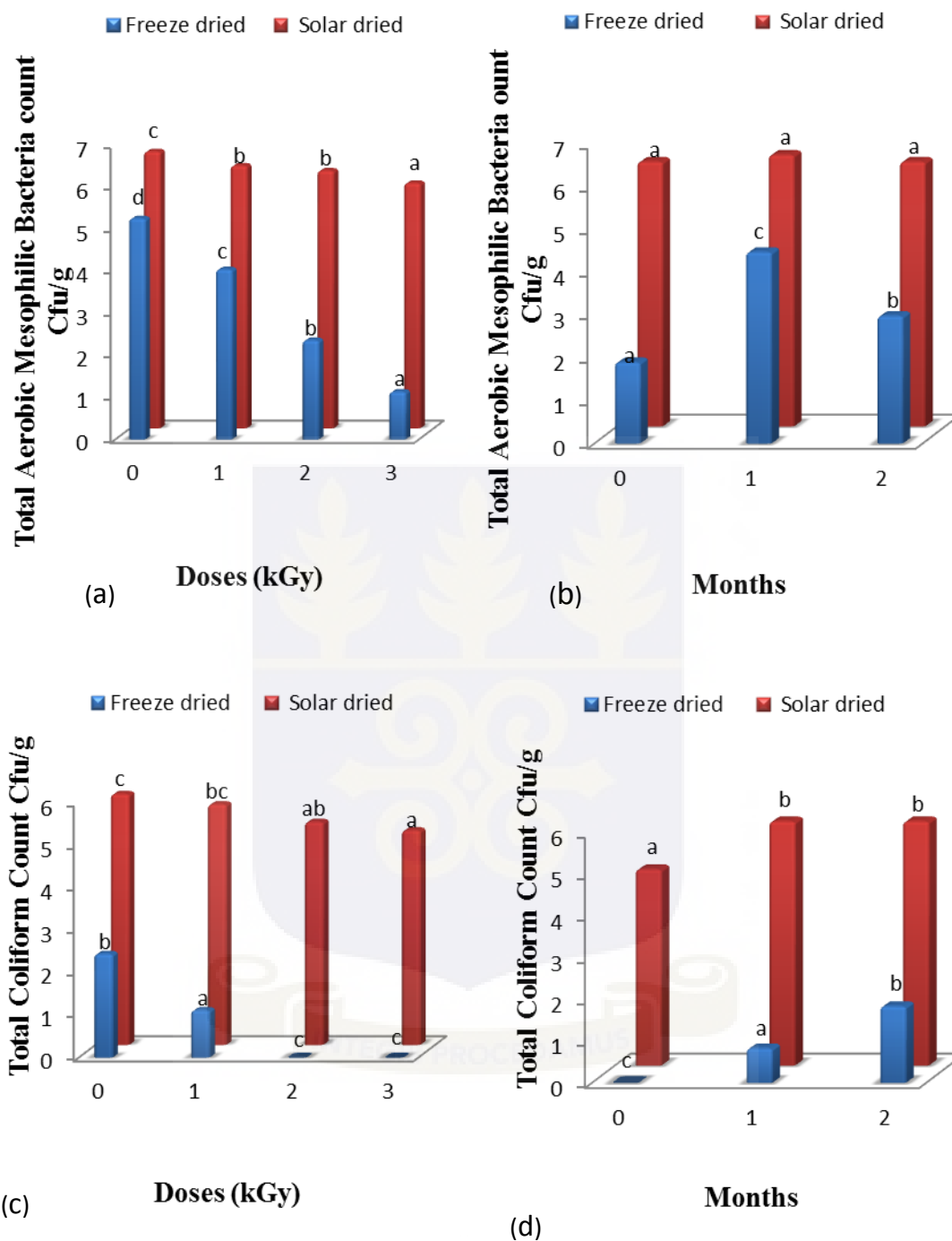


Fig. 4.3 (a) Effect of gamma radiation on the Total Aerobic Mesophilic Bacteria count (log₁₀ cfu/g) in solar and freeze dried tomato powder (b) Effect of storage period on the Total Aerobic Mesophilic Bacteria count (log₁₀ CfU/g) of solar and freeze dried tomato powder (c) Effect of gamma radiation on the Total Coliform Count (log₁₀ CfU/g) in solar and freeze dried tomato powder (d) Effect of storage period on the Total Coliform Count (log₁₀ CfU/g) in solar and freeze dried tomato powder

LSD: means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column).

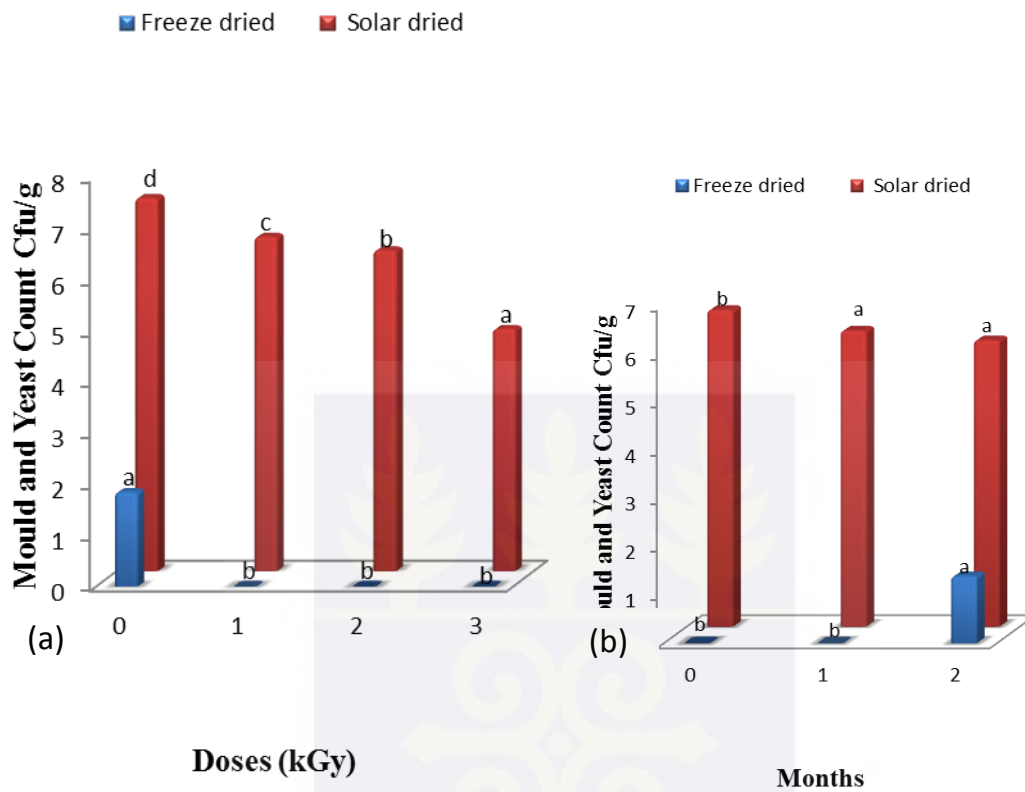


Fig. 4.4 (a) Effect of gamma radiation on the Mould and Yeast Count (\log_{10} Cfug) in solar and freeze dried tomato powder **(b)** Effect of storage period on the Mould and Yeast Count (\log_{10} Cfug) in solar and freeze dried tomato powder

LSD: means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column)

4.5.5 Microbes isolated from the shelf-life study

Table 4.3 shows the microorganisms that were isolated from tomato powder during the study.

Most microbes were common to the varieties. However the solar dried varieties recorded higher number of microbes as compared to the freeze dried. The most common isolates in all samples included *Bacillus subtilis* and *Bacillus licheniformis*.

Table 4.3: Microorganisms isolated from the shelf life study.

Varieties	Isolates
Akoma (Solar dried)	<i>B. subtilis</i> , <i>B. licheniformis</i> , <i>Lactobacillus</i> spp., <i>Enterobacter</i> spp., <i>Aspergillus flavus</i> , <i>Rhizopus</i> spp., <i>Cryptococcus neoformans</i> , <i>Trichoderma</i> spp.
Akoma (Freeze dried)	<i>B. subtilis</i> , <i>B. licheniformis</i> , <i>Rhizopus</i> spp., <i>Trichoderma</i> spp., <i>Cryptococcus neoformans</i> .
Pectofake (Solar dried)	<i>B. subtilis</i> , <i>B. licheniformis</i> , <i>Lactobacillus</i> spp., <i>Aspergillus</i> spp., <i>Aspergillus flavus</i> , <i>Rhizopus</i> spp., <i>Cryptococcus neoformans</i> , <i>Trichoderma</i> spp.,
Chibli (Solar dried)	<i>B. subtilis</i> , <i>B. licheniformis</i> , <i>Lactobacillus</i> spp., <i>Enterobacter</i> spp., <i>Aspergillus flavus</i> , <i>Rhizopus</i> spp., <i>Cryptococcus neoformans</i> , <i>Trichoderma</i> spp., <i>Aspergillus fumigatus</i> .

Table 4.4 Microbes isolated in the powders after radiation treatment

Microbes	Akoma Solar Dried				Pectofake solar dried				Chibli Solar Dried				Akoma Freeze Dried			
	Dose (kGy)				Dose (kGy)				Dose (kGy)				Dose (kGy)			
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
<i>Lactobacillus spp</i>	-	-	-	-	+	-	-	-	+	+	+	+	+	-	-	-
<i>Enterobacter spp</i>	+	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
<i>B. licheniformis</i>	-	+	-	-	+	+	+	+	+	+	-	-	+	+	-	-
<i>B. subtilis</i>	+	+	-	-	+	-	-	-	+	+	-	-	+	-	-	-
<i>Rhizopus spp</i>	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-
<i>Aspergillus flavus</i>	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-
<i>Aspergillus fumigates</i>	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-
<i>Cryptococcus neoformans</i>	+	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-
<i>Trichoderma spp</i>	-	-	+	+	+	-	-	-	-	-	-	-	+	-	-	-

4.6 DISCUSSION

4.6.1 Effect of gamma radiation and storage on the Total Aerobic Mesophilic Bacteria count (TAMB) in solar dried tomato powder

Irradiation had significant effect on the TAMB. Immediately after irradiation, the TAMB count in all three varieties reduced with increasing radiation dose. Three months after storage, no mesophilic bacteria were observed at 2 and 3 kGy in Pectofake. The absence of microbes in Pectofake was due to the high moisture (Buxton, 1987) content leading to effective impact of radiation in the powder. The indirect effect of radiation on the microbes was the result of radiolysis of water (Borrely *et al.*, 1998). Thus gamma radiation was effective in reducing the TAMB counts at all dose levels, with lower counts as radiation dose increased. The packaging material used also denied the microbes of oxygen and moisture for growth and survival. These observations were in consonance with literature (Hussain *et al.*, 2011; Youssef *et al.*, 2011; Song *et al.*, 2007; Prakash *et al.*, 2002). These researchers stated that gamma radiation at 2 kGy and 3 kGy was effective in eliminating microbes hence extending the shelf life of dried fruits as well as juices. Nonetheless in the control, there were reductions in the TAMB counts as storage period increased. Similar observations were made by Idah and Aderibigbe, (2007) who documented that after 3 months of storage of dried tomato in sealed HDPF, there was a reduction in TAMB counts from 5.6.10⁴ cfu/g to 0.76.10⁴ cfu/g. The reduction in TAMB counts was due to the packaging material used to package the powder and the storage environment. The packaging material used denied the organisms of oxygen and moisture

needed for microbial multiplication. Pectofake responded better to radiation than Akoma and Chibli. This was also due to reduced pH and varietal differences (Gowda and Huddar, 2000). Thus Pectofake was highly acidic while Akoma and Chibli were not hence Pectofake had less counts of TAMB since it did not favour the growth of microbes (Prescott *et al.*, 2005; Jawetz *et al.*, 1991).

4.6.2 Effect of gamma radiation on the total coliform count (TCC) in solar dried tomato powder

After irradiation, there were significant reductions in total coliform with increasing radiation dose all three varieties. After storage, reduction in TCC was drastic in Pectofake compared to Akoma and Chibli. There were no counts of total coliforms in Pectofake at all the doses. The TCC in the control had also reduced significantly with storage. Similar observations were made by Ahn *et al.* (2005) who stated that irradiation dose of 1 kGy and above was capable of reducing coliform counts in minimally processed Chinese cabbage. This indicates that coliforms were liable to radiation. The absence of TCC in Pectofake at 1, 2 and 3 kGy was in consonance with observations made by Youssef *et al.* (2011), Song *et al.* (2007) and Prakash *et al.* (2002). This was also as a result of the high moisture content in Pectofake; thus radiation was more effective in foods with higher moisture content (Buxton, 1987) and its acidic nature (Prescott *et al.*, 2005; Jawetz *et al.*, 1991) since microbes thrive well in basic pH environments. These researchers reported that in alkaline or neutral pH foods, bacteria are more dominant in spoilage.

4.6.3 Effect of gamma radiation on the mould and yeast count (MYC) in solar dried tomato powder

Mould and yeast are ubiquitous in dried vegetables and fruits. Moulds and yeast count decreased significantly with increasing radiation dose in all varieties. Upon 3 months storage, Pectofake recorded the least values with all the doses; this was followed by Akoma, then Chibli. The significant reduction in MYC as radiation dose increased was in accordance with previous studies. Prakash *et al.* (2002) documented that radiation dose of 3.7 kGy was effective in reducing mould and yeast counts in diced tomato to no detectable counts. Youssef *et al.* (2011) documented that radiation dose of 4.5 kGy was effective in destroying moulds and yeast in tomato juice. Fan *et al.* (2003) also detected that Cilantro irradiated at 3.0 kGy decayed during storage and stated that fungi are more resistant to radiation than vegetative bacteria. Hence radiation doses of 3.0 and 4.5 kGy were enough to reduce the number of moulds and yeast counts in tomato powder to acceptable levels. This implies that an increase in radiation dose up to 4.5 kGy would be effective in reducing moulds and yeast to undetectable numbers.

It can be well thought out that the decrease in microbial population in the irradiated tomato powder was as a result of the post-irradiation effects where the surviving cells that had been damaged by irradiation were gradually inactivated, thus not adapting to the surrounding environment during a storage (Byun *et al.* , 2001). The advantageous effect of radiation processing on reducing the number of viable cells in dried foods is accredited to the direct effect of radiations. The DNA present in the cell of microbes is the point of target when radiations interact with microorganisms. As radiations knock the DNA, the hydrogen bonds responsible for the double helix structure of DNA are broken. The

breaking of hydrogen bonds favours the breaking of the double helical structure of DNA hence renders the DNA unable to replicate resulting in death of the cell (Egae *et al.*, 2007; Swailam *et al.*, 2007; Palekar *et al.*, 2004).

