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INVESTIGATIONS INTO THE SHELF LIFE AND NUTRITIONAL QUALITY OF FRESH TOMATO FRUIT (*Solanum Lycopersicon*) FOLLOWING TWO POST - HARVEST TREATMENTS.

This Thesis is submitted to the University of Ghana, Legon

By

Linda Afriyie Gyimah (10363085)

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in partial fulfilment of the requirement for the award of

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DECLARATION

This thesis is the result of research work undertaken by Linda Afriyie Gyimah in the Department of Nuclear Agriculture and Radiation Processing, University of Ghana, under the supervision of Dr. Harry Mensah Amoatey and Dr. Rose Boatin.

Except for references of other peoples' work which I have cited, this thesis has not been presented either in whole or in part for another degree elsewhere.

Sign ……………………………… Date ……………………….

Linda Afriyie Gyimah

(Student)

Sign ……………………………… Date ……………………….

Dr Harry Mensah Amoatey

(Principal Supervisor)

Sign ……………………………… Date ……………………….

Dr Rose Boatin

(Co-Supervisor)

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DEDICATION

This work is dedicated to the Lord God Almighty for His Love and Grace so rich and free and to my role model, Ms. Evelyn Dadzie – Bonney. God richly bless you Mum.

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TABLE OF CONTENTS

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

LIST OF TABLES

Table **Page**

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

LIST OF PLATES

University of Ghana http://ugspace.ug.edu.gh

LIST OF FIGURES

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

University of Ghana http://ugspace.ug.edu.gh

ABSTRACT

Tomato production in Ghana is characterized by a glut and high post – harvest losses during the major season followed by scarcity and high prices during the off season. This is the result or absence of a standard method for preservation of fresh fruits. This research was conducted to determine an effective method for the post - harvest treatment of fresh tomato fruits to enhance shelf life while preserving its physicochemical and nutritional properties. Two experiments were conducted, each with a factorial design of 5x2. In experiment one, the fruits were subjected to 0, 1, 2, 3 and 4 kGy gamma radiation and stored at 10±1ºC and 28±1ºC. In experiment two, $CaCl_2$ dissolved in distilled water at 0, 1.00, 1.50, 2.00 and 2.50 % concentrations were used to coat tomato fruits and stored at 10±1ºC and 28±1ºC. Gamma radiation at 4kGy extended the shelf life of tomato by 5 and 9 days above control when stored at 28±1ºC and 10±1ºC respectively. The use of $CaCl_2$ at 2.50% greatly extended the shelf life of tomato by 11 days and 18 days above control when stored at 28±1ºC and 10±1ºC respectively. For both treatments, shelf life increased with increasing dose of radiation/ concentration of $CaCl_2$. Weight loss was higher in control fruits as well as fruits treated with gamma radiation or $CaCl_2$ coating stored at 28±1ºC temperature than treated fruits stored at 10±1ºC. Tomato fruits treated with gamma radiation at 1 and 2 kGy and untreated fruits showed an increase in pH and Total Soluble Solids (TSS) which was paralleled by a decrease in Total Titratable Acidity (TTA) as storage period advanced at both storage temperatures. However, fruits treated with $CaCl_2$ at 1.00% had little effect on pH and TTA of tomato during the storage period. Nutritionally, $CaCl_2$ coating significantly maintained the vitamin C and lycopene concentrations in tomato fruit more than control and gamma irradiation which reduced vitamin C and lycopene contents in the fruits significantly with days of

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storage. Storage at 10±1ºC better preserved the antioxidants properties of the fruits better than storage at 28±1ºC. Elemental composition (Na, K, Zn, Cu and Mn) of the tomato fruits analysed on the initial and final days of storage showed K to be the element with the highest concentration whilst Zn was the least. Generally, gamma irradiation led to an increase in the concentration of Na and K for all doses whilst $CaCl_2$ coating significantly decreased the concentrations of the same elements at both storage temperatures. Concentrations of Zn, Cu and Mn reduced significantly in the tomato fruits by the final day of storage for all treatments following storage at 10±1ºC whilst there were inconsistencies in the contents of the elements in tomato fruits stored at 28±1ºC. Gamma radiation and $CaCl_2$ significantly reduced the microbial load in tomato at both temperatures compared to the control. The reduction was proportional to increasing dose of irradiation and concentration of $CaCl_2$. However, $CaCl_2$ significantly reduced Total Aerobic Mesophiles as well as Mould and Yeast growth in tomato fruits compared to gamma irradiation at both temperatures. In general, treated tomato fruits stored at lower temperature (10±1ºC) had more stability and longer shelf life as well as the ability to maintain nutritional properties than those stored at 28±1ºC.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Tomato (*Solanum lycopersicon* L.) is a horticultural crop produced and consumed throughout the world (Nunes, 2008). Worldwide consumption is second only to potato as a vegetable (FAO, 2012; Javanmardi and Kubota, 2006). Tomato belongs to the *Solanaceae* family and has its origin in the South American Andes (Naika *et al.*, 2005). Though botanically it is a berry, it is usually considered as a vegetable due to its savoury flavour.

The health benefits conferred by certain vegetables and fruits have been the result of the presence of health-promoting phytochemicals with potent antioxidant properties such as carotenoids, flavonoids, phenylpropanoids, tocopherols, and ascorbic acid (vitamin C). Ripened fruit of tomato (*Solanum lycopersicon* L.) contains significant amounts of these compounds and are the principal dietary source of the carotenoid lycopene in the human diet (Giovannucci, 2002).

Tomato fruits are versatile; they can be consumed fresh in salads or cooked in sauces, soups and meat or fish dishes. They can be processed into purées, juices, ketchup, powders, canned whole or chopped.

Tomatoes contribute to a healthy, well-balanced diet. The fruit is mainly composed of water, soluble and insoluble solids (Nikbakht *et al.*, 2011; Pedro and Ferreira, 2007). Total solids are the summation of soluble and insoluble solids with soluble solids made up of mainly sugars, like sucrose and fructose, and salts and the insoluble solids mainly constituted by fibres, such as cellulose and pectin (Pedro and Ferreira, 2005). Usually, excluding seeds and skin, tomato presents 4.5-8.5% total solids, depending on variety, soil and climatic conditions (Pedro and Ferriera, 2005).

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Tomato contains organic acids (mostly citric acid) and such micronutrients as carotenoids, and vitamins A and C (Nikbakht *et al.*, 2011; Pedro and Ferreira, 2007). They are also rich in minerals, essential amino acids, sugars and dietary fibres. Tomato contains much vitamin B, E and K, iron and phosphorus.

As a tomato fruit ripens, its colour changes from green in the immature fruit to deep dark red in the fully mature fruit. Most of the orange, yellow and red colours of leaves, fruits and flowers are due to carotenoids. Carotenoids, such as beta-carotene and lycopene, are important components of antioxidant defence against lipid peroxidation in living cells (Bunghez *et al.*, 2011). They are essential nutrients in the human diet that are thought to provide health benefits by decreasing the risk of various diseases, particularly certain cancers, cardiovascular and eye diseases.

In tomato, fruit quality is an important factor that contributes to consumer acceptability. In addition to colour and firmness, measurements of acidity, total soluble solids content, and sugar-to-acid ratio, are factors that are used to select desirable sweet and sour flavour attributes in tomato fruit (Nikbakht *et al*., 2011; Shao *et al*., 2007).