4.6.4 Comparison between solar dried and freeze dried tomato powder

Irradiation had a significant effect in reducing the TAMB in the freeze dried and solar dried tomato powders during storage. Immediately after irradiation, no aerobic mesophilic bacteria were counted in the freeze dried powder whilst counts were recorded in 2 and 3 kGy in the solar dried powder. The absence of TAMB in freeze dried samples was due to radiation being more effective in foods with high moisture contents. Thus radiation has an indirect effect on water, resulting in the formation of radiolytic products which lead to indirect effect (Borrely *et al.*, 1998) of radiation on the freeze dried powder. This observation was related to previous study (Prakash *et al.* (2002) and Prakash *et al.* (2000) who observed a reduction in TAMB after irradiation at 3.07 kGy.

After storage, solar and freeze dried powders recorded significant reductions in TAMB with increasing radiation dose. At 3 kGy, no aerobic mesophilic bacteria were obtained in the freeze dried sample whereas lower values were recorded in the solar dried sample. This observation was similar to previous study (Hussain *et al.*, 2011; Youssef *et al.*, 2011; Song *et al.*, 2007; Prakash *et al.*, 2002). These workers stated that gamma radiation of 2 kGy and 3 kGy were effective in eliminating microorganisms hence extending the shelf life of dried fruits as well as juices.

Irradiation had a significant effect on the TCC in the solar and freeze dried samples. As radiation dose increased, TCC reduced significantly in both drying methods. After storage, there were significant reductions in the total coliform counts as radiation dose increased. The presence of TC in the low dose- treated samples was due to the packaging material (Idah and Aderibigbe, 2007) and the relative humidity in the environment (Hossain and Gottschalk, 2009; Hossain and Bala, 2000). The general reduction of total coliforms in the solar dried samples and their absence in the freeze dried powder at 2 and 3 kGy conforms to literature (Youssef *et al.*, 2011; Song *et al.*, 2007; Ahn *et al.*, 2005). They documented that irradiation doses of 1 kGy and above were capable of reducing coliforms counts in minimally processed fruits and vegetables.

Gamma radiations were effective in eliminating mould and yeast in solar and freeze dried tomato powder. Upon irradiation, significant reductions in MYC were recorded as radiation dose increased in the solar dried sample. In the freeze dried powder, the control and irradiated samples did not record any values for MYC. This was due to the difference in drying methods. The solar dried samples were exposed to the environment during drying while the freeze dried samples were not. The freeze dryer did not permit the entry or exit of air during drying hence very little environmental interaction.

After storage, no moulds and yeast were recorded in the freeze dried powder. The solar dried powder recorded a significant decrease in MYC in all treated samples; the control however recorded a significant increase in mould and yeast. The results obtained in this study were in accordance with Prakash *et al.* (2002) and Song *et al.* (2007). The reduction in microbial population was attributable to the post-irradiation effect where the surviving

cells that had been damaged by an irradiation were gradually inactivated, hence not adapting to the surrounding environment during the storage (Byun *et al.*, 2001).

The high microbial counts observed in the solar dried samples were due to environmental contamination during drying. The freeze dried samples recorded few microbes due to little interaction with the environment. The pH of the freeze dried samples were lower hence highly acidic and did not support microbial growth and survival while the solar dried samples were slightly acidic hence supported the survival of microbes (Prescott *et al.*, 2005; Jawetz *et al.*, 1991).

4.6.5. Effect of gamma radiation on the microbial load (different microorganisms) of tomato powder during storage

Out of the 52 samples observed, 7 microorganisms were isolated and identified. These were 3 bacteria and 4 fungi. The bacteria belong to the genera *Bacillus*, *Lactobacillus* and *Enterobacter*. The fungi were of genera *Cryptococcus*, *Rhizopus*, *Trichoderma*, and *Aspergillus*. The microbes found in the solar dried samples are same irrespective of the varieties except *Aspergillus fumigatus*, found only in Chibli. *Aspergillus fumigatus* survives in alkaline medium (Amich *et al.*, 2010) hence its survival in only Chibli. This also implies that some microbes can survive in basic or acidic medium provided it's the same product. At each dose, gamma radiation was effective in reducing and destroying microorganisms.

Organisms such as *Bacillus spp* produce spores which can cause infection of the eye, respiratory tract, septicemia, endocarditis, wounds and gangrenous infections (Logan,

1988). *Aspergillus spp.* *Cryptococcus spp.* and *Rhizopus spp.* also produce spores that cause cough, fever, lung nodules, skin infections, invasive disease in the eyes, heart and brain (Chen *et al.*, 2003, Baron, 1994



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CHAPTER FIVE

5.0 EFFECT OF GAMMA RADIATION ON SOME PHYTOCHEMICAL PROPERTIES IN DRIED TOMATO POWDER (*Solanum Lycopersicon L.*) POWDER

5.1 INTRODUCTION

Increasing interest in nutrition, fitness and beauty consciousness has enhanced concerns over a healthy diet. Fruits and vegetables have assumed the status of ‘functional’ foods, capable of providing additional health benefits, such as prevention or delaying onset of chronic diseases, as well as meeting basic nutritional requirements. Appropriate intake of a variety of fruits and vegetables ensures sufficient supply of nutrients and phytochemicals such as carotenoids. Low consumption of fruits and vegetables is among the top ten risk factors resulting in the global mortality. Annually, 2.7 million lives could be saved with sufficient consumption of various kinds of fruits and vegetables (WHO, 2003). Currently, food scientists have collaborated with nutrition researchers to develop plant-based functional foods to promote healthy eating habits. Carotenoids from fruits and vegetables have attracted a great deal of attention, mainly focused on the analysis of geometric carotenoid isomers as well as for their functional properties, health benefits and prevention of several major chronic diseases (Shahidi, 2009; Young *et al.*, 2008; Cooper, 2004).

Lycopene has been extensively studied over the past 10 years because of its potent antioxidant activity and medical evidence that dietary intake can reduce the incidence

of cardiovascular diseases and some cancers (Collins *et al.*, 2006). The quenching constant of lycopene was found to be more than double that of β -carotene and 10 times more than that of α -tocopherol, which makes its presence in the diet of considerable interest (Di Mascio *et al.*, 1989).

Beta-carotene is one of a number of naturally occurring compounds called carotenoids. Beta-carotene is the only carotene that can be converted into vitamin A by the body. Vitamin A is crucial to one's health, playing an important role in vision, bone growth, reproduction, and cell division. Beta Carotene is also of significant importance since it has significant effect on protecting low density lipoproteins (LDL) against oxidation (Romanchik *et al.*, 1997).

Lutein is a unique dihydroxy-carotenoid (or xanthophyll) present in many plants consumed in the human diet. In humans, lutein is believed to function: as a filter of high energy blue light and as an antioxidant that quenches photo-induced free radicals and reactive oxygen species (ROS). Epidemiologic evidence suggests that lutein consumption is inversely related to eye diseases such as age-related macular degeneration (AMD) and cataracts (Shao, 2001). With increasing interest and awareness of the health benefits of these carotenoids, its stability during food processing and storage has received much attention and research (Tonucci *et al.*, 1995; Tavares and Rodriguez Amaya, 1994).

The objectives of the study were to determine the:

- i. total carotenoids in the irradiated and unirradiated tomato powder.
- ii. lycopene content in irradiated and unirradiated powdered tomato samples.
- iii. quantity of β -carotene and lutein content in irradiated and unirradiated powdered samples of tomato.

5.2 MATERIALS AND METHODS

5.2.1 Sample Collection and Preparation

Sixty (60) kg each of fresh and matured Akoma, Pectofake and Chibli varieties of tomato (*Solanum lycopersicon* L.) fruits were purchased from Akomadan in the Offinso North District of the Ashanti Region of Ghana and transported in plastic crates to the laboratory. This location was chosen because it is a major producing area of tomato for the local market. Each variety was sorted to eliminate the injured and damaged fruits before work commenced. The samples were washed in brine and rinsed in distilled water. They were then divided into groups for solar and freeze drying. For the solar drying samples, the fruits were cut into two, seeds removed and each half was further chopped into four with an alcohol sterilized stainless knife to aid drying. The chopped tomatoes were then arranged on aluminium sheets. The stainless steel knife and aluminium sheets were sterilized with alcohol before use. Drying was done for six days in a Solar dryer (2.78 x 5.45 x 16.46m) after which the dried samples were ground into powder with cleaned Philips blender (Pengisar HR 2021 model) with stainless steel blades.

Samples for freeze drying were similarly prepared. The blended tomatoes were packed into new plain polyethylene bags and kept in a freezer till they were frozen. After freezing, samples were dried in a freeze dryer (Vertis Consul 24 model).

5.2.2 Irradiation of Samples

Thirty (30) grammes of each solar and freeze dried powdered samples were weighed into polyethylene zip lock bags for irradiation and storage. For each dose, samples were bagged in triplicates and each set was further kept in a large zip lock bag for

storage. Samples of the solar and freeze dried tomato powder were then irradiated in air at doses of 0, 1, 2 and 3 kGy at a dose rate of 2.6 kGy/h using Cobalt-60 source at the Gamma Irradiation Facility of the Ghana Atomic Energy Commission. The Lithium fluoride photo-flourescent film (SUNNA Dosimeter System, UK) was used to determine the absorbed dose.

5.2.3 Storage of Tomato Powder

The irradiated tomato powder and their controls were kept in zip lock bags and further stored in a clean box at room temperature ($30\pm 2^{\circ}\text{C}$). Solar dried samples were stored for 90 days whilst freeze dried samples were stored for 60 days. A laboratory thermometer was kept in the box to observe the temperature throughout the storage period.

5.3 Determination of the total carotenoid, lycopene, beta carotene and lutein in irradiated tomato powder

The total carotenoid content in the irradiated and unirradiated tomato powder were determined every month according to the Harvest Plus Handbook on Carotenoid Analysis. A quantity of 0.3000g of the irradiated and unirradiated tomato powder was weighed on a filter paper. The tomato powder was transferred into a mortar and three (3) g of celite were added to prevent oxidation and to enhance the grinding. Fifty (50) mL of cold acetone (acetone refrigerated for about 2 hours) were added to the powder in the mortar and ground. The mixture was filtered by suction through a Buchner funnel with filter paper. The mortar, pestle and residue were washed with small amounts of acetone and filtered through the funnel. The extraction and filtration was repeated until a colourless residue was obtained.

Petroleum ether (PE) (25mL) was put in a 500 mL separating funnel with teflon-stop-cock. The acetone extract was carefully poured unto the PE. Distilled water (about 300 mL) was slowly added along the walls of the funnel. To avoid the formation of an emulsion, the mixture was devoid of shaking. The two phases were then separated and the lower aqueous phase was discarded. The mixture was washed with distilled water along the walls of the funnel for four times to remove the residual acetone. At the end of the last washing, the lower phase was discarded as completely as possible without discarding any of the upper phase. The PE phase was collected by passing the solution through a small funnel containing fifteen (15) gm anhydrous sodium sulfate. The separatory funnel was washed with the PE and this was added to the PE solution of carotenoids after passing through the funnel with anhydrous sodium sulfate. All extracts were kept in a freezer at -20°C before HPLC analysis. The lycopene content was quantified using a standard lycopene calibration curve of $R^2=0.9996$ (Bunghez *et al.*, 2011).

Lycopene, beta carotene and lutein contents in the samples were determined by a high performance liquid chromatography (HPLC). The chromatographic condition used for the analysis was Shimadzu HPLC programme containing LC-6A pump, having C18 column (ZORBA XODS 0.25X4.6) reverse phase and connected with SPD-6A UV/VIS detector. Peak identification and quantification was done by “CSW 32 software” for HPLC system. The HPLC was calibrated by running the mobile phase (Acetonitrile, dichloromethane and methanol in the ratio of 70:20:10, respectively) at the rate of two (2) ml per minute. Wave length was fixed at 450nm.

The extract was then concentrated in a rotary evaporator ($T \leq 35^\circ\text{C}$). The sample was dried under liquid nitrogen and immediately before injection, re-dissolved in one (1)mL of solution made up of acetonitrile, dichloromethane and methanol in the ratio of 70:20:10) respectively. Twenty (20) μL of each sample was then injected into the injector (Rehodyne 7154) when it was in the load mode. The solvents acetone, petroleum ether, acetonitrile, methanol and dichloromethane were all HPLC grade. Each sample was analysed in triplicate

The elution times of the standards are as follows:

Beta Carotene	Standard	2.3 ± 0.3 minutes
Lutein	Standard	3.9 ± 0.3 minutes
Lycopene	Standard	$12-20 \pm 0.3$ minutes

After injecting the samples, the assumption was that peaks which eluded at 2.4-2.6 minutes is Beta Carotene, those which eluded at 3.9- 4.1, the peak is lutein and peaks which eluded at 12-20 was assumed to be lycopene. Knowing the concentration of each carotenoid and its area, the carotenoid concentrations were calculated using the formula below (Rodriguez-Amaya and Kimura, 2004):

$$\text{Carotenoid concentration } C_x (\mu\text{g/g}) = \frac{A_x \times C_s \left(\frac{\mu\text{g}}{\text{mL}}\right) \times \text{total volume of extract (mL)}}{A_s \times \text{Sample weight (g)}}$$

Where C_x = concentration of carotenoid X; A_x = peak area of the carotenoid X; C_s = concentration of the standard; A_s = peak area of the standard.

The total carotenoids were determined by reading the absorbance of the extract with a Shimadzu spectrophotometer (Plate 6) at wave length of 450nm. The spectrophotometer was calibrated with petroleum ether after which one (1) ml of the extract was poured into a cuvette and the absorbance for each sample was read in triplicate. The total carotenoid was then calculated using the formula below (Rodriguez-Amaya and Kimura, 2004):

$$\text{Total carotenoid content } (\mu\text{g/g}) = \frac{A \times \text{volume (mL)} \times 10^4}{A^{1\%}_{1\text{cm}} \times \text{sample weight}}$$

Where A = absorbance; volume = total volume of extract; $A^{1\%}_{1\text{cm}}$ = absorption coefficient of 2500 (recommended for mixtures).



Plate 6: A Shimadzu UV-Spectrophotometer

5.4 Data Analysis

Data were analysed using STATGRAPHICS Centurion software and GenStat version 12. Means were separated using the least significant difference and the chosen level of significance was $P < 0.05$. Graphs were drawn using Microsoft Excel on the Microsoft Office 2010 package.



5.5 RESULTS

5.5.1 Effect of gamma radiation and storage on the Total Carotenoid ($\mu\text{g/g}$) content in solar dried tomato powder

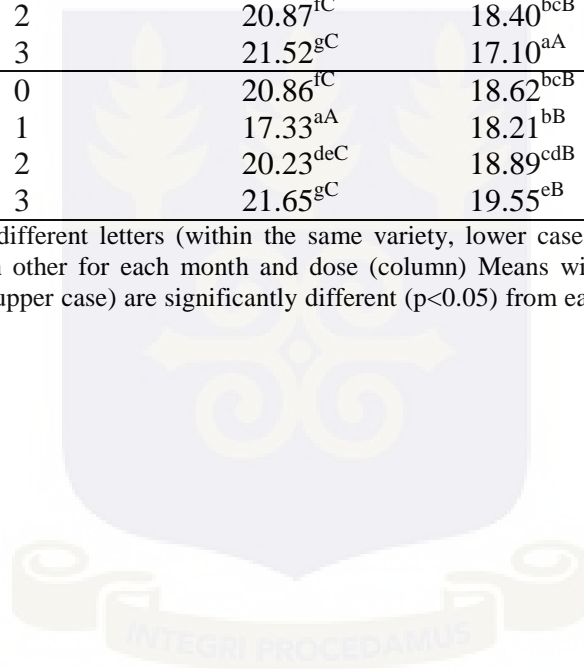
The total carotenoid content in the powdered samples after irradiation and storage are shown in Table 5.1 and Fig 5.1 (a) and (b). Significant differences ($p < 0.05$) were observed within and between all parameters and their interactions (Appendix 2.1) Total carotenoid content in Pectofake during storage varied between $17.33 \mu\text{g/g}$ at 1 kGy in month 3 to $23.55 \mu\text{g/g}$ at 0 kGy in month 2, Akoma also varied from $17.62 \mu\text{g/g}$ at 0 kGy in month 1 to $23.64 \mu\text{g/g}$ in month 1. Chibli recorded carotenoid content between of $17.54 \mu\text{g/g}$ at 2 kGy in months 2 and 3 and $22.55 \mu\text{g/g}$ at 1 kGy in month 0. Akoma however recorded the largest total carotenoid content of $23.64 \mu\text{g/g}$ at 0 kGy in month1 while Chibli recorded the least of $22.55 \mu\text{g/g}$ at 1 kGy in month 0 (Table 5.1). Carotenoid contents in all the varieties fluctuated with increasing radiation dose (Fig 5.1a) and increasing storage months (Fig 5.1 b and Appendices 2.2 and 2.3)



Table 5.1: Effect of gamma radiation and storage on total carotenoid (ug/g) content in solar dried tomato powder

Month	Dose (kGy)	Total Carotenoids		
		Varieties		
		Pectofake	Akoma	Chibli
0	0	19.62 ^{bcC}	18.94 ^{cdB}	17.96 ^{bcdA}
	1	19.08 ^{bA}	22.05 ^{fB}	22.55 ^{iB}
	2	20.08 ^{deA}	23.03 ^{gC}	21.45 ^{hB}
	3	20.46 ^{efA}	23.45 ^{ghC}	21.08 ^{hB}
1	0	19.67 ^{cdB}	23.64 ^{hC}	17.60 ^{bA}
	1	20.88 ^{fB}	21.64 ^{fC}	18.43 ^{deA}
	2	19.43 ^{bcB}	19.22 ^{deB}	17.94 ^{bcdA}
	3	22.30 ^{hB}	22.97 ^{gC}	17.93 ^{bcdA}
2	0	23.55 ^{iC}	17.62 ^{aA}	20.39 ^{gB}
	1	19.15 ^{bcA}	18.57 ^{bcA}	18.62 ^{eA}
	2	20.87 ^{fC}	18.40 ^{bcB}	17.54 ^{bA}
	3	21.52 ^{gC}	17.10 ^{aA}	19.52 ^{fB}
3	0	20.86 ^{fC}	18.62 ^{bcB}	17.79 ^{bcA}
	1	17.33 ^{aA}	18.21 ^{bB}	18.31 ^{cdeB}
	2	20.23 ^{deC}	18.89 ^{cdB}	17.54 ^{bA}
	3	21.65 ^{gC}	19.55 ^{eB}	16.69 ^{aA}

LSD: Means with different letters (within the same variety, lower cases) are significantly different ($p < 0.05$) from each other for each month and dose (column) Means with different letters (between different varieties (upper case) are significantly different ($p < 0.05$) from each other for each month and dose (row)



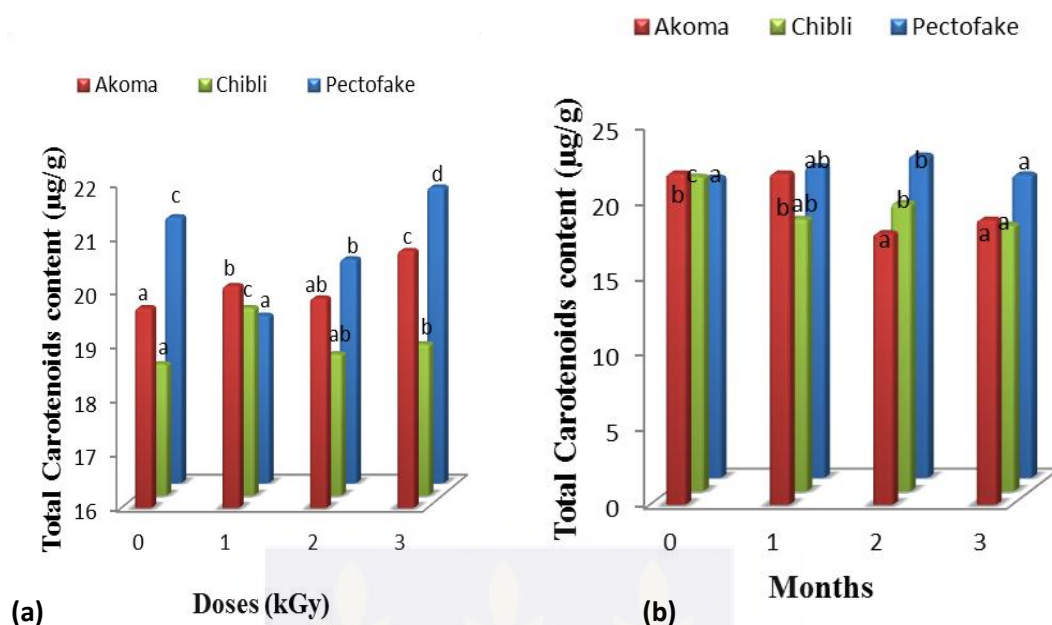


Fig. 5.1 (a) Effect of gamma radiation on the Total Carotenoid content (µg/g) in solar dried tomato powder **(b)** Effect of storage on the Total Carotenoid content (µg/g) in solar dried tomato powder

LSD: Means with different letters (within the same variety, lower cases) are significantly different ($p < 0.05$) from each other for each month and dose (column)

5.5.2 Effect of gamma radiation and storage on the Lycopene content (µg/g) in solar dried tomato powder

Table 5.2 and Fig. 5.2 (a) and (b) show the lycopene content in the tomato powder after irradiation and storage. Significant differences ($p < 0.05$) were observed within and between the varieties, doses, months and all their interactions (Appendices 2.4, 2.5 and 2.6). Amongst the three varieties, the highest lycopene content was observed in Akoma with 8574.6 µg/g at 2 kGy in month 0 while the lowest of 324.5 µg/g was recorded in Pectofake at 2 kGy in month 3. The lycopene content recorded in Pectofake ranged between 324.5 µg/g at 2 kGy in month 3 and 5491.0 µg/g at 2 kGy in the second month. Akoma also varied between 1341.9 µg/g at 2 kGy in month 1 and 8574.6 µg/g at 2 kGy in month 0. Chibli recorded the highest lycopene content of

3888.8 $\mu\text{g/g}$ at 1 kGy in month 3. The three varieties exhibited sinusoidal trends in lycopene content as radiation dose and storage months increased (Fig. 5.2 a and b).

5.5.3 Effect of gamma radiation and storage on the Beta Carotene content ($\mu\text{g/g}$) in solar dried tomato powder

Beta carotene contents in the powdered samples after irradiation and storage are shown in Table 5.2 and Fig. 5.2 (c) and (d). There were significant differences ($p < 0.05$) in all the parameters as well as their interactions (Appendix 2.7). Within the three varieties, Pectofake recorded the largest beta carotene content of 745.49 $\mu\text{g/g}$ at 2 kGy in the first month while Chibli recorded the least of 63.40 $\mu\text{g/g}$ at 3 kGy in month 0. Pectofake recorded beta carotene between 121.53 $\mu\text{g/g}$ at 3kGy in month 0 and 745.49 $\mu\text{g/g}$ at 2 kGy in month 1. Akoma also recorded values varying between 82.60 at 0 kGy in month 1 and 383.09 $\mu\text{g/g}$ at 2 kGy in month 0 and Chibli observed beta carotene contents between 63.40 $\mu\text{g/g}$ at 3 kGy in month 0 and 386.17 $\mu\text{g/g}$ at 0 kGy in month 3. Beta carotene in the three varieties fluctuated as radiation dose and storage period increased (Fig 5.2 (c) and (d) and Appendices 2.8 and 2.9).

5.5.4 Effect of gamma radiation and storage on the Lutein content ($\mu\text{g/g}$) in solar dried tomato powder

Lutein contents in the powdered samples after irradiation and storage are shown in Table 5.2 and Fig 5.3 (a) and (b). Significant differences ($p < 0.05$) were observed in all factors and their interactions (Appendix 2.10). Lutein content in the powdered samples varied from 0.80 $\mu\text{g/g}$ at 0 kGy in month 0 to 9.93 $\mu\text{g/g}$ at 3 kGy in month 2 in Chibli. Pectofake also observed lutein content in the ranged of 6.54 $\mu\text{g/g}$ at 0 kGy

in month 3 and 23.43 $\mu\text{g/g}$ at 1 kGy in month 1. Akoma recorded lutein contents between 2.70 $\mu\text{g/g}$ at 3 kGy in month 1 and 13.27 $\mu\text{g/g}$ at 2 kGy in month 3. Amongst the three varieties, the largest lutein of 23.43 $\mu\text{g/g}$ was recorded in Pectofake at 1 kGy in month 1 whilst the least of 0.80 $\mu\text{g/g}$ was recorded in Chibli at 0 kGy in month 0. Lutein content in the three tomato powders fluctuated with increasing radiation dose and storage months (Fig 5.3 (a) and (b) and Appendices 2.11 and 2.12).



Table 5.2 Effect of gamma radiation and storage on the Lycopene, Beta Carotene and Lutein ($\mu\text{g/g}$) content in solar dried tomato powder

Months	Doses (kGy)	Lycopene			Beta Carotene			Lutein		
		Varieties			Varieties			Varieties		
		Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli	Pectofake	Akoma	Chibli
0	0	2837.8 ^{bB}	4462.6 ^{hC}	1415.0 ^{dA}	278.14 ^{eC}	238.77 ^{fB}	87.79 ^{bA}	12.41 ^{hC}	5.30 ^{eB}	0.80 ^{bA}
	1	3352.8 ^{cB}	7235.7 ^{iC}	1713.7 ^{eA}	287.63 ^{eB}	379.20 ^{iC}	106.35 ^{cA}	12.69 ^{iC}	9.29 ^{jB}	1.12 ^{cA}
	2	4081.9 ^{fB}	8574.6 ^{mC}	736.8 ^{aA}	285.42 ^{eA}	383.09 ^{iB}	288.81 ^{jA}	11.99 ^{gC}	8.06 ^{hB}	1.03 ^{cA}
	3	3309.6 ^{cB}	6694.2 ^{kC}	1405.9 ^{dA}	121.53 ^{aB}	163.38 ^{dC}	63.40 ^{aA}	11.25 ^{fC}	6.69 ^{fB}	1.00 ^{bcA}
1	0	4294.0 ^{gC}	1632.2 ^{bB}	3082.5 ^{jA}	180.89 ^{bB}	82.60 ^{abA}	248.97 ^{iC}	8.32 ^{cC}	8.15 ^{hB}	7.20 ^{jA}
	1	7043.1 ^{jC}	1421.6 ^{aB}	874.1 ^{bA}	349.31 ^{iC}	116.17 ^{cB}	72.01 ^{aA}	23.43 ^{nC}	5.12 ^{eB}	1.36 ^{dA}
	2	3849.4 ^{eB}	1341.9 ^{aA}	1246.7 ^{cA}	745.49 ^{kC}	222.69 ^{eB}	206.89 ^{ghA}	18.89 ^{mC}	3.43 ^{bB}	3.19 ^{fA}
	3	5424.5 ^{iC}	1429.1 ^{aA}	1630.7 ^{eB}	239.03 ^{dC}	87.98 ^{bA}	100.81 ^{cB}	11.10 ^{efB}	2.70 ^{aA}	2.74 ^{eA}
2	0	4689.0 ^{hC}	4300.6 ^{gB}	3330.4 ^{kA}	330.24 ^{hC}	236.69 ^{fB}	149.25 ^{eA}	8.99 ^{dB}	10.2 ^{iC}	0.54 ^{aA}
	1	3266.0 ^{cB}	2480.8 ^{dA}	3617.5 ^{iC}	305.24 ^{fC}	273.44 ^{gB}	194.76 ^{gA}	7.35 ^{bC}	7.031 ^{gB}	5.71 ^{hA}
	2	5491.0 ^{iC}	2924.7 ^{eB}	2221.3 ^{gA}	346.95 ^{iC}	70.85 ^{aA}	146.39 ^{eB}	14.27 ^{iC}	3.74 ^{cA}	7.55 ^{kB}
	3	5481.8 ^{iC}	2363.6 ^{cA}	2844.5 ^{iB}	321.02 ^{ghC}	94.27 ^{bA}	123.86 ^{dB}	13.92 ^{kC}	4.73 ^{dA}	9.93 ^{mB}
3	0	3660.5 ^{dB}	4219.2 ^{gC}	1944.7 ^{fA}	235.51 ^{dA}	238.22 ^{fB}	386.17 ^{iC}	6.54 ^{aB}	9.61 ^{kC}	4.41 ^{gA}
	1	2779.9 ^{bA}	3590.5 ^{fB}	3888.8 ^{mC}	197.23 ^{cA}	229.74 ^{efB}	309.60 ^{kC}	8.19 ^{cA}	8.61 ^{iB}	8.94 ^{iC}
	2	324.5 ^{aA}	5080.5 ^{jC}	2389.7 ^{hB}	411.50 ^{jC}	321.09 ^{hB}	219.48 ^{ghA}	13.36 ^{jB}	13.27 ^{nB}	5.79 ^{hA}
	3	3604.6 ^{dB}	4955.1 ^{iC}	2320.4 ^{hA}	313.63 ^{fgC}	270.46 ^{gB}	167.12 ^{fA}	9.12 ^{deB}	11.94 ^{mC}	6.33 ^{iA}

LSD: means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). Means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose (row)