Tomato is considered a low-high acid food with a pH value of between 3.7- 4.5.The pH of a food is one of several important factors that determines the survival and growth of microorganisms during processing, storage and distribution, thus the final safety of the food product. Therefore, determining the pH of foods helps to prevent product deterioration and spoilage. Canned and dried tomatoes are economically important processed products (Naika *et al.*, 2005).

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1.2 PROBLEM STATEMENT

As a whole product, tomato maintains a delicate tissue structure that is extremely susceptible to chilling injury, mechanical damage and the presence of microorganisms. It is highly perishable with shelf life stability ranging from three days to three weeks depending on the time of harvest and/or variety (Prakash *et al*., 2002; Ellis *et al.*, 1998). Kader (1992) stated that post - harvest losses in tomato as a result of improper storage and handling are enormous and can range from 20-50 % in developing countries.

In Ghana, availability of tomato fruit on the market is variable depending on the season and hence, the inability to meet manufacturing demands and an all-year-round production of the fruit for consumers. Market women usually display the fruits on table tops, in plastic baskets or wooden boxes and leave them in the sun till the close of day. This renders the fruit short-lived, due to the action of microorganisms and the inappropriate storage conditions under which the fruits are kept. During the peak seasons, the problem of glut sets in due to lack of appropriate methods/facilities for long term preservation of the fruits in their unprocessed state. Shortages of fresh tomato fruits occur during the lean season immediately following the glut, leading to a rise in the price of the fruit. Consequently, Ghana imports tomato fruits from neighbouring countries.

The shelf life, fruit quality characteristics as well as the optimum storage conditions and post - harvest treatment of common tomato fruits in Ghana need to be identified to curb the problem of postharvest losses. Irradiation has been known to inhibit microbial growth, delay ripening and extend the shelf life of minimally processed fruits and vegetables (Prakash *et al*. 2002; Hagenmaier and Baker, 1998). In addition edible coatings create a modified atmosphere within the fruit and thus help to preserve it for a longer time. Calcium chloride has been proven to reduce post - harvest decay, controls the development of physiological disorders, and improves quality and delay aging or ripening

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(Stanly *et al.*, 1995). Low temperature is also effective in delaying the onset of senescence and decay.

1.3 JUSTIFICATION

There is no standard method of extending shelf life of tomato fruit in Ghana. There is therefore the need to investigate the appropriate post - harvest methods and storage conditions for the fruit. Utilizing improved post - harvest practices will result in reduced losses, improved overall quality and food safety, and higher profits for growers and marketers (Talukder *et al.*, 2003). This study also determined the nutritional value, the shelf life as well as quality characteristics of tomato fruit stored over a period of time. The study identified the suitable dose range and concentration levels of gamma irradiation and $CaCl_2$ coating respectively for application without compromising the quality of the fruit in any form (that is, physical, nutritional and microbial state). Successful outcome of this study should contribute to a reduction in the quantity of tomato imported into the country especially by manufacturing companies as well as the problem of food insecurity in the area of tomato production. The study facilitated the selection of appropriate storage conditions and post - harvest treatment of tomato.

1.3 OBJECTIVES

The main objective of this study was to determine an effective method for the post - harvest treatment of fresh tomato fruits to enhance shelf life while preserving its physico-chemical and nutritional properties.

The specific objectives were to;

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1. Determine the effects of gamma irradiation and $CaCl_2$ coating on the shelf life of fresh tomato fruits stored under two temperature regimes.
2. Identify the effects of gamma irradiation and $CaCl_2$ coating on the physico-chemical properties of fresh tomato fruits stored under two temperature regimes.
3. Determine the effects of gamma irradiation and $CaCl_2$ coating on the nutritional composition of fresh tomato fruits stored under two temperature regimes.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 ORIGIN

Tomato (*Solanum lycopersicon* L.) is a herbaceous crop which originated from the coastal strip of western South America, from the equator to about 30° latitude south, especially Peru and the Galápagos Islands. It was first domesticated in Mexico and introduced into Europe in the mid-16th century (http://www.growtomatoes.com/historical-background/). Earlier on before it was considered fit to consume, tomatoes were thought to be poisonous because many of the allied species contain alkaloids and were grown only as an ornamental garden plant. Today, tomato is recognized as one of the important commercial and dietary vegetable crops (Bauer *et al.*, 2004). Tomato is now one of the most popular and widely grown crop both privately (home gardening) and on commercial basis. The highest producing countries are China, United States, Turkey, India, Egypt and Italy (FAO, 2012).

In Ghana, according to Ellis *et al*. (1998), tomato is grown on a large scale in the Northern (Tono and Vea areas), Ashanti (Akumadan, Kumawu, Agogo areas), Brong Ahafo (Techiman, Derma and Techimantia areas) and Greater Accra Regions. Some of the varieties commonly cultivated include Roma VF, Marglove, Anecho, *Wosowoso*, Caterpillar, Early Dwarf, Navrongo among others.

As a result of the numerous potential health benefits of tomato, it has been identified as a functional and 'nutraceutical' food. A nutraceutical is any substance considered as food, or part of a food, that provides medical or health benefits, including disease prevention and treatment (Jack, 1995).

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2.2 CLASSIFICATION

Tomato is a member of the *Solanaceae* family or the nightshade family which also include potato, bell pepper, and eggplant. It belongs to the genus *Lycopersicon,* sub family *Solanoideae* and tribe *Solaneae* (Taylor, 1986). Linnaeus, a Swedish botanist named it *Solanum lycopersicon* in 1753. Philip Miller, however, disagreed with it and replaced the Linnaeus name with *Lycopersicum esculentum* (Taylor, 1986). According to Heiser and Anderson (1999), taxonomists have recently reintroduced its original name *Solanum lycopersicon*. Thus, the taxonomic classification of tomato is still debated. However, the nomenclature adopted in this thesis is *Solanum lycopersicon* L.

2.3 PLANT DESCRIPTION

The plant typically grows to 1–3 metres in height and has a weak stem that often sprawls over the ground and vines over other plants. Tomato is a perennial, often grown in temperate and tropical climates as an annual crop. It is grown in sandy to heavy clay soils but well drained soils, like sandy or loamy is ideal. The optimum temperature required for its cultivation is 15 to 27°C. It can withstand drought fairly well but does not do well in heavy rainfall areas (Purkayastha and Mahanta, 2010).

Tomato fruit can be red, pink, orange, or yellow, and from 1 to 6 inches in diameter. It may be globular, fleshy berry or oblate in shape and round, smooth or furrowed (Naika *et al.*, 2005). The ripening of tomato is characterised by the softening of the fruit, the degradation of chlorophylls and an increase in the respiration rate, ethylene production, as well as the synthesis of acids, sugars and lycopene (Cano *et al.*, 2003).

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2.4 TOMATO PRODUCTION

Tomato is one of the major vegetables produced worldwide. Global production of tomato has increased by 300% in the last four decades with an estimation of 110 million tonnes and a total production area of about 4.2 million ha (Costa and Heuvelink, 2005). Worldwide production of tomato in 2009 totalled 158,368,530 tonnes, 3.7% up on the previous year with the top tomato producer being China, followed by the United States, Turkey, India, Egypt and Italy (about 75% of world production). In 2011, China's production of tomato was about 47,116,084 metric tonnes with the United States producing about 12,858,700 metric tonnes (FAO, 2012).