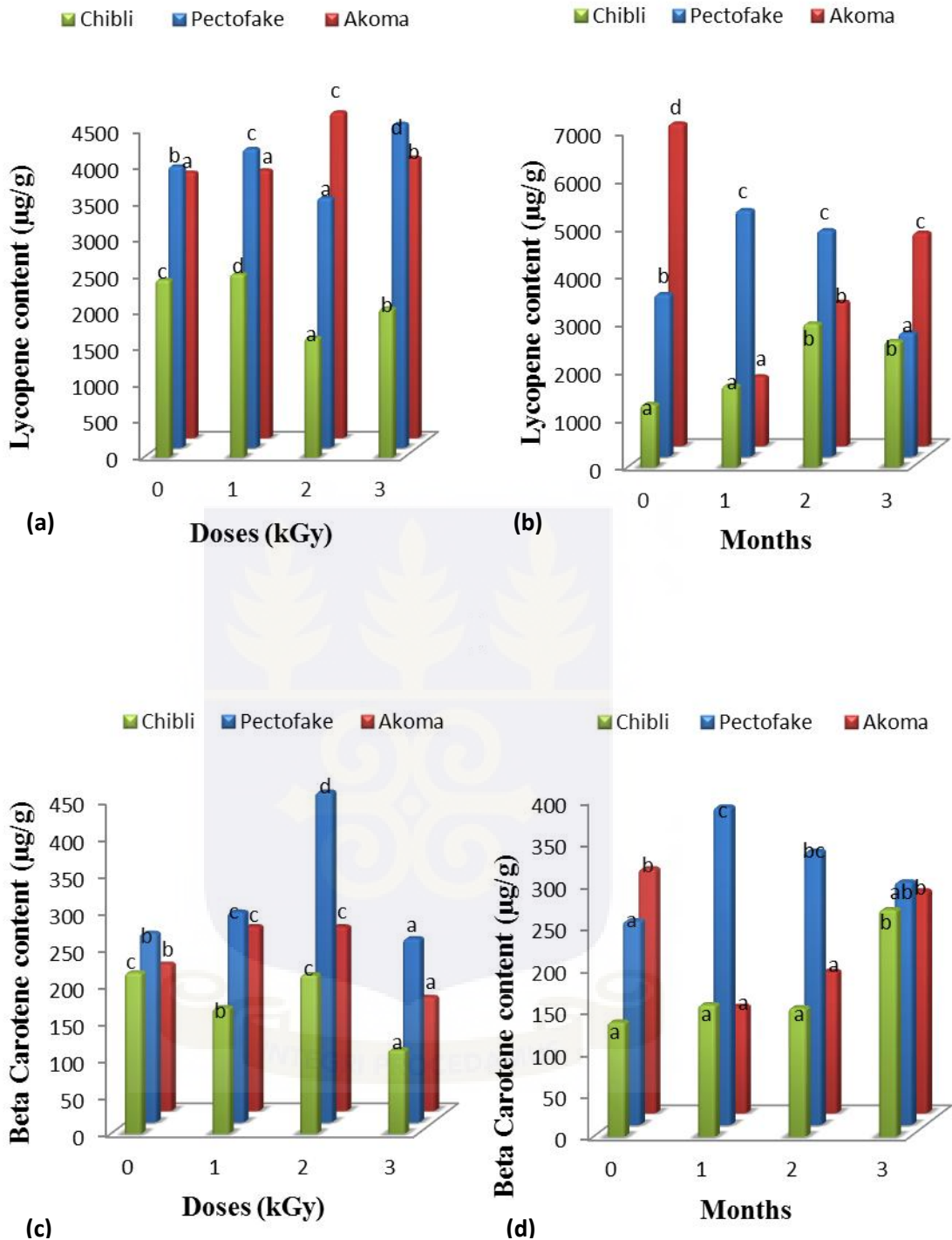


Fig. 5.2 (a) Effect of gamma radiation on the Lycopene content ($\mu\text{g/g}$) in solar dried tomato powder (b) Effect of storage on the Lycopene content ($\mu\text{g/g}$) in solar dried tomato powder (c) Effect of gamma radiation on the Beta Carotene content ($\mu\text{g/g}$) in solar dried tomato powder (d) Effect of storage on the Beta Carotene content ($\mu\text{g/g}$) in solar dried tomato powder

LSD: Means with different letters (within the same variety, lower cases) are significantly different ($p < 0.05$) from each other for each month and dose (column)

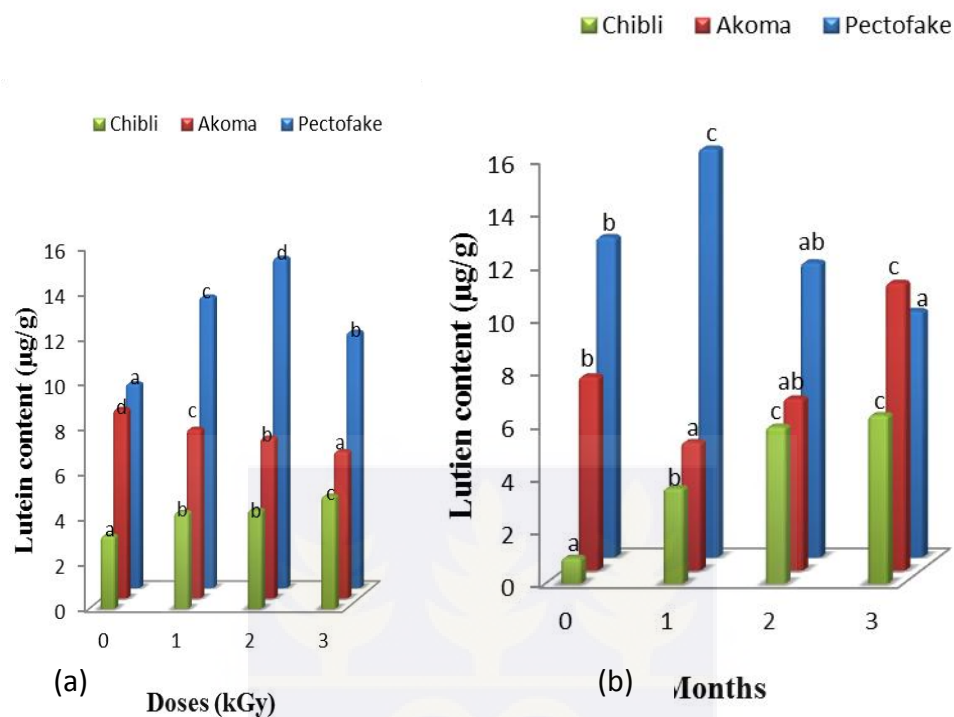


Fig. 5.3 (a) Effect of gamma radiation on the Lutein content ($\mu\text{g/g}$) in solar dried tomato powder **(b)** Effect of storage on the Lutein content ($\mu\text{g/g}$) in solar dried tomato powder

LSD: Means with different letters (within the same variety, lower cases) are significantly different ($p < 0.05$) from each other for each month and dose (column)

5.5.5 Comparison between Solar dried and Freeze dried Akoma

5.5.5.1 Effect of gamma radiation and storage on the Total Carotenoid ($\mu\text{g/g}$) content in solar dried and freeze dried tomato powder

Total carotenoid contents in the solar dried and freeze dried tomato powders after irradiation and storage are shown in Table 5.3 and Fig. 5.4 (a) and (b). Significant differences ($p < 0.05$) were observed in all factors and their interactions (Appendix 2.13) Solar dried Akoma recorded a larger total carotenoid content of $23.64 \mu\text{g/g}$ at 0 kGy in month 1 compared to $20.64 \mu\text{g/g}$ at 1 kGy the same month in freeze dried Akoma. The solar dried samples recorded total carotenoids between $17.10 \mu\text{g/g}$ at 3 kGy in month 2 and $23.64 \mu\text{g/g}$ at 0 kGy in month 1. Total carotenoid content in the freeze dried samples varied from $14.80 \mu\text{g/g}$ at 2 kGy in month 0 to $20.46 \mu\text{g/g}$ at 1 kGy in month 1). The total carotenoid content in the solar dried and freeze dried powder exhibited sinusoidal trends with increasing radiation dose (Fig 5.4 a). A gradual decline in total carotenoid was observed as storage months increased was observed (Fig. 5.4 (b) and Appendices 2.14 and 2.15).

5.5.5.2 Effect of gamma radiation and storage on the Lycopene content ($\mu\text{g/g}$) content in solar and freeze dried tomato powder

Table 5.3 and Fig 5.4 (c) and (d) show the lycopene contents in the solar dried and freeze dried tomato powder after irradiation and storage. Significant differences ($p < 0.05$) were observed in all the parameters and their interactions (Appendix 2.16). Lycopene content in solar dried sample varied between $1342.0 \mu\text{g/g}$ at 2 kGy in month 1 and $8575.0 \mu\text{g/g}$ at 2 kGy in month 0. Freeze dried samples recorded

lycopene contents ranging between 964.0 $\mu\text{g/g}$ in the control in month 0 and 4062 $\mu\text{g/g}$ at 1 kGy in the first month. Solar dried samples recorded higher lycopene content as compared to freeze dried samples. The lycopene contents fluctuated as radiation dose and storage months increased (Fig. 5.4 (c) and (d), and Appendices 2.17 and 2.18).

5.5.5.3 Effect of gamma radiation and storage on the Beta Carotene content $\mu\text{g/g}$ content in solar and freeze dried tomato powder

Beta carotene content in the solar dried and freeze dried samples after irradiation and storage is shown in Table 5.3 and Fig. 5.5 (a) and (b). There were significant differences ($p < 0.05$) in the beta carotene content in all the factors and their interactions (Appendix 2.19). Solar dried powder observed a high beta carotene content of 383.09 $\mu\text{g/g}$ at 2 kGy in month 2 compared to 228.04 $\mu\text{g/g}$ at 3 kGy in month 0. Freeze dried powder recorded beta carotene content varying between 46.54 $\mu\text{g/g}$ at 0 kGy in month 0 and 228.04 $\mu\text{g/g}$ at 3 kGy in month 0. The solar dried powder recorded beta carotene content ranging between 70.85 $\mu\text{g/g}$ at 2 kGy in the third month and 383.09 $\mu\text{g/g}$ in month 0. The beta carotene content in the solar dried and freeze dried powders fluctuated as radiation dose and storage months increased (Fig 5.5 (a) and (b) and Appendices 2.20 and 2.21).

5.5.5.4 Effect of gamma radiation and storage on the Lutein content $\mu\text{g/g}$ content in solar dried and freeze dried tomato powder

Lutein content in the solar and freeze dried tomato powder after irradiation and storage is shown in Table 5.3 and Fig. 5.5 (c) and (d). Significant differences ($p < 0.05$)

were observed in all the factors and their interactions (Appendix 2.22). Solar dried powder recorded a higher lutein content of 10.49 $\mu\text{g/g}$ at 0 kGy in month 2 compared to 0.57 $\mu\text{g/g}$ at 1 kGy in month 1 in the freeze dried powder. At 0 kGy in month 2, solar dried powder recorded a high lutein content of 10.49 $\mu\text{g/g}$ as compared to the lutein content of 3.74 $\mu\text{g/g}$ recorded at 2 kGy in the second month. Freeze dried powder recorded lutein content varying between 0.57 $\mu\text{g/g}$ at 1 kGy in month 1 to 7.51 $\mu\text{g/g}$ at 2 kGy in the first month. Lutein content in the freeze dried powder decreased significantly ($p < 0.05$) with increasing radiation dose while the solar dried powder exhibited a sinusoidal trend with increasing radiation dose (Fig. 5.5 (c)). Lutein in the freeze dried powders fluctuated with increasing storage months (Fig. 5.5 (d) and Appendices 2.22 and 2.23).

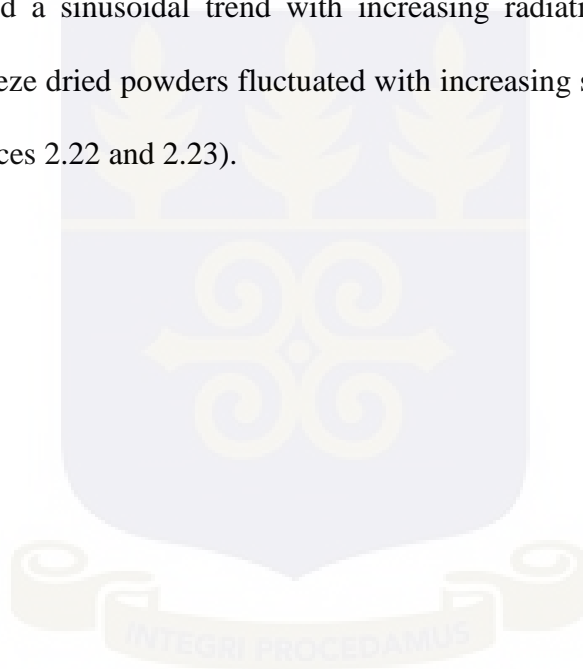


Table 5.3 Effect of gamma radiation and storage on the Total Carotenoid, Lycopene, Beta Carotene and Lutein ($\mu\text{g/g}$) content in solar and freeze dried tomato powder

Months	Doses (kGy)	Total Carotenoids ($\mu\text{g/g}$)		Lycopene ($\mu\text{g/g}$)		Beta Carotene ($\mu\text{g/g}$)		Lutein ($\mu\text{g/g}$)	
		Variety- Akoma		Variety -Akoma		Variety- Akoma		Variety- Akoma	
		Solar dried	Freeze dried	Solar dried	Freeze dried	Solar dried	Freeze dried	Solar dried	Freeze dried
0	0	18.94 ^{cB}	15.40 ^{abA}	4463.00 ^{dB}	964.00 ^{aA}	238.77 ^{fB}	46.54 ^{aA}	5.30 ^{eB}	2.87 ^{dA}
	1	22.05 ^{deB}	20.30 ^{fgA}	7236.00 ^{fB}	2566.00 ^{eA}	379.20 ^{hB}	62.13 ^{bA}	9.29 ^{fB}	5.09 ^{gA}
	2	23.03 ^{efB}	14.80 ^{aA}	8575.00 ^{gB}	1443.00 ^{bA}	383.09 ^{hB}	95.21 ^{cA}	8.06 ^{eB}	2.99 ^{deA}
	3	23.45 ^{fB}	19.13 ^{efA}	6694.00 ^{eB}	3160.00 ^{fA}	163.38 ^{dA}	228.04 ^{fB}	6.69 ^{dB}	1.15 ^{aA}
1	0	23.64 ^{fB}	17.57 ^{cdA}	1632.00 ^{aA}	2216.00 ^{dB}	82.60 ^{abA}	69.86 ^{bA}	8.15 ^{eB}	1.22 ^{bA}
	1	21.64 ^{dB}	20.64 ^{gA}	1422.00 ^{aA}	4062.00 ^{gB}	116.17 ^{cA}	126.89 ^{dB}	5.12 ^{cB}	0.57 ^{aA}
	2	19.22 ^{cB}	14.83 ^{aA}	1342.00 ^{aA}	2942.00 ^{fB}	222.69 ^{eB}	158.65 ^{eA}	3.43 ^{bA}	7.51 ^{hB}
	3	22.97 ^{deB}	18.67 ^{deA}	1429.00 ^{aA}	3122.00 ^{fB}	87.98 ^{bA}	121.12 ^{dB}	2.70 ^{aA}	4.38 ^{fB}
2	0	17.62 ^{abA}	19.04 ^{efB}	4301.00 ^{dB}	1937.00 ^{cA}	236.69 ^{fB}	47.25 ^{aA}	10.49 ^{gB}	2.47 ^{cdA}
	1	18.57 ^{bcB}	16.52 ^{bcA}	2481.00 ^{bB}	1561.00 ^{bA}	273.44 ^{gB}	47.76 ^{aA}	7.03 ^{dB}	2.15 ^{cA}
	2	18.40 ^{abcB}	18.08 ^{deA}	2925.00 ^{cB}	1466.00 ^{bA}	70.85 ^{aA}	75.89 ^{bA}	3.74 ^{bB}	1.53 ^{bA}
	3	17.10 ^{aA}	19.21 ^{efB}	2364.00 ^{bA}	2227.00 ^{deA}	94.27 ^{bB}	69.45 ^{bA}	4.73 ^{cB}	3.51 ^{eA}

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column). Means with different letters (between different varieties) are significantly different ($p < 0.05$) from each other for each month and dose (row).