Tomato is an economically attractive crop as it gives high yield (Naika *et al.*, 2005). According to FAO (2012), tomato is a rapidly growing crop and a relatively short duration crop with a growing period of 90 to 150 days. Tomato production in Ghana has increased from 200,300 tonnes in 2005 to an estimate of 350,000 tonnes in 2010. Total land area utilized for tomato production in Ghana increased from 28,400ha in 1996 to 37,000ha in 2000 with an average yield of 7.5 MTs/ha (GIPC, 2001). By 2010, total land area for tomato production increased to 60,000ha with an average yield of 58333.33Kg/ha (FAO, 2012). According to Wolff (1999), vegetables account for 9.6% of total food expenditure and 4.9% of total expenditure in Ghana, and tomato alone makes up to 38% of the vegetable expenditure.

2.5 QUALITY CHARACTERISTICS OF TOMATO

Quality, the degree of excellence of fresh fruits and their products is a combination of attributes, properties or characteristics that give each commodity value in terms of human food (Kader, 1986). Kader (1986) added that producers relate quality to high yield of a commodity, good appearance, easy to harvest and the ability to withstand long – distance shipping to markets. Wholesalers and retailers relate the quality of a commodity to appearance, firmness and shelf life whilst consumers' judge quality of fresh fruits based on appearance and firmness at the time of initial purchase.

Ethylene and CO_2 production influence the qualitative nature of colour, flavour volatiles, sugars, and organic acids in tomato, which taken together determine the concept of fruit quality (Saeed *et al*., 2010). Consumers' subsequent purchases depend on the flavour of the product. In agreement with these attributes, Nunes (2008) noted that the quality of fresh tomato fruit is determined by various attributes such as appearance, firmness, flavour, and nutritional value.

Tomato is harvested at different stages for different purposes. Fruits to be processed are harvested red ripe for immediate use by processing companies whilst those to be sold on the market in the fresh state are harvested at the onset of ripening in order to withstand long distance transportation.

2.5.1 Colour

Colour is one of the most important quality factors that affect tomato appearance and is determined by skin and flesh pigmentation (Brandt *et al*., 2006). Colour is based on human perception of light and refers to one narrow band of the electromagnetic spectrum, called the visible spectrum. Colour is an important factor in consumer preference of tomato (Batu, 2003). Consumers in Ghana associate yellowish, pale red colour and non-uniformity in colour to unripenness. Thus, topmost quality in relation to colour is attributed to bright red tomato fruit.

Colour in tomato is due to carotenoids, a class of isoprenoid compounds varying from yellow to red colour (Hui, 2006). Hobson and Grierson (1993) stated that, the colour of a ripe tomato is determined by the ratio of two pigments, lycopene and β-carotene. As

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tomato progresses from mature green stage to red ripe stage, there is loss of chlorophyll and accumulation of lycopene (Costa and Heuvelink, 2005).

2.5.2 Firmness

Firmness of tomato is an important quality decisive factor because it is associated with good eating quality and longer postharvest life. As tomato ripens, firmness decreases, and so ripe fruits are much softer than mature-green fruits (Wann and McFerran, 1960). A good eating quality tomato should be firm and not easily deformed because softening is often associated with overripeness.

2.5.3 Flavour

Flavour, is an important food quality attribute. The flavour of tomato fruit is perceived through a blend of aroma, taste, and mouth feel and can be defined as a balance among sugars, organic acids, volatile compounds, and free amino acids (Baldwin *et al*., 1998). Sugars, acids and their interactions are important to sweetness, sourness and overall flavour intensity in tomatoes.

The taste of tomato can be good, tasteless, bland or tart. High acidity and high sugar content produce good taste. Tart taste is attributed to high acidity and low sugar. When the fruit has low acid but high sugar content, it has a bland taste whilst a tasteless fruit has low acidity and low sugar content. High sugars and relatively high acids are thus, required for best flavour development. Therefore, acidity of the fruit is also important as a contributor to the flavour of tomato products.

About 2 - 2.5% of the total dry matter of tomatoes are free amino acids. Organic acids, soluble sugars, amino acids, pigments and over 400 aromatic compounds contribute to the taste, flavour and aroma volatile profiles of the tomato (Petro-Turza, 1987).

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The longer the fruit remains on the plant, the more flavourful it becomes. Thus, tomato fruit not ripened on the plant does not have the same flavour and aroma as fruit that has developed its red colour (or final fruit colour) on the plant. Less handling reduces the incidence of bruising, and it has been suggested that flavour is reduced with increased handling (Saeed *et al*., 2010). Another aspect of fruit flavour is fruit size; smaller fruits are more flavourful as compared to larger ones (Thorne and Alvarez, 1982).

2.5.4 pH and Total Titratable Acidity

Two important quality attributes of processing tomato are pH and titratable acidity (Anthon *et al*., 2011). The pH of tomato can vary depending on the variety and degree of ripeness. The more ripened a tomato is the higher its pH and thus, the less acidic. The pH of tomato is determined primarily by the acid content of the fruit. The acidity of the fruit is also important as a contributor to the flavour of the tomato products (Anthon *et al*., 2011). Citric acid is the most abundant acid in tomato and the largest contributor to the total titratable acidity (Stevens, 1972). Gallic and glutamic acid also contribute significantly to total titratable acid. Glutamic acid is an important contributor to tomato flavour (Anthon *et al*., 2011). Anthon *et al*. (2011) stated further that tomato is not a low-acid food and thus requires less drastic thermal treatments than foods classified as low acid (pH>4.6) for the destruction of spoilage microorganisms to ensure food safety. A pH value of 4.4 is considered the maximum desirable for safety while the optimum target pH should be 4.25. This is because higher values would mean susceptibility of the pulp to thermophilic pathogens during processing of tomato (Monti, 1980).

2.5.5 Total Soluble Solid

Total soluble solid content (TSS) is one of the main components of tomato flavour and it is the property in tomato most likely to match consumer perception of internal quality (Kader, 1986). Water content and soluble solids exert a profound influence on the length

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of storage period, mechanical properties and quality characteristics of fruits and vegetables (Sharma *et al*., 2006). The percentage of solids in tomato varies depending on the variety, character of the soil and especially the amount of irrigation and rainfall during the growing and harvesting season (Jongen, 2002). According to Mizrahi *et al*. (1988), total soluble solids content is the most important quality criterion for tomato paste processing and serves as the base for fixing the price to be paid to the producer. In a study by Saliba-Colombani *et al*. (2001), it was reported that there is a positive correlation between sugar content and total soluble solids content in tomato fruit and in most cases this correlation is high. Thus, measurement of soluble solids content can give a fair estimate of the sugar level in tomato fruit. The sugars are mostly glucose and fructose and constitute about 65% of total soluble solids in expressed fruit juice (Winsor *et al*., 1962).

2.5.6 Total solids

Total solids are the dry matter that remains after moisture removal (Nielsen, 2010). High dry matter is a desirable characteristic for the canned tomato industry since it improves the quality of the processed product and consequently reduces processing cost (DePascale *et al*., 2001). Chemical analysis revealed that sugar and organic acids make major contribution to the total dry solids (Davies and Hobson, 1981).

2.6 HEALTH BENEFITS AND NUTRITIVE CONTENT

2.6.1 USES OF TOMATO

Tomato is a significant fruit in the global agricultural market due to its wide use in the food industry, both for fresh consumption and as processed products (Nikbakht *et al*., 2011). Three major processed products of tomato include tomato preserves (examples are whole peeled, tomato juice, tomato pulp, tomato puree, tomato paste, pickled tomatoes); dried tomatoes (examples are tomato powder, tomato flakes and dried tomato fruits); and tomato-based foods (including tomato soup, tomato sauce, chilli sauce, ketchup) (Costa and Heuvelink, 2005). It can also be used in sauces, soups and meat or fish dishes. Raw or unripe green fruits are used for the preparation of pickles and chutney. Tomato is also a very good appetizer and its soup is said to be a good remedy for patients suffering from constipation.

2.6.2 NUTRITIONAL COMPOSITION

The beneficial effects of tomato is primarily attributed to the occurrence of vitamins, minerals and secondary phytochemicals such as carotenoids, anthocyanins, flavonoids, and other phenolic compounds that are widely distributed throughout the plant kingdom (Anttonen and Karjalainenb, 2005). Indeed, tomato fruit is a reservoir and predominant source of a diverse range of antioxidant molecules, such as phenolic acids, ascorbic acid and vitamin E. Thus a high amount of tomato in the diet contributes significantly to the supply of the antioxidants required by humans. Ripening of tomato involves a number of physiological processes that include the visible breakdown of chlorophyll accompanied by a build-up of carotenoids, with massive accumulation of such antioxidant components as lycopene and carotene (Lai *et al.*, 2007).

2.6.2.1 Antioxidants

Interest in tomato antioxidants and their potential protective role in the prevention of chronic diseases stems largely from the epidemiological observations on normal and at risk populations (Agarwal and Rao, 2000). Consumption of tomato and its products can significantly reduce the risk of developing of colon, rectal, and stomach cancer. Antioxidants are protective agents that inactivate reactive oxygen species or excess free radicals and therefore significantly delay or prevent oxidative damage. Many biological processes can lead to the spontaneous formation of free radicals in the body. Environmental sources such as cigarette smoke, UV radiation and oxidizing agents may

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also increase the production of free radicals. Excessive accumulation of these free radicals may damage cells by the oxidation of lipids, proteins and DNA, and induce peroxidation and DNA strand-breaks (Del Mastero, 1980).

The intake of fruits and vegetables makes an important contribution to the levels of antioxidants in the body though antioxidants such as superoxide dismutase, catalase and glutathione peroxidase are naturally present within human cells (Agarwal and Rao, 2000). Carotenoids, such as beta-carotene and lycopene, are important components of antioxidant defence against lipid peroxidation in living cells (Bunghez *et al*., 2011). They are natural pigments synthesized by plants and microorganisms, but not by animals (Paiva and Russell, 1999).

2.6.2.2 Lycopene

Lycopene is a member of the carotenoid family of phytochemicals and is the natural pigment responsible for the deep red colour of several fruits, most notably tomato (http://www.whfoods.com/genpage.php?tname=nutrient&dbid=121) and also in red fruits and vegetables, including watermelon, pink grapefruit, apricot, and pink guava. Lycopene is also present in processed tomato products such as juice, ketchup, paste, sauce and soup. However, lycopene is more bioavailable in this state than in raw tomatoes. It is the most abundant carotenoid present in ripe red tomato, comprising up to 90% of the pigments present. Lycopene is a very labile compound and, in its pure form, will break down quickly in the presence of light, heat and oxygen (Nguyen & Schwartz, 1999). This property of lycopene could be due to water preventing oxygen and heat build-up within cells as well as the presence of even more reactive compounds which absorb the destructive power of light, oxygen and heat before they react with lycopene (Cox, 2001).

Lycopene, an aliphatic hydrocarbon, has received particular attention as a result of studies indicating that it has a highly efficient antioxidant and free radical scavenging capacity

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(Bunghez *et al*., 2011). It is the most predominant carotenoid in human plasma. In human plasma, it is present in an isomeric mixture, with 50% as cis isomers. Its formula is $C_{40}H_{56}$.

Strong evidence exists from numerous studies which associate high serum or plasma lycopene with decreased risks of cancer of the lung, stomach, gastrointestinal tract and cancers of the colorectal (Edhardt *et al*., 2003). Recent studies have also reported a decrease in the risk of total cardiovascular disease with higher concentrations of plasma lycopene by inhibiting free radical damage to Low Density Lipoprotein cholesterol (http://www.whfoods.com/genpage.php?tname=nutrient&dbid=121).

In addition to its antioxidant activity, lycopene has been shown to suppress the growth of tumours *in vitro* (test tube) and *in vivo* (animal) experiments by limiting tumour growth via stimulating cell to cell communication. Researchers now believe that poor communication between cells is one of the causes of the abnormal growth of cells, a condition which ultimately leads to the development of cancerous tumours (http://www.whfoods.com/genpage.php?tname=nutrient&dbid=121). Recent research has suggested that lycopene can boost sperm concentrations in infertile men. (http://www.whfoods.com/genpage.php?tname=nutrient&dbid=121).

Lycopene levels in tomato may vary based on the type of cultivar, stage of ripeness and growing conditions. Lycopene is also used in many antioxidant dietary supplements.

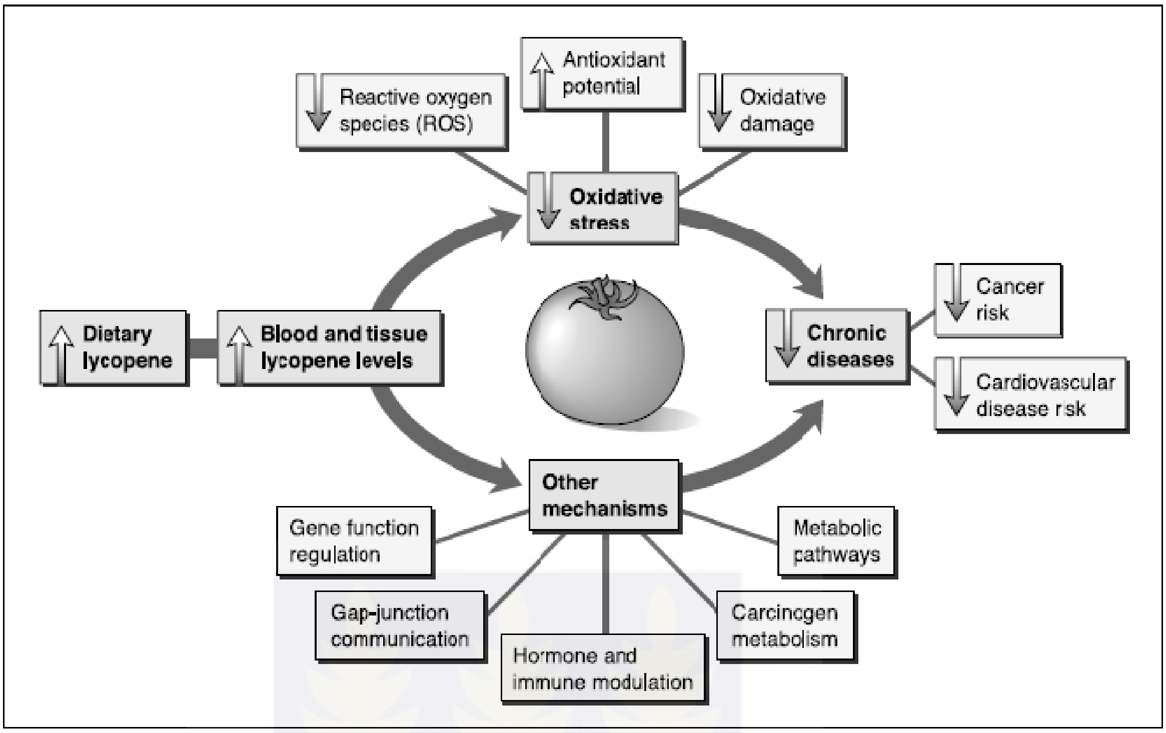

Fig. 2 Diagram showing the proposed Mechanisms for the role of Lycopene in preventing Chronic Diseases (Agarwal and Rao, 2000).