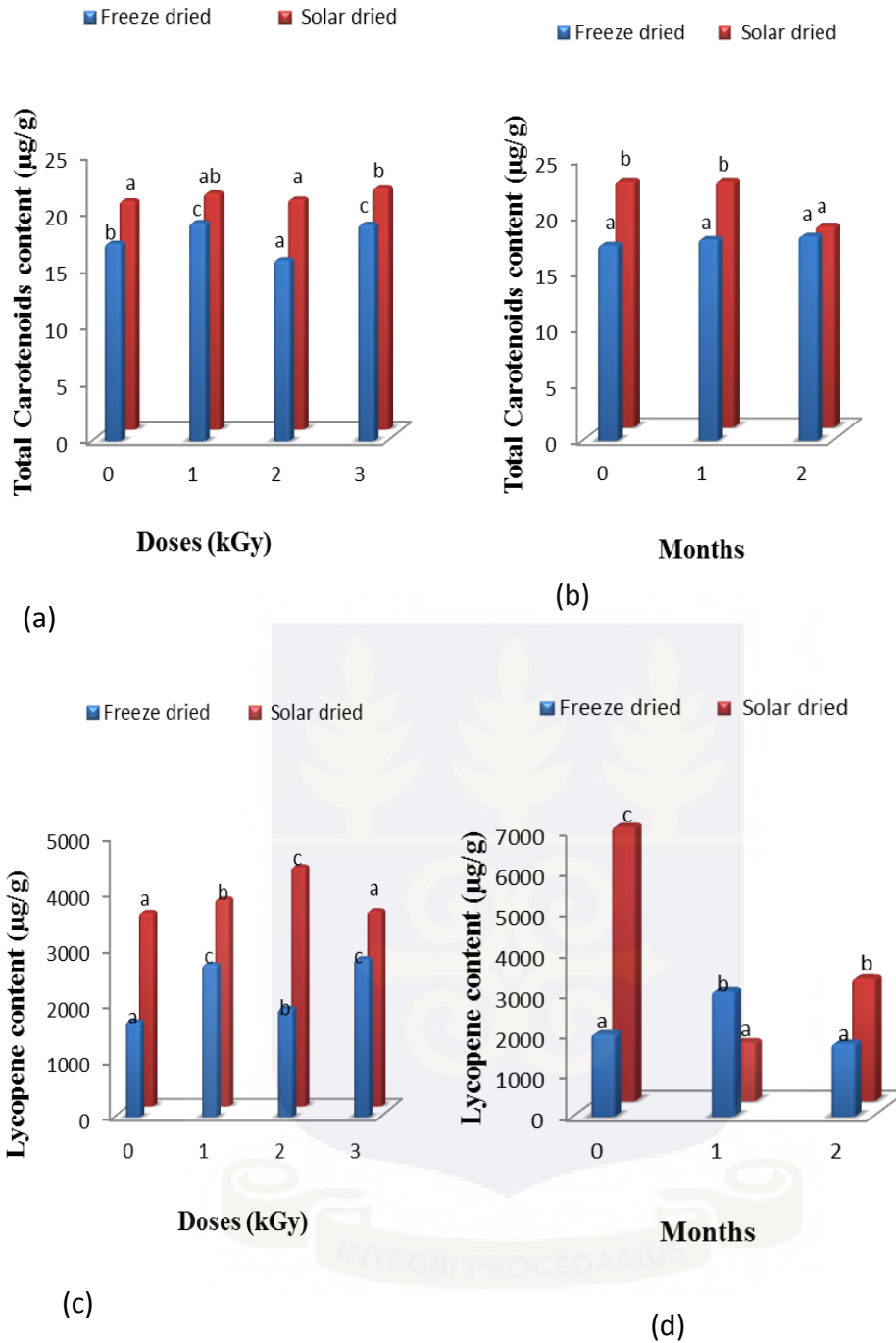


Fig. 5.4 (a) Effect of gamma radiation on the Total Carotenoid content (µg/g) in solar and freeze dried tomato powder (b) Effect of storage on the Total Carotenoid content (µg/g) in solar and freeze dried tomato powder (c) Effect of gamma radiation on the Lycopene content (µg/g) in solar and freeze dried tomato powder (d) Effect of storage on the Lycopene content (µg/g) in solar dried tomato powder.

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column)

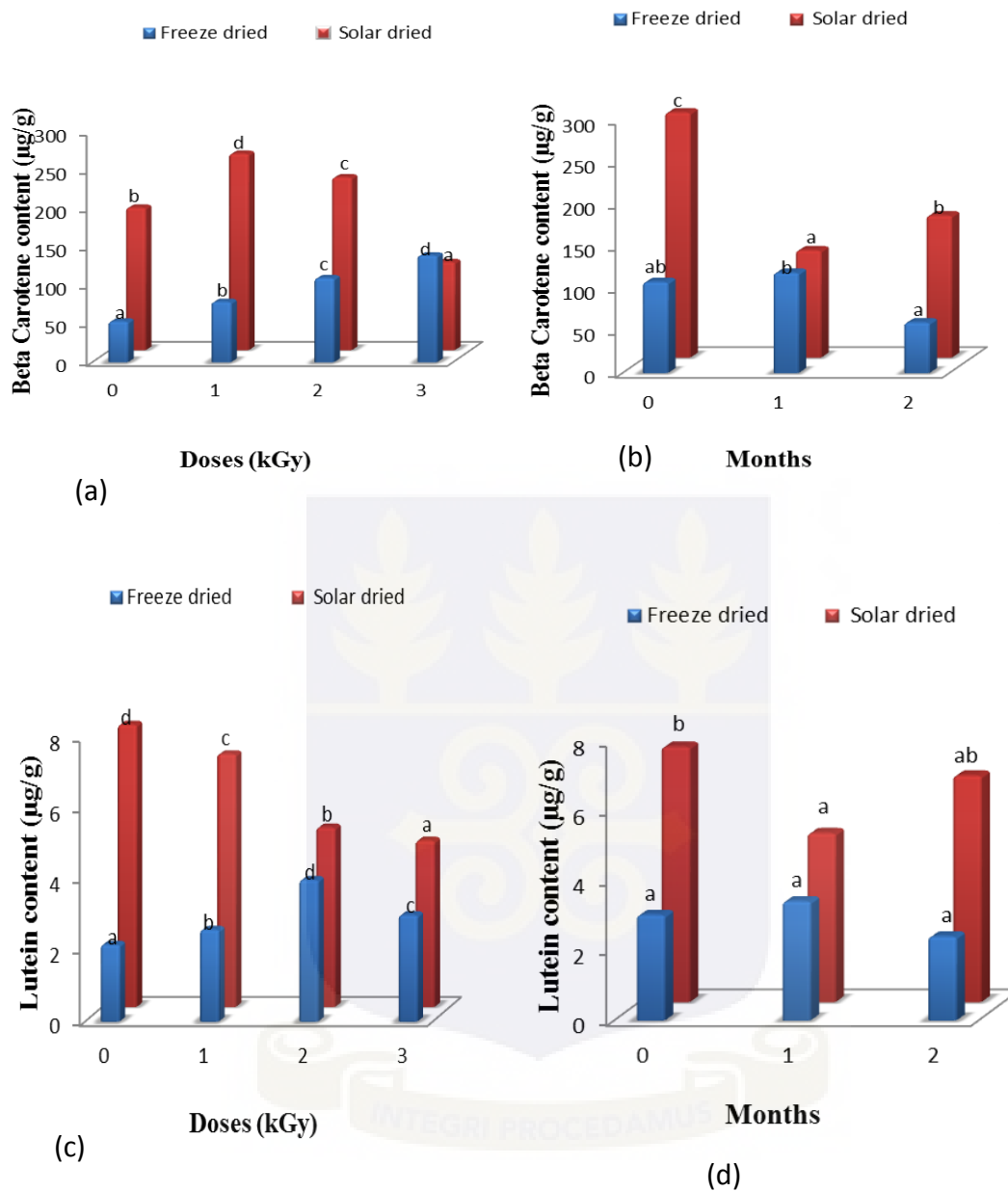


Fig. 5.5 (a) Effect of gamma radiation on the Beta Carotene content (µg/g) in solar and freeze dried tomato powder (b) Effect of storage on the Beta Carotene content (µg/g) in solar and freeze dried tomato powder (c) Effect of gamma radiation on the Lutein content (µg/g) in solar and freeze dried tomato powder (d) Effect of storage on the Lutein content (µg/g) in solar and freeze dried tomato powder

LSD: Means with the different letters (within the same variety) are significantly different ($p < 0.05$) from each other for each month and dose (column)

5.6. DISCUSSION

5.6.1 Effect of gamma radiation and storage on the total carotenoid of solar dried tomato powder

Gamma radiation had significant impact on the total carotenoid content during storage. Immediately after irradiation, the total carotenoid contents in all varieties increased significantly with increasing gamma radiation dose. The increasing levels of total carotenoids with increasing gamma radiation dose was attributed to radiation induced rupture of covalent bonding between carotenoid pigments and other food constituents resulting in easy extractability of pigments (Kamat *et al.*, 2003). Similar observations have been reported by earlier researchers (Lemoine *et al.*, 2007; Fan, 2005; Kamat *et al.*, 2003). Kamat *et al.* (2003) observed an increase in total carotenoid content from 53.91 mg/100g at 0 kGy to 62.43 mg/100g at 3 kGy when fresh coriander leaves were irradiated.

Irradiation followed by three months storage showed that total carotenoid content in Pectofake and Akoma exhibited sinusoidal patterns as radiation dose increased but Chibli recorded a decreasing trend as radiation dose increased. The results obtained by Chibli were in consonance with literature (Urrea *et al.*, 2011; Çinar, 2004; Kamat *et al.*, 2003; Tang and Chen, 2000). These authors noticed that total carotenoid content decreased with storage period and temperature due to oxidation (Ishida *et al.*, 2007; Unlu *et al.*, 2007). This was also due to the isomerisation and re-isomerisation of the carotenoid molecule.

Hussain *et al.* (2011) and Rubio-Diaz *et al.* (2010) observed that carotenoids undergo isomerization during storage hence may be in the *cis* or *trans* form.

Pectofake performed well throughout the storage due to its varietal difference (Abushita *et al.*, 2000; Gowda and Huddar, 2000). They documented that different varieties of the same crop tend to have different characteristics hence the observed phenomenon.

5.6.2 Effect of gamma radiation and storage on the lycopene content in solar dried tomato powder

The lycopene contents in the various tomato powders were significantly affected by gamma radiation treatment. Shortly after irradiation, Pectofake and Akoma observed increasing lycopene content with increasing radiation dose. However at 3 kGy, the lycopene contents decreased significantly. Related observations were made by Chipurura and Muchuweti, (2010) and Villegas *et al.* (1972). These scientists documented that the increase in lycopene content was dependent on the dose administered.

Upon storage, the changes in the lycopene content did not correspond with the radiation dose administered. Results obtained in this study were in accordance with observations made by Ghavidel and Davoodi, (2010); Okanlawon *et al.* (2002); Shi *et al.* (1999); Sablek and Boskovic, (1970). They attributed such observations to isomerisation and re-isomerization of the lycopene molecule during storage. The trends observed in all the three varieties were not in consonance with some earlier studies. Shi *et al.* (2007), Shi and Le Maguer, (2000), Anguelova, (1999) and Villegas *et al.* (1972) documented that

the lycopene content in tomatoes decreases with storage due to oxidation. The behaviours of the tomato powder were due to interaction between the varieties, doses and the storage period.

5.6.3 Effect of gamma radiation and storage on beta carotene in solar dried tomato powder

Beta carotene content in tomato powder was significantly affected by gamma radiation treatment in all the varieties. Akoma and Chibli exhibited fluctuations in carotene content with increasing gamma radiation dose shortly after irradiation. This observation was as a result of the effect of increasing extractability of the carotenoids due to changes in the cellular structure due to the radiation administered (Hussain *et al.*, 2011; Moreno *et al.*, 2007; El-Samahy *et al.*, 2001; Lu *et al.*, 1989). The difference in response to radiation was due to varietal differences (Gowda and Hudda, 2000) as well as interaction between the varieties and doses.

Storage did not significantly affect the beta carotene content. These observations were contrary to earlier studies conducted on beta carotene during storage (Hussain *et al.*, 2011; Mir *et al.*, 2009; Tang and Chen, 2000). These authors documented that beta carotene degrades during storage hence the decreases observed in this study. They attributed this degradation to photosensitivity, isomerisation and epoxide formation.

5.6.4 Effect of gamma radiation and storage on the lutein in solar dried tomato powder

The effect of irradiation on lutein was very significant during storage. Immediately after irradiation, there were increases in lutein content with increasing radiation dose Chibli. Akoma and Pectofake observed an increase in lutein content at 1 kGy (low dose), however beyond 1 kGy (thus 2 and 3 kGy), there was a decline in lutein content. The above observation was in accordance with Zobel, (1997) who documented that phytochemicals may be enhanced upon exposure to radiations. Blessington *et al.* (2007) reported that irradiation dose exerted a limited influence on lutein.

No definite pattern was observed in all varieties as radiation dose increased during storage. The fluctuating trends observed with storage were due to isomerization and re-isomerisation of the lutein molecule (Çinar, 2004). The behaviours shown by the three varieties were, however, contrary to results of some studies. This is because Blessington *et al.* (2007) and Sharma *et al.* (2000) documented that lutein content increased with increasing storage. Moreno *et al.* (2007) explained the increase in lutein content as an increase in the extractability of carotenoids because of changes in the structure of the cells rather than an increase in synthesis by enzymatic action.

The interaction between radiation dose and storage was dependent on varietal differences (Hossain and Gottschalk, 2009), technological factors and the biochemical changes (Abushita *et al.*, 2000) within each variety. Abushita *et al.* (2000) and Simonne *et al.* (2000) also documented that the changes in carotenoid contents of tomatoes was a function of varietal and technological factors and that different tomatoes varied in the

distribution of the various pigments (lycopene, beta carotene and lutein) as well as genotype distribution (Thompson *et al.*, 2000).

5.6.5 Comparison between Solar dried and Freeze dried Akoma

Irradiation and storage had significant effect on total carotenoids content of solar and freeze dried powders. Fluctuations in total carotenoid content were observed in solar and freeze dried powders as radiation dose increased, during storage. Nonetheless solar dried powder recorded higher total carotenoid content than freeze dried powder at all doses throughout storage. Park, (1987) reported a significant reduction in carotene concentration when carrots were freeze dried. This report is in accordance with the observation made in this study. These findings were however contrary to reports made by Marques *et al.* (2007); Marques *et al.*, (2006); Çinar. (2004); Desobry *et al.* (1998), who documented that freeze drying of fruits and vegetables resulted in high retention of nutrients, carotenoids, minerals, original flavour and aroma due to low temperatures and absence of liquid water.

Solar dried samples recorded higher lycopene contents than freeze dried samples, before, during and after the storage period with significant differences between the two. Significant increases were noticed in the solar dried samples whilst freeze dried samples recorded fluctuations as radiation dose increased. Similar observations were made by Chipurura and Muchuweti, (2010) and Villegas *et al.* (1972). These researchers reported that the increase in lycopene content was dependent on the dose administered.

After storage, there were significant reductions in lycopene content in the irradiated samples compared to the control in the solar dried samples. Thus the control had the highest amongst the samples. This was due to degradation of lycopene due to oxidation (Shi *et al.*, 2007; Shi and Le Maguer, 2000; Boskovic, 1979). In the freeze dried samples, there were fluctuations as radiation dosage increased. These fluctuations were as a result of isomerization and re-isomerisation of the lycopene molecule as reported by Ghavidel and Davoodi, (2010), Okanlawon *et al.* (2002) and Sablek and Boskovic, (1970).

Beta carotene was significantly affected after radiation treatment and storage. After the storage period, fluctuations were observed in samples of both drying methods as radiation dose increased. These observations were contrary to earlier reports which revealed that beta carotene decreases with storage (Hussain *et al.*, 2011; Mir *et al.*, 2009; Tang and Chen, 2000). The fluctuations were attributed to isomerization and re-isomerization of the beta carotene molecule.

Lutein content in solar and freeze dried tomato powder were affected after irradiation and storage. After storage, sinusoidal trends were observed as radiation dose increased in both methods. This trend was observed throughout the storage period. This was similar to reports made by Çinar, (2004) who attributed the trend to isomerization and re-isomerisation in the lutein molecule. The control in the solar dried samples however recorded a significant increase in lutein content with storage, thus from 5.30 to 10.49

$\mu\text{g/g}$. This was due to re-isomerization and storage temperature (Rubio-Diaz *et al.*, 2010) since these affected carotenoids during storage

Solar dried samples had better retention of carotenoids compared to freeze dried samples.

This was as a result of the type of dryer used since earlier reports suggested the preference of freeze drying to solar drying.



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CHAPTER SIX

6.0 GENERAL CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The present study sought to reduce postharvest losses associated with tomato (*Solanum lycopersicon* L.) through drying and irradiation. The following conclusions have been drawn based on the objectives

- Solar drying emerged as a more effective method of drying tomatoes in the Akoma variety.
- Solar energy was effective in drying all three varieties of tomatoes.
- The physico-chemical analysis indicated that the method of drying had a significant effect ($p < 0.05$) on each parameter; nonetheless irradiation has little effect on the physicochemical properties of tomato notwithstanding the method of drying used.
- Irradiation had no effect on the moisture content of tomato powder during storage. There were no significant differences ($p < 0.05$) in moisture contents in Akoma and Chibli at the various doses used except Pectofake which showed a significant difference ($p < 0.05$) in moisture content amongst the three varieties. Control and irradiated powder were not significantly different ($p < 0.05$) during storage. The moisture content increased significantly in the control and irradiated powders with

increasing storage period. Therefore irradiation had no effect on the moisture content of solar dried tomato powder.

- Irradiation had no effect on the total soluble solids of the tomato powder during. Unirradiated powder was not significantly different ($p < 0.05$) from the irradiated powder. There was no significant difference ($p > 0.05$) in the total soluble solids between Akoma and Chibli but Pectofake which was significantly different ($p < 0.05$) with a higher TSS.
- Radiation had a significant effect ($p < 0.05$) on the pH. There was no dose dependent effect of gamma radiation on the varieties; however, the pH was inconsistent for the various doses. Storage affected the pH in all varieties; however, Pectofake was the most acidic. As storage months increased, pH reduced significantly in Akoma and Chibli which resulted in increase in total titratable acidity however pH increased significantly ($p < 0.05$) in Pectofake as total titratable acidity reduced with storage.
- Irradiation had a significant effect ($p < 0.05$) on colour but it was not dose dependent in all the varieties. Among the three varieties, Akoma recorded the highest redness, an indication of high lycopene content compared to the other varieties. Storage period significantly ($p < 0.05$) decreased colour in all varieties irrespective of radiation dose.

- Irradiation had no effect on the moisture contents of solar dried and freeze dried tomato powder however freeze dried powder had higher moisture content than the solar dried powder.
- Irradiation had no effect on the TSS of solar dried and freeze dried tomato powder. Freeze dried powder had higher total soluble solids than the solar dried powder. There was a gradual decrease in the TSS of freeze dried powders as storage months increased; however, there was no change in the TSS of solar dried powder.
- Freeze dried powders were more acidic than solar dried powders even though tomatoes to the same variety. The pH reduced significantly ($p < 0.05$) with storage while TTA increased significantly ($p < 0.05$) in the freeze dried and solar dried powders. Irradiation significantly affected the pH but it was not dose dependent.
- Freeze dried powder recorded higher colour values than the solar dried powder hence it looked very attractive and more appealing than the solar dried powder. Irradiation significantly affected the colour but it was not dose dependent. The colour of both powders reduced significantly with storage. The freeze dried samples recorded higher redness but this did not reflect in the lycopene content.
- The packaging material used was suitable for the solar dried powder but not the freeze dried powder.

- (a) Irradiation had a significant effect ($p < 0.05$) on the total aerobic mesophilic bacteria, total coliform counts and moulds and yeast counts at the various doses in all varieties during storage. As gamma radiation dose increased, the counts of microbes reduced significantly ($p < 0.05$). Pectofake was significantly ($p < 0.05$) different from Akoma and Chibli.
- There were significant differences ($p < 0.05$) in microbial counts between the solar dried and freeze dried tomato powder after irradiation and storage. The freeze dried powder recorded lower counts for total aerobic mesophilic bacteria, total coliforms and moulds and yeast compared to the solar dried powder after irradiation and storage.
- Irradiation was effective in extending the shelf life of solar dried and freeze dried tomato powder. The irradiated powders had lower microbial counts compared to the control.
- Irradiation had a significant effect on the total carotenoids, lycopene, beta carotene and lutein although the effects were not dose dependent. There were varietal differences in each case due to distribution of the various pigments (lycopene, beta carotene and lutein) as well as genotype distribution in each variety.
- Gamma radiation had significant impact ($p < 0.05$) on the total carotenoid content during storage. The effect of radiation on the total carotenoid content was not dose dependent in all the varieties. Akoma recorded the highest total carotenoid

content among the 3 varieties used at the commencement of storage but Pectofake recorded the highest at the end of the study period. The total carotenoid content in Akoma and Chibli reduced with storage after irradiation.

- Lycopene was the highest carotenoid in all three tomato varieties. Irradiation significantly ($p < 0.05$) affected the lycopene content of all the solar dried varieties but the effect was not dose dependent. Akoma recorded the highest lycopene content among the three varieties during storage. This was shown in the high redness value in the colour. There were sinusoidal patterns in the lycopene content of Akoma and Chibli after irradiation and storage. There were varietal differences between Akoma, Chibli and Pectofake.
- Irradiation had a significant effect ($p < 0.05$) on the beta carotene content in all the varieties although the effects were not dose dependent. There were fluctuations in the beta carotene content in all three varieties after irradiation and storage; the fluctuations observed in the carotenoid values of the three varieties suggest that varietal differences affected the carotenoid content.
- Irradiation had a significant effect on the lutein content but the effect was not dose dependent in all these varieties. Lutein was the carotenoid with the least concentration among the three carotenoids. The highest lutein content was in Pectofake while the least was in Chibli.
- Solar dried powder recorded higher total carotenoid content compared to the freeze dried powder. Irradiation affected the total carotenoid content in solar dried

powder and freeze dried powders significantly ($p < 0.05$) nonetheless the effects were not dose dependent. The total carotenoid content in the solar dried powder reduced significantly with storage.

- The lycopene contents in the solar dried and freeze dried powder were significantly ($p < 0.05$) affected by irradiation although the effect was not dose dependent. Solar dried powder recorded higher lycopene content as compared to the freeze dried powder. There was a general reduction in the lycopene content with storage in the solar dried and freeze dried powder.
- The beta carotene content in both methods were significantly affected by irradiation however the effect was not dose dependent. Solar dried powder had higher beta carotene content as compared with the freeze dried powder.
- Lutein was the carotenoid with the least value in each drying method. Irradiation had a significant effect on lutein but it was not dose dependent. Solar dried powder recorded higher lutein content as compared with freeze dried powder hence significant differences ($p < 0.05$) between the two methods.
- The two drying method used in drying the same variety of tomato led to the significant difference ($p < 0.05$) in the total carotenoid content, lycopene content, beta carotene content and lutein content.

6.2 RECOMMENDATIONS

Based on the findings of this study and considering future research, the following recommendations would be of significant importance:

- i. Pectofake can be recommended for processing since it has high TSS and longer shelf life.
- ii. Dried tomato powder can be well-preserved by irradiation and can be extended to other vegetable powders
- iii. Further studies on the effect of drying method on some phytochemical (total carotenoids, lycopene, beta carotene and lutein) properties should be conducted.
- iv. Further studies on the effect of irradiation on some phytochemical (total carotenoids, lycopene, beta carotene and lutein) properties should be conducted.
- v. Further studies on the effect of freeze drying on physico-chemical and phytochemical parameters should be conducted.
- vi. Further studies on a suitable packaging material for freeze dried tomato powder should be conducted.

APPENDIX

APPENDIX 1: ANOVA Tables for some physico-chemical properties of tomato powder.

1.1. Analysis of Variance for moisture content (%) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	3.97416	3	1.32472	3.54	0.0175*
B:Varieties	1156.3	2	578.149	1546.27	0.0000*
C:Months	159.807	3	53.2688	142.47	0.0000*
INTERACTIONS					
AB	11.3574	6	1.8929	5.06	0.0001*
AC	8.86012	9	0.984458	2.63	0.0091*
BC	44.4984	6	7.41639	19.84	0.0000*
ABC	11.9062	18	0.661453	1.77	0.0405*
RESIDUAL	35.8943	96	0.373899		
TOTAL (CORR.)	1432.6	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.2. Analysis of Variance for moisture content (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	159.8111	53.2704	142.47	<.001
TREATMENT	11	1171.6632	106.5148	284.86	<.001
MONTHS.TREATMENT	33	65.2710	1.9779	5.29	<.001
Residual	96	35.8962	0.3739		
Total	143	1432.6415			

1.3. Analysis of Variance for moisture content (%)

Source of variation	Df	Sum of Squares	Mean square	v.r.	F pr.
MONTHS	3	159.8111	53.2704	97.67	<.001
VARIETIES	2	1156.3310	578.1655	1060.09	<.001
MONTHS.VARIETIES	6	44.5078	7.4180	13.60	<.001
Residual	132	71.9916	0.5454		
Total	143	1432.6415			

1.4. Analysis of Variance for pH- Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	0.0149028	3	0.00496759	123.33	0.0000*
B:Months	2.21422	3	0.738075	18324.62	0.0000*
C:Varieties	38.5055	2	19.2528	477999.43	0.0000*
INTERACTIONS					
AB	0.031025	9	0.00344722	85.59	0.0000*
AC	0.0910181	6	0.0151697	376.63	0.0000*
BC	1.08376	6	0.180627	4484.53	0.0000*
ABC	0.0897542	18	0.00498634	123.80	0.0000*
RESIDUAL	0.00386667	96	0.0000402778		
TOTAL (CORR.)	42.0341	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.5. Analysis of Variance for pH

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	2.214E+00	7.381E-01	18324.62	<.001
TREATMENT	11	3.861E+01	3.510E+00	87148.06	<.001
MONTHS.TREATMENT	33	1.205E+00	3.650E-02	906.24	<.001
Residual	96	3.867E-03	4.028E-05		
Total	143	4.203E+01			

1.6. Analysis of Variance for pH

Source of variation	Df	Sum of Square	Mean Square	v.r.	F pr.
MONTHS	3	2.214225	0.738075	422.55	<.001
VARIETIES	2	38.505510	19.252755	11022.25	<.001
MONTHS.VARIETIES	6	1.083762	0.180627	103.41	<.001
Residual	132	0.230567	0.001747		
Total	143	42.034064			

1.7. Analysis of Variance for Total Titratable Acidity (%) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	0.000953465	3	0.000317822	1.14	0.3353
B:Months	0.0582314	3	0.0194105	69.87	0.0000*
C:Varieties	1.54672	2	0.773361	2783.96	0.0000*
INTERACTIONS					
AB	0.0124147	9	0.00137941	4.97	0.0000*
AC	0.00334801	6	0.000558002	2.01	0.0719
BC	0.142323	6	0.0237205	85.39	0.0000*
ABC	0.0166582	18	0.000925456	3.33	0.0001*
RESIDUAL	0.026668	96	0.000277792		
TOTAL (CORR.)	1.80732	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.8. Analysis of Variance for Total Titratable Acidity (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	0.0583692	0.0194564	69.92	<.001
TREATMENT	11	1.5527450	0.1411586	507.31	<.001
MONTHS.TREATMENT	33	0.1713414	0.0051922	18.66	<.001
Residual	96	0.0267120	0.0002782		
Total	143	1.8091676			

1.9. Analysis of Variance for Total Titratable Acidity (%)

Source of variation	Df	Sum of Squares	Mean Squares	v.r.	F pr.
MONTHS	3	0.0583692	0.0194564	42.73	<.001
VARIETIES	2	1.5484713	0.7742357	1700.43	<.001
MONTHS.VARIETIES	6	0.1422252	0.0237042	52.06	<.001
Residual	132	0.0601019	0.0004553		
Total	143	1.8091676			