According to (Agarwal and Rao, 2000), dietary lycopene may increase the lycopene status in the body and, acting as an antioxidant, may trap reactive oxygen species, increase the overall antioxidant potential or reduce the oxidative damage to lipid (lipoproteins, membrane lipids), proteins (important enzymes) and DNA (genetic material), thereby lowering oxidative stress. This reduced oxidative stress may lead to reduced risk for cancer and cardiovascular disease. Alternatively, the increased lycopene status in the body may regulate gene functions, improve intercellular communication, modulate hormone and immune response, or regulate metabolism, thus lowering the risk for chronic disease (Fig. 2).

Excessive intake of lycopene can lead to the discolouration of the skin, a condition known as lycopenodermia. Stahl and Sies (1996) reported of a middle aged woman who had prolonged and excessive consumption of tomato juice, her skin and liver were coloured

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orange-yellow and she had elevated levels of lycopene in her blood. However, after three weeks on a lycopene-free diet her skin colour returned to normal.

2.6.2.3 Vitamins

Vitamins only account for a small portion of the total dry matter of tomato (Turhan and Seniz, 2009). Tomato is an excellent source of free radical-scavenging vitamin C which prevents the onset of scurvy and maintains skin and blood vessels (Lee and Kader, 2000). Tomato also contains vitamin A as well as bone-healthy vitamin K. It is a very good source of vitamin B6, vitamin B1 and vitamin E (http://www.whfoods.com/genpage.php?tname=foodspice&dbid=44).

2.6.2.4 Mineral Elements

Mineral elements considered essential in the human body are the major elements (which include sodium, magnesium, phosphorus, chloride, potassium and calcium) and the minor elements (including chromium, manganese, iron, cobalt, copper, zinc, selenium, molybdenum and iodine). In addition to these major and minor elements, there are the newer trace elements, which are possibly essential. They are lithium, boron, fluorine, silicon, vanadium, nickel, arsenic and lead (Crews, 1998).

These essential elements function as constituent of bones and teeth, as soluble salts which help to control the composition of body fluids and cells and serve as essential adjuncts to many enzymes and other functional proteins (Dashti *et al*., 2004).

Mineral elements commonly found in tomato fruit are Potassium, Calcium, Magnesium and Phosphorus and may constitute about 8% of the dry matter (Davies and Hobson, 1981). They have an effect on pH and titratable acidity and have buffering capacity which influences the taste of tomato.

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2.7 POSTHARVEST LOSSES

It is estimated that post - harvest losses of tomato in Ghana ranges between 30 and 70% and that the rate and extent of spoilage of tomato depends on handling practices, storage conditions, temperature and microbial infections (Ellis *et al*., 1998). In Ghana, tomato is mishandled though the fruit is highly perishable. It goes through a long chain at the hands of farmers who produce, harvesters, packers, drivers who transport, wholesalers and retailers before reaching the final consumer. At any stage in this chain quality is reduced such that by the time the produce reaches the retailer, half of the fruit gets rotten leading to high postharvest loss.

Post-harvest loss as defined by De Lucia and Assennato (1994) is "measurable quantitative and qualitative loss of a given product at any moment along the post-harvest chain". FAO (1989) also defines it as "change in the availability, edibility, wholesomeness or quality of the food that prevents it from being consumed" (FAO, 1989).

In a case study on tomatoes in Ghana by Robinson and Kolavalli (2010), it was observed that Ghana's tomato sector is characterized by low-productivity and high-cost. They mentioned further that Ghana is increasingly dependent on imported tomato paste and, from January through May every year, imported fresh tomato from Burkina Faso. They added that yields in the country are low with two-thirds of farmers having yields of less than 10 tons/ha. Furthermore, they added that the variety of tomato grown is an important determinant of yield, yet there is absence of breeding in the country and efforts to supply farmers with appropriate varieties and certified seeds.

For improved food security in developing countries, Kader (2005) mentioned that the reduction of post-harvest losses of perishables is of major importance.

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2.8 MICROBIAL INFECTIONS IN TOMATO

The surfaces of raw vegetables are contaminated with a variety of microorganisms depending on factors such as; the microbial population of the environment from which the food was taken, the condition of the raw product, the method of handling, the time and conditions of storage (Pelczar *et al*., 2006).

Tomatoes grown close to the ground and indeterminate types produce numerous branches which sprawl. Thus they can be contaminated in the field by soil, water used in irrigation, wild and domestic animals or improperly composted manure. Bacteria may also be transferred during and after harvest from handling, storing and transporting. When tomato fruits are not handled and stored properly to maintain a pH at or below 4.7, *Clostridium botulinum* growth will occur. Indeed, the fruits contain large amounts of water which makes them more susceptible to spoilage by the action of various microorganisms.

Acid-tolerant bacteria and fungi (yeasts and moulds) can use the fruit as a substrate. This action leads to spoilage, which in turn produces off flavours and odours, discoloration of the product, and if the contaminating micro-organisms are pathogens can also cause human illness (Tournas *et al*., 2006). This makes the transportation and storage of this vegetable difficult and its transportation too. According to Ghosh (2009), fungi were the source of spoilage in most of tomatoes samples accessed rather than bacteria. In his work, Ghosh (2009) identified that among the fungi, *Aspergillus niger* and *Fusarium* sp. were found in most of the spoiled samples with a few samples containing *Penicillium* sp.

Aspergillus species and *Fusarium* species are a source of potent mycotoxins which exhibits a wide spectrum of diseases which can even be fatal (Ibrahim *et al*., 2011). *Aspergillus niger* is a source of ochratoxin which is considered to be a potent carcinogen and suspected of playing a role in the etiology of oesophageal cancer and Balkan endemic

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nephrotoxicity. *Fusarium* produces Trichothecenes. Hence spoiled tomatoes should not be consumed under any circumstances and should not be fed to cattle as well (Ghosh, 2009).

Tomato producers, handlers, and marketers are required to take the necessary precautions in preventing contamination of the fruits to reduce possible risks of mycotoxins, enterotoxins and other metabolites that are deleterious to human health.

2.9 FOOD IRRADIATION

Food irradiation is a food safety and preservation technology. It is a processing technique that exposes food to electron beams, X-rays or gamma rays (Tiwari. *et al*., 2009). The process produces a similar effect to pasteurisation, cooking or other forms of heat treatment, but with less effect on look and texture. The World Health Organization considers ionizing radiation an important process toward ensuring food safety (Diehl, 1995). The shelf life of many fruits and vegetables, meat, poultry, fish and seafood can be considerably prolonged by treatment with irradiation (ICGFI, 1999).

Ionizing radiation can dissipate its energy by ionization or excitation. These excitations and ionizations can produce free radicals, break chemical bonds produce new chemical bonds and cross-linkage between macromolecules, damage molecules such as DNA, RNA, and proteins that regulate vital cell processes. Food irradiation reduces food losses by reducing the level of bacteria and parasites that contaminate food and cause food borne illness. It also slows down the ripening or sprouting of certain fruits and vegetables, making it possible to store food longer and in better condition. Irradiating food presents an effective treatment for post-harvest damage by destroying bacteria, moulds and yeasts which cause food to spoil, and control insect and parasite infestation. The major purpose of irradiating food is to cause changes in living cells such as contaminating organisms, to reduce pathogenic microorganisms or cells of the living foods to achieve better quality.