1.10. Analysis of Variance for Total Soluble Solids (%) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	0.114167	3	0.0380556	1.76	0.1607
B:Months	5.10083	3	1.70028	78.47	0.0000*
C:Varieties	10.7467	2	5.37333	248.00	0.0000*
INTERACTIONS					
AB	0.2225	9	0.0247222	1.14	0.3420
AC	0.133333	6	0.0222222	1.03	0.4135
BC	4.78	6	0.796667	36.77	0.0000*
ABC	0.98	18	0.0544444	2.51	0.0021*
RESIDUAL	2.08	96	0.0216667		
TOTAL (CORR.)	24.1575	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.11. Analysis of Variance for Total Soluble Solids (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	5.10083	1.70028	78.47	<.001
TREATMENT	11	10.99417	0.99947	46.13	<.001
MONTHS.TREATMENT	33	5.98250	0.18129	8.37	<.001
Residual	96	2.08000	0.02167		
Total	143	24.15750			

1.12. Analysis of Variance for Total Soluble Solids (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	5.10083	1.70028	63.58	<.001
VARIETIES	2	10.74667	5.37333	200.93	<.001
MONTHS.VARIETIES	6	4.78000	0.79667	29.79	<.001
Residual	132	3.53000	0.02674		
Total	143	24.15750			

1.13. Analysis of Variance for L* - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	9.97631	3	3.32544	5707.55	0.0000*
B:Months	335.893	3	111.964	192167.43	0.0000*
C:Varieties	1939.82	2	969.91	1664684.63	0.0000*
INTERACTIONS					
AB	3.33231	9	0.370256	635.48	0.0000*
AC	17.3043	6	2.88404	4949.97	0.0000*
BC	71.5687	6	11.9281	20472.56	0.0000*
ABC	10.9381	18	0.607673	1042.97	0.0000*
RESIDUAL	0.0559333	96	0.000582639		
TOTAL (CORR.)	2388.89	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.14. Analysis of Variance for a - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	2.24814	3	0.749379	158.90	0.0000*
B:Months	36.6866	3	12.2289	2593.08	0.0000*
C:Varieties	94.8311	2	47.4155	10054.24	0.0000*
INTERACTIONS					
AB	0.762181	9	0.0846867	17.96	0.0000*
AC	4.70916	6	0.784859	166.43	0.0000*
BC	13.7887	6	2.29812	487.31	0.0000*
ABC	2.41933	18	0.134407	28.50	0.0000*
RESIDUAL	0.452733	96	0.00471597		
TOTAL (CORR.)	155.898	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.15. Analysis of Variance for b - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:DOSES	14.3728	3	4.79092	2.12	0.1030
B:MONTHS	408.479	3	136.16	60.19	0.0000*
C:VARIETIES	2053.42	2	1026.71	453.86	0.0000*
INTERACTIONS					
AB	29.922	9	3.32467	1.47	0.1702
AC	15.8536	6	2.64226	1.17	0.3299
BC	125.901	6	20.9835	9.28	0.0000*
ABC	79.9719	18	4.44288	1.96	0.0192*
RESIDUAL	217.168	96	2.26217		
TOTAL (CORR.)	2945.09	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.16. Analysis of Variance for Moisture Content (%) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Drying Methods	2240.86	1	2240.86	17619.40	0.0000*
B:Doses	0.908128	3	0.302709	2.38	0.0812
C:Months	12.2249	2	6.11247	48.06	0.0000*
INTERACTIONS					
AB	0.176188	3	0.0587292	0.46	0.7103
AC	16.2506	2	8.1253	63.89	0.0000*
BC	1.23811	6	0.206352	1.62	0.1614
ABC	0.898799	6	0.1498	1.18	0.3339
RESIDUAL	6.10471	48	0.127181		
TOTAL (CORR.)	2278.66	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.17. Analysis of Variance for Moisture Content (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	12.2253	6.1127	48.03	<.001
TREATMENT	7	2241.9856	320.2837	2516.82	<.001
MONTHS.TREATMENT	14	18.3863	1.3133	10.32	<.001
Residual	48	6.1083	0.1273		
Total	71	2278.7056			

1.18. Analysis of Variance for Moisture Content (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	12.2253	6.1127	43.25	<.001
DRYING METHODS	1	2240.9022	2240.9022	15855.21	<.001
MONTHS.DRYING METHODS	2	16.2500	8.1250	57.49	<.001
Residual	66	9.3281	0.1413		
Total	71	2278.7056			



1.19. Analysis of Variance for pH - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	0.0312375	3	0.0104125	47.75	0.0000*
B:Months	1.20944	2	0.604718	2773.23	0.0000*
C:Drying Methods	51.4267	1	51.4267	235842.20	0.0000*
INTERACTIONS					
AB	0.019875	6	0.0033125	15.19	0.0000*
AC	0.0226264	3	0.00754213	34.59	0.0000*
BC	0.478803	2	0.239401	1097.89	0.0000*
ABC	0.0317528	6	0.00529213	24.27	0.0000*
RESIDUAL	0.0104667	48	0.000218056		
TOTAL (CORR.)	53.2309	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.20. Analysis of Variance for pH

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	1.2094361	0.6047181	2773.23	<.001
TREATMENT	7	51.4805653	7.3543665	33727.03	<.001
MONTHS.TREATMENT	14	0.5304306	0.0378879	173.75	<.001
Residual	48	0.0104667	0.0002181		
Total	71	53.2308986			

1.21. Analysis of Variance for pH

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	1.209436	0.604718	344.19	<.001
DRYING METHODS	1	51.426701	51.426701	29270.53	<.001
MONTHS.DRYING	2	0.478803	0.239401	136.26	<.001

METHODS			
Residual	66	0.115958	0.001757
Total	71	53.230899	

1.22. Analysis of Variance for Total Titratable Acidity (%) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:DOSES	0.0048116	3	0.00160387	23.74	0.0000*
B:Months	0.469787	2	0.234893	3477.04	0.0000*
C:Drying Methods	8.18573	1	8.18573	121170.38	0.0000*
INTERACTIONS					
AB	0.00999969	6	0.00166662	24.67	0.0000*
AC	0.0066386	3	0.00221287	32.76	0.0000*
BC	0.0586942	2	0.0293471	434.41	0.0000*
ABC	0.011484	6	0.001914	28.33	0.0000*
RESIDUAL	0.00324267	48	0.000067555		
TOTAL (CORR.)	8.75039	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.22. Analysis of Variance for Total Titratable Acidity (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	0.46954083	0.23477041	3434.73	<.001
TREATMENT	7	8.19765393	1.17109342	17133.27	<.001
MONTHS.TREATMENT	14	0.08024642	0.00573189	83.86	<.001
Residual	48	0.00328090	0.00006835		
Total	71	8.75072208			

1.23. Analysis of Variance for Total Titratable Acidity (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	0.4695408	0.2347704	427.60	<.001
DRYING METHODS	1	8.1861127	8.1861127	14909.79	<.001
MONTHS.DRYING METHODS	2	0.0588317	0.0294159	53.58	<.001

Residual	66	0.0362368	0.0005490
Total	71	8.7507221	

1.24. Analysis of Variance for Total Soluble Solids (%) - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	0.26	3	0.0866667	1.84	0.1533
B:Months	0.431111	2	0.215556	4.56	0.0153*
C:DryingMethods	82.7756	1	82.7756	1752.89	0.0000*
INTERACTIONS					
AB	0.453333	6	0.0755556	1.60	0.1677
AC	0.295556	3	0.0985185	2.09	0.1144
BC	0.217778	2	0.108889	2.31	0.1106
ABC	0.471111	6	0.0785185	1.66	0.1508
RESIDUAL	2.26667	48	0.0472222		
TOTAL (CORR.)	87.1711	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.25. Analysis of Variance for Total Soluble Solids (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	0.43111	0.21556	4.56	0.015
TREATMENT	7	83.33111	11.90444	252.09	<.001
MONTHS.TREATMENT	14	1.14222	0.08159	1.73	0.081
Residual	48	2.26667	0.04722		
Total	71	87.17111			

1.26. Analysis of Variance for Total Soluble Solids (%)

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	0.43111	0.21556	3.80	0.027
DRYING METHODS	1	82.77556	82.77556	1458.15	<.001
MONTHS.DRYING METHODS	2	0.21778	0.10889	1.92	0.155
Residual	66	3.74667	0.05677		
Total	71	87.17111			

1.27. Analysis of Variance for L* - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:DOSES	24.5342	3	8.17808	12318.44	0.0000*
B:Months	60.5943	2	30.2971	45635.86	0.0000*
C:DryingMethods	0.9522	1	0.9522	1434.28	0.0000*
INTERACTIONS					
AB	15.9842	6	2.66404	4012.78	0.0000*
AC	12.013	3	4.00433	6031.63	0.0000*
BC	19.2151	2	9.60753	14471.59	0.0000*
ABC	7.17965	6	1.19661	1802.42	0.0000*
RESIDUAL	0.0318667	48	0.000663889		
TOTAL (CORR.)	140.505	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

1.28. Analysis of Variance for a* - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	1.03748	3	0.345826	33.83	0.0000*
B:Months	153.792	2	76.8959	7523.13	0.0000*
C:DryingMethods	2036.08	1	2036.08	199200.55	0.0000*
INTERACTIONS					
AB	4.56907	6	0.761511	74.50	0.0000*
AC	5.02556	3	1.67519	163.89	0.0000*
BC	62.6433	2	31.3217	3064.36	0.0000*
ABC	2.47924	6	0.413206	40.43	0.0000*
RESIDUAL	0.490621	48	0.0102213		
TOTAL (CORR.)	2266.12	71			

All F-ratios are based on the residual mean square error.

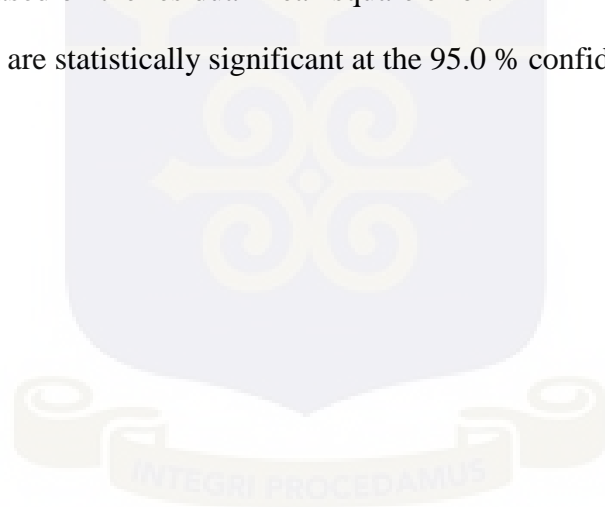
Values marked * are statistically significant at the 95.0 % confidence level.

1.29. Analysis of Variance for b* - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	31.2924	3	10.4308	2.31	0.0878
B:Months	140.229	2	70.1146	15.55	0.0000*
C: Drying Methods	101.057	1	101.057	22.41	0.0000*
INTERACTIONS					
AB	73.8896	6	12.3149	2.73	0.0230*
AC	12.6337	3	4.21123	0.93	0.4316
BC	3.25167	2	1.62583	0.36	0.6991
ABC	34.9529	6	5.82548	1.29	0.2789
RESIDUAL	216.419	48	4.50874		
TOTAL (CORR.)	613.726	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.



Appendix 2: ANOVA Tables for some phytochemical properties of tomato powder

2.1. Analysis of Variance for Total Carotenoids $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Months	82.257	3	27.419	213.16	0.0000*
B:Doses	15.4988	3	5.16627	40.16	0.0000*
C:Varieties	67.9339	2	33.9669	264.07	0.0000*
INTERACTIONS					
AB	81.127	9	9.01411	70.08	0.0000*
AC	157.345	6	26.2241	203.87	0.0000*
BC	37.8479	6	6.30799	49.04	0.0000*
ABC	78.305	18	4.35028	33.82	0.0000*
RESIDUAL	12.3484	96	0.128629		
TOTAL (CORR.)	532.663	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

2.2. Analysis of Variance for Total Carotenoids $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	82.1962	27.3987	213.04	<.001
TREATMENT	11	121.3659	11.0333	85.79	<.001
MONTHS.TREATMENT	33	316.7668	9.5990	74.64	<.001
Residual	96	12.3466	0.1286		
Total	143	532.6756			

2.3. Analysis of Variance for Total Carotenoids $\mu\text{g/g}$

Source of variation	Df	Sum of Square	Mean Square	v.r.	F pr.
MONTHS	3	82.196	27.399	16.06	<.001
VARIETIES	2	67.958	33.979	19.92	<.001
MONTHS.VARIETIES	6	157.308	26.218	15.37	<.001
Residual	132	225.213	1.706		
Total	143	532.676			

2.4. Analysis of Variance for Lycopene $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:DOSES	1.64827E6	3	549422.	150.61	0.0000*
B:MONTHS	2.23995E7	3	7.46651E6	2046.69	0.0000*
C:VARIETIES	1.01133E8	2	5.05665E7	13861.06	0.0000*
INTERACTIONS					
AB	2.51682E7	9	2.79646E6	766.55	0.0000*
AC	1.61145E7	6	2.68574E6	736.20	0.0000*
BC	2.31983E8	6	3.86638E7	10598.35	0.0000*
ABC	6.75069E7	18	3.75038E6	1028.04	0.0000*
RESIDUAL	350217.	96	3648.1		
TOTAL (CORR.)	4.66303E8	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

2.5. Analysis of Variance for Lycopene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Squares	v.r.	F pr.
MONTHS	3	22399472.	7466491.	2046.71	<.001
TREATMENT	11	118895693.	10808699.	2962.87	<.001
MONTHS.TREATMENT	33	324657819.	9838116.	2696.82	<.001
Residual	96	350212.	3648.		
Total	143	466303196.			

2.6. Analysis of Variance for Lycopene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	22399472.	7466491.	8.90	<.001
VARIETIES	2	101132967.	50566484.	60.25	<.001
MONTHS.VARIETIES	6	231982757.	38663793.	46.07	<.001
Residual	132	110788000.	839303.		
Total	143	466303196.			

2.7. Analysis of Variance for Beta Carotene $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:months	81905.8	3	27301.9	441.38	0.0000*
B:doses	317471.	3	105824.	1710.81	0.0000*
C:varieties	435912.	2	217956.	3523.61	0.0000*
INTERACTIONS					
AB	309299.	9	34366.6	555.59	0.0000*
AC	389012.	6	64835.3	1048.17	0.0000*
BC	158247.	6	26374.5	426.39	0.0000*
ABC	443505.	18	24639.2	398.33	0.0000*
RESIDUAL	5938.17	96	61.8559		
TOTAL (CORR.)	2.14129E6	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

2.8. Analysis of Variance for Beta Carotene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Squares	v.r.	F pr.
MONTHS	3	81905.78	27301.93	441.31	<.001
TREATMENT	11	911626.23	82875.11	1339.60	<.001
MONTHS.TREATMENT	33	1141823.00	34600.70	559.29	<.001
Residual	96	5939.10	61.87		
Total	143	2141294.11			

2.9. Analysis of Variance for Beta Carotene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Squares	v.r.	F pr.
MONTHS	3	81906.	27302.	2.92	0.037
VARIETIES	2	435912.	217956.	23.31	<.001
MONTHS.VARIETIES	6	389016.	64836.	6.93	<.001
Residual	132	1234460.	9352.		
Total	143	2141294.			