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Chemical effects or changes occur when there is the breakdown of the excited molecules and ions and their reaction with neighbouring molecules, giving a cascade of reactions during irradiation. Some of the primary reactions include isomerisation and dissociation. These reactions occur within molecules as well as with neighbour≤ing species which produces a series of new products including the highly reactive free radicals. The free radicals generated in food during irradiation have a short life time. However, in dried or frozen foods containing hard components such as bone, free radicals have limited mobility and thus, persist for a longer period of time (Grandison. 2006; Stewart, 2001).

Water radiolysis is another important chemical reaction that occurs from ionizing radiation. Hydroxyl radicals and hydrogen peroxide are generated upon the irradiation of water molecules and are highly reactive. They readily react with most aromatic compounds, carboxylic acids, ketones, aldehydes, and thiols (Stewart, 2001). These chemical changes are important as they contribute to the elimination of living food contaminants in foods. However, undesirable side effects, such as off-flavour, will be inevitable for certain food commodities if condition of irradiation is not well controlled (Grandison, 2006). For fruits and vegetables, especially tomatoes, most researchers recommend a maximum of dose 3kGy dose for elimination of food contaminants and extension of shelf life (Youssef *et al*., 2011; Prakash *et al*., 2002).

Nutritional changes in food from cooking, canning, pasteurising, blanching and other forms of heat processing are similar to changes that occur during food irradiation (Diehl, 1995). Macronutrients (protein, lipid and carbohydrate) as well as mineral quality are not affected during irradiation, they remain stable. Different types of vitamins have varied sensitivity to radiation. Riboflavin, niacin, and vitamin D, are fairly insensitive to radiation. However, vitamins A, B1 (thiamine), E and K are relatively sensitive. Their sensitivities depend on the complexity of the food, whether the vitamins are soluble in water or fat, and the atmosphere in which irradiation occurs. At low doses (up to 1 kGy), the effects of radiation on nutritional value of foods are insignificant, but may be greater at medium doses (1-10kGy) if food is irradiated in the presence of air.

2.9.1 Effects of Radiation on Tomato

Irradiation at low doses (1kGy or lower) has no significant effects on vitamin C content of fruits and vegetables (Lee and Kader, 2000). Irradiation at 0.5kGy can reduce microbial counts substantially to improve microbial shelf life without adverse effects on sensory qualities (Prakash *et al*., 2002). According to Fan and Sokorai (2008), irradiation at 1kGy, potentially inactivates *E. coli* O157:H7 by 5 log cycles on fresh vegetables. Youssef *et al*. (2011) reported that irradiating tomato juice at a dose of 3kGy could reduce total aerobic bacterial counts greatly as well as the counts of total moulds and yeasts without affecting sensory properties of tomato juice. At this dose, lactic acid bacteria also reduced to undetectable level (<10 cfu/ml) and coliform bacteria were eliminated completely.

Youssef *et al*. (2011) reported that the ascorbic acid content of tomato juice was reduced significantly and the reduction was proportional to the dose (1.5kGy, 3.0kGy and 4.5kGy) used. In contrast, the same doses did not show significant effect on the total lycopene content in the tomato juice. Irradiating at a dose of 4.5 kGy, however, affects the sensory properties of tomato juice, thus it is recommended to use 3.0 kGy. According to Prakash *et al*. (2002), treatment of diced tomatoes with 3.7 kGy decreased firmness by 50% as compared to 20% with 0.5 kGy.

2.10 CALCIUM CHLORIDE COATING

Calcium chloride is obtained from calcium chloride brine which is drawn from naturally occurring underground reservoirs. Calcium plays an important role in maintaining cell wall structure in fruit. It interacts with pectic acid to form calcium pectate, which has a

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firming effect on cell walls (Poovaiah, 1986). Calcium forms cross links or bridges between free carboxyl groups of the pectin chains, resulting in strengthening of the walls. The addition of calcium chloride obstructs enzymes such as polygalcturonase from reaching their active sites, thereby retarding tissue softening and delaying ripening. Post - harvest calcium application maintains cell turgor by making the cell wall and tissues more resistant and less accessible to the enzymes produced by fungi and bacteria limiting infection (De-Souza *et al.*, 1999; Scott and Wills, 1979). It also maintains membrane integrity and delays membrane lipid catabolism thus extending storage life of fresh fruits.

As a result of the role calcium plays in maintaining cell walls, researchers have investigated the use of post-harvest calcium treatments to increase the quality and shelf-life of fruit after harvest (Martin-Diana *et al*., 2007). Different studies have explained that calcium chloride reduces post - harvest decay, controls development of physiological disorders, improves quality and delays aging or ripening (Shehla and Tariq**,** 2007; Stanly *et al.*, 1995; Grant *et al.* 1973). Senevirathna and Daundasekera (2010), treated tomato fruits with $CaCl_2$ and this resulted in a delay in fruit colour development, lowering of ethylene production rates and delay in the time taken to reach the ethylene climacteric were observed with increased $CaCl_2$ concentration.

Nutritionally, addition of calcium chloride improved the lycopene contents and ascorbic acid contents (Garcia *et al*., 1996) and this was confirmed in the work of Upadhayaya and Sanghavi (2001) where treating strawberry fruits with 1, 2 and 3% $CaCl_2$ retained the highest level of total sugars, acidity and ascorbic acid and exhibited the highest overall acceptability. The shelf life was extended to 7 days while the control fruit had a shelf life of one day.

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2.11 STORAGE TEMPERATURE

Ball (1997) mentioned that, temperature plays an important role in maintaining post-harvest quality of tomato fruits. The effect of storage temperature on physicochemical quality and quantity changes in tomatoes, varies with the cultivar (Abou-Aziz *et al*., 1976) and harvesting conditions (Auito and Bramlage, 1986). Low temperature is the most important factor in maintaining quality and extending the shelf-life of fruits and vegetables after harvest due to its effects on reducing respiration rate, transpiration, ethylene production, ripening, senescence and rot development (Majidi *et al*., 2011). According to Lee and Kader (2000), vitamin C content of many crops can be lowered with more frequent irrigation, by bruising the fruits, and other mechanical injuries, and by excessive trimming. They added that, temperature management after harvest is the most important factor to maintain vitamin C content of fruits and vegetables; losses are accelerated at higher temperatures and with longer storage durations. It is generally agreed that for longer period ripe tomato can be stored at a temperature of 10-15°C and 85-95% relative humidity (De Castro *et al*., 2005). Tomato can also be stored at ambient temperatures for a period of up to 7 days.

Shewfelt (1986), defined shelf life as the period in which a product should maintain a predetermined level of quality under specified storage conditions. During shelf storage in vegetables and fruits, a number of chemical and physical processes take place**.** Fruit and vegetables deteriorate through the action of spoilage microorganisms, which become activated because of the changing physiological state of the fruit and vegetables (Saeed *et al*., 2010). Water loss during storage which is as a result of temperature and relative humidity conditions also affects the quality of most fruits and vegetables (Perez *et al*., 2003).

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In a study by Ait-Oubahou and Dilley (1990), tomato fruit kept within sealed packages resulted in an atmosphere with high carbon dioxide and low oxygen contents which retained flesh firmness, low acidity and soluble solids concentration and delayed fruit lycopene development.

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE

The study was conducted at the Food and Medical Laboratory, Polymer Laboratory, Sensory Evaluation Laboratory, Dosimetry Laboratory (Gamma Irradiation Facility - GIF) of the Radiation Technology Centre, and the Nuclear Chemistry and Environmental Research Centre, all of the Ghana Atomic Energy Commission (GAEC). Microbial analysis was conducted at the Animal Science Microbiology Laboratory at University of Ghana, Legon.

3.2 SAMPLE PREPARATION

Tomato fruits at the red riped stage were sorted and fruits with uniform shape, size and weight without any injuries or defects were selected, hand washed in brine to destroy all forms of contaminants that may be present on the fruit and dried with tissue paper. The Burkina variety was used in this experiment as it was the only variety available during the experimental period. The Burkina variety was obtained from distributors at the Accra market in Accra, Ghana.

3.2.1 Post - harvest Treatment 1 – Gamma Radiation

Ten tomato fruits were then packaged in sealed Low Density Polyethylene bag (LDPE) thickness 0.025mm. The packaged samples were taken to the GIF for irradiation at the following doses; 0kGy (control), 1kGy, 2kGy, 3kGy and 4kGy at a dose rate 1.962kGy. The irradiated samples were then transported to the Food and Medical Laboratory for analysis.

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3.2.2 Post - harvest Treatment 2 – Calcium Chloride Coating

Different concentrations of $CaCl_2$ solutions were prepared by dissolving in 100 ml of distilled water and making the volume up to 1000 ml/1L of distilled water. The percentages were 0% (control), 1.00% (10g $CaCl_2$), 1.50% (15g $CaCl_2$), 2.00% (20g $CaCl_2$) and 2.50% (25g $CaCl_2$). Fruits were dipped in $CaCl_2$ solution for 1 minute, removed and dried. The fruits were then packaged in sealed Low Density Polyethylene bag (LDPE) thickness 0.025mm and stored.

The storage conditions used were 10±1°C (low temperature) and 28±1°C (ambient temperature). The analysis was conducted every 3rd and 5th day for samples stored at ambient and low temperatures respectively throughout the period of study. The analysis lasted for 9 days for samples stored at 28±1°C and 25 days for those stored at 10±1°C. Those stored at ambient temperature were placed in plastic baskets in duplicates and stored on shelves whilst those to be stored at 10±1°C were stored in LDPE bags.

To obtain a homogenate sample of the juice, the fruits were placed in a stomacher bag and subjected to a Stomacher- 400 laboratory blender (Seward Scientific, London, England) for 3 minutes to bring out the juice. The juice was filtered through a muslin cloth to remove the seed and skin. All measurements were done in triplicate.

3.3 ANALYTICAL PROCEDURES

3.3.1 Shelf Life

The shelf life was calculated by counting the number of days required when fruit remained acceptable for marketing. The shelf life of fruits was decided based on the appearance and spoilage of fruits but up to the stage where they remained still acceptable for marketing (Mondal, 2000). Each day, the tomatoes stored at ambient temperature were sorted to remove fruits with signs of spoilage so as to prevent the whole batch from getting infected

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quickly. When 50% of fruits showed symptoms of shrinkage or spoilage due to pathogens and chilling injury, that lot of fruits were considered to have reached the end of shelf life.

3.3.2 Physiological Weight Loss (%)

The weight loss of tomato fruit sample was recorded to an accuracy of 0.01g using a Scientech balance model SL5000. Percentage weight loss was calculated by differences between initial weight and final weight (fruit weight on the final day of observation) divided by initial weight and expressed as percentage (AOAC, 1992).

$$\text{PLW (\%)} = \frac{\text{Initial fruit weight} - \text{Fruit weight on the day of observation}}{\text{Initial fruit weight}} \times 100$$

3.3.3 pH

The Mettler Toledo pH meter (model T3KFTLH) was used to determine the pH of the homogenate samples (AOAC, 1992).

3.3.4 Total Titratable Acidity

Titratable acidity was determined by the method of Srivastava and Kumar (1993). Extracted tomato juice of 10ml was thoroughly mixed in 50ml of distilled water and titrated against 0.1N NaOH with three drops of phenolphthalein as indicator until a pH of 8.1 was attained. Milli-equivalent weight of citric acid = 0.06404.

The percentage acid was calculated using the following equation;

$$\text{\% acid} = \frac{\text{Titre value x Normality x Milli-equivalent weight of acid}}{\text{Volume of sample}} \times 100$$

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3.3.5 Total Soluble Solids

The total soluble solids of the fruits were determined by putting a drop of homogenate tomato juice on Westover RHB-32ATC hand refractometer held at 20°C and expressed as °Brix (AOAC, 1992).

3.3.6 Moisture Content

A quantity of 5g of homogenate juice of each of the varieties of tomato was weighed into petri – dishes (pd) and dried overnight (16hrs) in an oven at 105°C (Basoglu and Uylaser, 2000). The dishes were allowed to cool in a desiccator and final weight recorded with an AccuLab ALC-150.3. The moisture content was determined using the following equation;

$$\%\ \text{Moisture content} = \frac{\text{Wt of pd+ sample} - \text{Wt of pd + dry sample}}{\text{Wt of pd + sample} - \text{Wt of empty pd}} \times 100$$

3.3.7 Vitamin C

An amount of 100g of tomato was added to 50 mL of distilled water in a 250 mL conical flask and 1 mL of starch indicator solution was added. The sample was titrated with 0.005M iodine solution. The endpoint of the titration was be identified as the first permanent trace of a dark blue-black colour was seen due to the starch-iodine complex.

3.3.8 Lycopene

An amount of 0.5g of tomato paste was put into screw top vials and wrapped with aluminium foil to reduce the penetration of light. A volumetric burette was used to deliver 5.0ml of 0.05% garlic acid in acetone into vials containing the sample with 5.0ml absolute ethanol and 10.0ml hexane. Vials were introduced into ice and subjected to an orbital shaker to mix the content at 200 rpm for 15 minutes. After shaking, 3ml deionised water was added to each vial and shaken for another 5minutes. The vials were left at room temperature to allow for phase separation for 5minutes. The absorbance of the upper layer (hexane) was measured using a Shimadzu UV-VIS Spectrophotometer model UV-1201 in

1cm path length quartz cuvettes at 503nm blanked with hexane solvent. The absorbance of the hexane layer was read thrice and the lycopene estimation was calculated using the equation by Fish *et al*. (2002);

$$\text{Lycopene (mg/Kg tissue)} = \frac{A_{503} \times 536.9\text{g} \times 1\text{L} \times 10^{3}\text{mg} \times 10.0\text{ml}}{17.2\text{x}10^{4}/\text{M} \times \text{cm} \times \text{mole} \times 10^{3}\text{mL} \times 1\text{g} \times \text{kg tissue}}$$

$$= \frac{A_{503} \times 0.0312}{\text{kg tissue}}$$

$$= \frac{A_{503} \times 31.2}{\text{g tissue}}$$

Where the molar extinction coefficient of $17.2\text{x}10^{4}$ / M × cm is the lycopene in hexane (Zechmeister *et al*., 1943); A_{503} is absorbance at 503 nm and kg tissue is the quantity of sample used. The lycopene values were expressed in mg/kg.

3.3.9 Elemental Composition Analyses

Elemental Composition Analyses were determined using the Atomic Absorption Spectrophotometer (AAS) and the Flame Photometer.