2.10. Analysis of Variance for Lutein $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	66.753	3	22.251	1175.36	0.0000*
B:Months	75.3915	3	25.1305	1327.46	0.0000*
C:Varieties	1462.46	2	731.228	38625.43	0.0000*
INTERACTIONS					
AB	165.318	9	18.3687	970.28	0.0000*
AC	175.974	6	29.329	1549.24	0.0000*
BC	613.729	6	102.288	5403.14	0.0000*
ABC	650.672	18	36.1485	1909.46	0.0000*
RESIDUAL	1.8174	96	0.0189313		
TOTAL (CORR.)	3212.11	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

2.11. Analysis of Variance for Lutein $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	75.33801	25.11267	1330.04	<.001
TREATMENT	11	1705.37210	155.03383	8211.01	<.001
MONTHS.TREATMENT	33	1429.76473	43.32620	2294.67	<.001
Residual	96	1.81260	0.01888		
Total	143	3212.28743			

2.12. Analysis of Variance for Lutein $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	75.338	25.113	3.13	0.028
VARIETIES	2	1462.674	731.337	91.03	<.001
MONTHS.VARIETIES	6	613.735	102.289	12.73	<.001
Residual	132	1060.540	8.034		
Total	143	3212.287			

2.13. Analysis of Variance for Total Carotenoids $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	52.1841	3	17.3947	27.34	0.0000*
B:Months	47.0233	2	23.5117	36.95	0.0000*
C:Drying Methods	131.544	1	131.544	206.74	0.0000*
INTERACTIONS					
AB	87.1303	6	14.5217	22.82	0.0000*
AC	18.4754	3	6.15848	9.68	0.0000*
BC	81.4516	2	40.7258	64.01	0.0000*
ABC	51.1932	6	8.53221	13.41	0.0000*
RESIDUAL	30.5408	48	0.636267		
TOTAL (CORR.)	499.543	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

 2.14. Analysis of Variance for Total Carotenoids $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	47.0166	23.5083	36.92	<.001
TREATMENT	7	202.2298	28.8900	45.37	<.001
MONTHS.TREATMENT	14	219.6843	15.6917	24.64	<.001
Residual	48	30.5668	0.6368		
Total	71	499.4975			

 2.15. Analysis of Variance for Total Carotenoids $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	47.017	23.508	6.48	0.003
DRYING METHODS	1	131.576	131.576	36.26	<.001
MONTHS.DRYING METHODS	2	81.427	40.713	11.22	<.001
Residual	66	239.478	3.628		
Total	71	499.498			

2.16. Analysis of Variance for Lycopene $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	4.67553E6	3	1.55851E6	34.76	0.0000*
B:Months	6.73598E7	2	3.36799E7	751.10	0.0000*
C:Drying Methods	3.69594E7	1	3.69594E7	824.24	0.0000*
INTERACTIONS					
AB	2.42141E7	6	4.03569E6	90.00	0.0000*
AC	7.70503E6	3	2.56834E6	57.28	0.0000*
BC	1.20903E8	2	6.04517E7	1348.15	0.0000*
ABC	1.24883E7	6	2.08138E6	46.42	0.0000*
RESIDUAL	2.15235E6	48	44840.6		
TOTAL (CORR.)	2.76458E8	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

 2.17. Analysis of Variance for Lycopene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	67359779.	33679890.	751.10	<.001
TREATMENT	7	49339980.	7048569.	157.19	<.001
MONTHS.TREATMENT	14	157605874.	11257562.	251.06	<.001
Residual	48	2152344.	44840.		
Total	71	276457978.			

 2.18. Analysis of Variance for Lycopene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	67359779.	33679890.	43.39	<.001
DRYING METHODS	1	36959417.	36959417.	47.61	<.001
MONTHS.DRYING METHODS	2	120903444.	60451722.	77.87	<.001
Residual	66	51235337.	776293.		
Total	71	276457978.			

2.19. Analysis of Variance for Beta Carotene $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	35038.3	3	11679.4	166.63	0.0000*
B:Months	105122.	2	52561.2	749.90	0.0000*
C:Drying Methods	180101.	1	180101.	2569.53	0.0000*
INTERACTIONS					
AB	73024.7	6	12170.8	173.64	0.0000*
AC	102035.	3	34011.8	485.25	0.0000*
BC	92444.6	2	46222.3	659.46	0.0000*
ABC	101630.	6	16938.4	241.66	0.0000*
RESIDUAL	3364.37	48	70.091		
TOTAL (CORR.)	692761.	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

 2.20. Analysis of Variance for Beta Carotene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	105122.59	52561.29	749.95	<.001
TREATMENT	7	317173.18	45310.45	646.50	<.001
MONTHS.TREATMENT	14	267103.54	19078.82	272.22	<.001
Residual	48	3364.14	70.09		
Total	71	692763.45			

 2.21. Analysis of Variance for Beta Carotene $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	105123.	52561.	11.01	<.001
DRYING METHODS	1	180103.	180103.	37.72	<.001
MONTHS.DRYING METHODS	2	92446.	46223.	9.68	<.001
Residual	66	315092.	4774.		
Total	71	692763.			

2.22. Analysis of Variance for Lutein $\mu\text{g/g}$ - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	15.4212	3	5.14041	36.96	0.0000*
B:Months	13.7277	2	6.86386	49.36	0.0000*
C:Drying Methods	193.029	1	193.029	1388.06	0.0000*
INTERACTIONS					
AB	95.9843	6	15.9974	115.04	0.0000*
AC	68.968	3	22.9893	165.31	0.0000*
BC	30.749	2	15.3745	110.56	0.0000*I
ABC	101.23	6	16.8717	121.32	0.0000*
RESIDUAL	6.67507	48	0.139064		
TOTAL (CORR.)	525.784	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

2.23. Analysis of Variance for Lutein $\mu\text{g/g}$

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	13.7272	6.8636	49.39	<.001
TREATMENT	7	277.5435	39.6491	285.33	<.001
MONTHS.TREATMENT	14	228.0662	16.2904	117.23	<.001
Residual	48	6.6700	0.1390		
Total	71	526.0069			

2.24. Analysis of Variance for Lutein $\mu\text{g/g}$

Source of variation	d.f.	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	13.727	6.864	1.57	0.216
DRYING	1	193.070	193.070	44.18	<.001
METHODS					
MONTHS.DRYING	2	30.758	15.379	3.52	0.035
METHODS					
Residual	66	288.452	4.370		
Total	71	526.007			

Appendix 3: ANOVA Tables for the microbial load in tomato powder

 3.1. Analysis of Variance for Total Aerobic Mesophilic Bacteria log₁₀Cfu/g - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Varieties	91.7482	2	45.8741	35268.91	0.0000*
B:Months	65.3625	3	21.7875	16750.66	0.0000*
C:Doses	60.7363	3	20.2454	15565.11	0.0000*
INTERACTIONS					
AB	89.4819	6	14.9137	11465.92	0.0000*
AC	58.4344	6	9.73907	7487.59	0.0000*
BC	29.6576	9	3.29528	2533.48	0.0000*
ABC	55.7313	18	3.09618	2380.41	0.0000*
RESIDUAL	0.124867	96	0.00130069		
TOTAL (CORR)	451.277	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

 3.2. Analysis of Variance for Total Aerobic Mesophilic Bacteria log₁₀Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	65.450294	21.816765	16858.18	<.001
TREATMENT	11	210.811849	19.164714	14808.90	<.001
MONTHS.TREATMENT	33	174.935912	5.301088	4096.24	<.001
Residual	96	0.124237	0.001294		
Total	143	451.322292			

 3.3. Analysis of Variance for Total Aerobic Mesophilic Bacteria log₁₀Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	65.450	21.817	14.07	<.001
VARIETIES	2	91.720	45.860	29.58	<.001
MONTHS.VARIETIES	6	89.496	14.916	9.62	<.001
Residual	132	204.657	1.550		
Total	143	451.322			

3.4. Analysis of Variance for Total Coliform Count \log_{10} Cfu/g - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	72.0256	3	24.0085	10213.38	0.0000*
B:Months	25.4824	3	8.49414	3613.46	0.0000*
C:Varieties	408.067	2	204.034	86797.17	0.0000*
INTERACTIONS					
AB	11.8174	9	1.31304	558.58	0.0000*
AC	54.7691	6	9.12819	3883.19	0.0000*
BC	96.1735	6	16.0289	6818.80	0.0000*
ABC	30.0883	18	1.67157	711.10	0.0000*
RESIDUAL	0.225667	96	0.00235069		
TOTAL (CORR.)	698.649	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

3.5. Analysis of Variance for Total Coliform Count \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	25.436412	8.478804	3576.85	<.001
TREATMENT	11	534.917646	48.628877	20514.45	<.001
MONTHS.TREATMENT	33	138.093433	4.184649	1765.33	<.001
Residual	96	0.227565	0.002370		
Total	143	698.675056			

3.6 Analysis of Variance for Total Coliform Count \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	25.436	8.479	6.62	<.001
VARIETIES	2	408.016	204.008	159.32	<.001
MONTHS.VARIETIES	6	96.194	16.032	12.52	<.001
Residual	132	169.028	1.281		
Total	143	698.675			

3.7. Analysis of Variance for Mould and Yeast Count \log_{10} Cfu/g - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:MONTHS	22.1732	3	7.39106	4195.16	0.0000*
B:DOSES	98.5555	3	32.8518	18646.69	0.0000*
C:VARIETIES	2.69116	2	1.34558	763.75	0.0000*
INTERACTIONS					
AB	13.9785	9	1.55317	881.58	0.0000*
AC	1.57312	6	0.262186	148.82	0.0000*
BC	2.60964	6	0.43494	246.87	0.0000*
ABC	4.99011	18	0.277228	157.35	0.0000*
RESIDUAL	0.169133	96	0.00176181		
TOTAL (CORR.)	146.74	143			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

3.8. Analysis of Variance for Mould and Yeast \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	22.168778	7.389593	4178.62	<.001
TREATMENT	11	103.830238	9.439113	5337.56	<.001
MONTHS.TREATMENT	33	20.585026	0.623789	352.74	<.001
Residual	96	0.169769	0.001768		
Total	143	146.753811			

3.9. Analysis of Variance for Mould and Yeast \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	3	22.1688	7.3896	8.11	<.001
VARIETIES	2	2.7020	1.3510	1.48	0.231
MONTHS.VARIETIES	6	1.5824	0.2637	0.29	0.941
Residual	132	120.3006	0.9114		
Total	143	146.7538			

3.10. Analysis of Variance for Total Aerobic Mesophilic Bacteria log₁₀Cfu/g - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Drying Methods	162.24	1	162.24	2530.55	0.0000*
B:Months	28.3445	2	14.1722	221.05	0.0000*
C:Doses	60.8452	3	20.2817	316.35	0.0000*
INTERACTIONS					
AB	21.8361	2	10.9181	170.30	0.0000*
AC	31.188	3	10.396	162.15	0.0000*
BC	8.98069	6	1.49678	23.35	0.0000*
ABC	7.00524	6	1.16754	18.21	0.0000*
RESIDUAL	3.0774	48	0.0641125		
TOTAL (CORR.)	323.517	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

3.11. Analysis of Variance for Total Aerobic Mesophilic Bacteria log₁₀Cfu/g

Source of variation	Df	Sum of Squares	Mean square	v.r.	F pr.
MONTHS	2	28.33143	14.16572	221.49	<.001
TREATMENT	7	254.29731	36.32819	568.00	<.001
MONTHS.TREATMENT	14	37.80263	2.70019	42.22	<.001
Residual	48	3.06998	0.06396		
Total	71	323.50136			

3.12. Analysis of Variance for Total Aerobic Mesophilic Bacteria log₁₀Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	28.331	14.166	8.41	<.001
DRYING METHODS	1	162.182	162.182	96.29	<.001
MONTHS.DRYING METHODS	2	21.827	10.913	6.48	0.003
Residual	66	111.161	1.684		
Total	71	323.501			

3.13. Analysis of Variance for Total Coliform Count \log_{10} Cfu/g - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	31.8519	3	10.6173	30.39	0.0000*
B:Months	27.7115	2	13.8558	39.65	0.0000*
C:Drying Methods	378.859	1	378.859	1084.26	0.0000*
INTERACTIONS					
AB	8.593	6	1.43217	4.10	0.0021*
AC	8.67381	3	2.89127	8.27	0.0002*
BC	3.1657	2	1.58285	4.53	0.0158*
ABC	28.1038	6	4.68397	13.41	0.0000*
RESIDUAL	16.7719	48	0.349415		
TOTAL (CORR.)	503.73	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level

3.14. Analysis of Variance for Total Coliform Count \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	27.7385	13.8693	39.69	<.001
TREATMENT	7	419.2960	59.8994	171.43	<.001
MONTHS.TREATMENT	14	39.8326	2.8452	8.14	<.001
Residual	48	16.7713	0.3494		
Total	71	503.6385			

3.15. Analysis of Variance for Total Coliform Count \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	27.739	13.869	9.74	<.001
DRYING METHODS	1	378.759	378.759	265.95	<.001
MONTHS.DRYING METHODS	2	3.147	1.574	1.11	0.337
Residual	66	93.994	1.424		
Total	71	503.638			

3.16. Analysis of Variance for Moulds and Yeast Count \log_{10} Cfu/g - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:Doses	45.3313	3	15.1104	18254.23	0.0000*
B:Months	7.79635	2	3.89818	4709.21	0.0000*
C:Drying Methods	595.758	1	595.758	719707.25	0.0000*
INTERACTIONS					
AB	27.3293	6	4.55488	5502.54	0.0000*
AC	9.07086	3	3.02362	3652.70	0.0000*
BC	10.1779	2	5.08894	6147.72	0.0000*
ABC	25.5038	6	4.25063	5134.99	0.0000*
RESIDUAL	0.0397333	48	0.000827778		
TOTAL (CORR.)	721.007	71			

All F-ratios are based on the residual mean square error.

Values marked * are statistically significant at the 95.0 % confidence level.

 3.17. Analysis of Variance for Moulds and Yeast Count \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	7.782E+00	3.891E+00	4739.36	<.001
TREATMENT	7	6.503E+02	9.289E+01	1.131E+05	<.001
MONTHS.TREATMENT	14	6.303E+01	4.502E+00	5483.77	<.001
Residual	48	3.941E-02	8.210E-04		
Total	71	7.211E+02			

 3.18. Analysis of Variance for Moulds and Yeast Count \log_{10} Cfu/g

Source of variation	Df	Sum of Squares	Mean Square	v.r.	F pr.
MONTHS	2	7.782	3.891	2.39	0.099
DRYING METHODS	1	595.908	595.908	366.77	<.001
MONTHS.DRYING METHODS	2	10.196	5.098	3.14	0.050
Residual	66	107.233	1.625		
Total	71	721.120			