3.3.9.1 AAS (Varian AA240FS Model, USA) Analysis

0.5g of the samples prepared was weighed into a labelled 100mL polytetrafluoroethylene Teflon bombs. 6 mL of conc. HNO_3 (65%) and 1 mL of H_2O_2 (30%) were added to the samples in a fume chamber. The samples were then loaded on a microwave carousel. The vessel caps were secured tightly. The complete assembly was microwave irradiated for 20 minutes in a milestone microwave laboratory station ETHOS 900 D model (Fig. 3) using the following parameters; 250W for 2 minutes, 0 W for 2 minutes, 250 W for 6 minutes, 400W for 5 minutes, 600 W for 5 minutes with 100 pressure, 400°C and 500°C. 5 minutes was allowed for venting.

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After digestion, the Teflon bombs mounted on the microwave carousel were cooled in a water bath to reduce internal pressure to allow volatilized materials to re-solubilise. The digest was made up to 20 mL with distilled water and assayed for the presence of copper, zinc and manganese in an acetylene-air flame.

Reference standards for the elements of interest, blanks and repeats of the samples were digested the same way as the actual samples. These served as internal positive controls.

The digested samples were then aspirated using Varian AA240FS fast sequential Atomic Absorption Spectrophotometer. The instrument was initially calibrated before the reading of any element with a standard solution of the element. A linearity of the calibration curve was always checked before the samples were aspirated. The final concentration was obtained as stated below:

$$\text{Final concentration (ppm)} = \frac{(\text{concentration} \times \text{nominal volume})}{\text{Weight of sample in grams}}$$

Concentration recorded = given on the monitor attached to the instrument

Nominal volume = 20ml

Weight of sample = 0.5g

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Fig. 3 Milestone microwave laboratory station ETHOS 900 D model.

3.3.9.2 Flame Photometry (Sherwood 420 Model, England U.K.) Analysis

The flame photometer was allowed to warm up for about 20 minutes. Five (5) ml of the blank (distilled or deionised water) and 2ml of lithium standard of concentration 100mg/l were mixed thoroughly and then aspirated by placing the capillary tube in the solution. Some seconds were allowed to elapse for a reaction to occur in the nebuliser, and then the knob for the blank was pressed for calibration to complete. Five (5) ml of the Na/K standard was measured and 2ml of the lithium standard added to it. It was thoroughly mixed and aspirated. Five (5) ml of the filtered tomato sample and 2ml of the lithium standard were measured and thoroughly mixed. The solution was aspirated and the concentration of Na/K recorded in mg/L of the sample.

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3.3.10 Microbial Load Determination

Total Aerobic Mesophiles, Yeast and Mould colony forming units (cfu) were determined by standard spread plate methodology using Plate Count Agar (PCA) (Difco,Detroit, MI) or Potato Dextrose Agar (PDA) (Difco) containing 25 mg /ml chloramphenicol (Sigma, St. Louis, M O). One (1) ml of the homogenate tomato sample was poured into sterile Petri dishes and 10 ml of hot agar was gently dispensed on it. The plate was swirled gently and was inverted after it had solidified. The plates were inverted and incubated at 37°C for 24 hours. The colonies were counted and the number of colonies per plate was multiplied by the dilution factor to obtain the total viable counts per ml of the original sample (Babarinde and Fabunmi, 2009).

3.4 DATA ANALYSES

The data obtained were analysed using Statgraphics Centurion XVI.I. One – way Analysis of Variance (ANOVA) and multi factor Analysis of Variance were used to assess the significant differences ($p \leq 0.05$) among properties analysed with respect to storage period, storage conditions and treatment used (gamma radiation doses and $CaCl_2$ levels). The Fisher's least significant difference (LSD) was used to discriminate among the means. The data for both storage conditions were analysed separately as the number of days for evaluation were different for each storage condition (ambient temperature storage was analysed every 3rd day whilst fruits stored at low temperature were analysed every 5th day).

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CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 SHELF LIFE STUDY OF BURKINA TOMATO FRUITS FOLLOWING GAMMA RADIATION AND $CaCl_2$ COATING.

4.1.1 Shelf Life Study of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following Irradiation.

Fig. 4.1.1(a) shows the effect of increasing dose of gamma radiation on storage life (in days) of ripe fruits of tomato variety Burkina, stored at ambient temperature (28±1°C). The shelf life of fruits was reached when more than 50% of the fruits showed signs of spoilage.

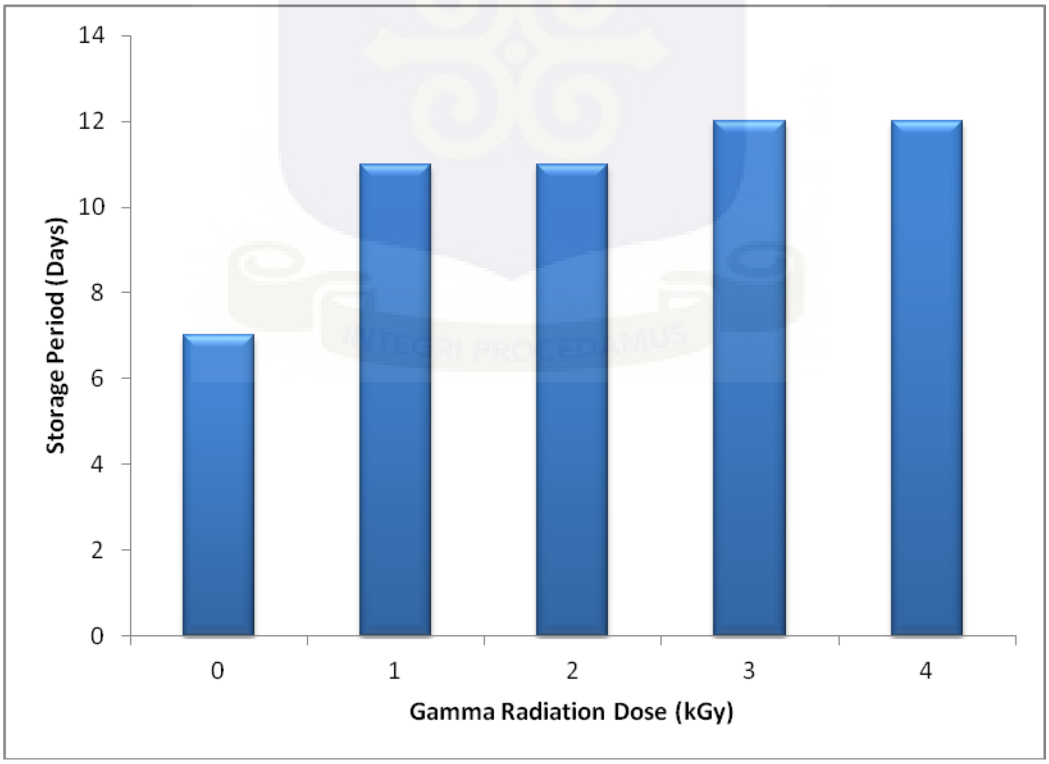

Fig. 4.1.1(a) Effect of radiation dose on the shelf life of tomato fruits stored at ambient temperature (28±1°C).

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Control fruits showed the minimum shelf life with 80% fruit spoilage on the 7th day (Plate 1b). Therefore, further analysis was discontinued on day 9 throughout this research for control fruit. Fruits treated with gamma radiation however lasted from 11-12 days as demonstrated in Fig. 4.1.1(a) above. Fruits treated with 3 and 4 kGy showed the longest shelf life with 12 days (Plate 2b) whilst 1 and 2 kGy lasted for 4 days more than the control fruits. The shelf life increased with increasing dose. This result confirms work done by Nasarin *et al*., (2008) when non-treated tomato kept in ambient condition without packaging showed the minimum shelf life of 7 days.

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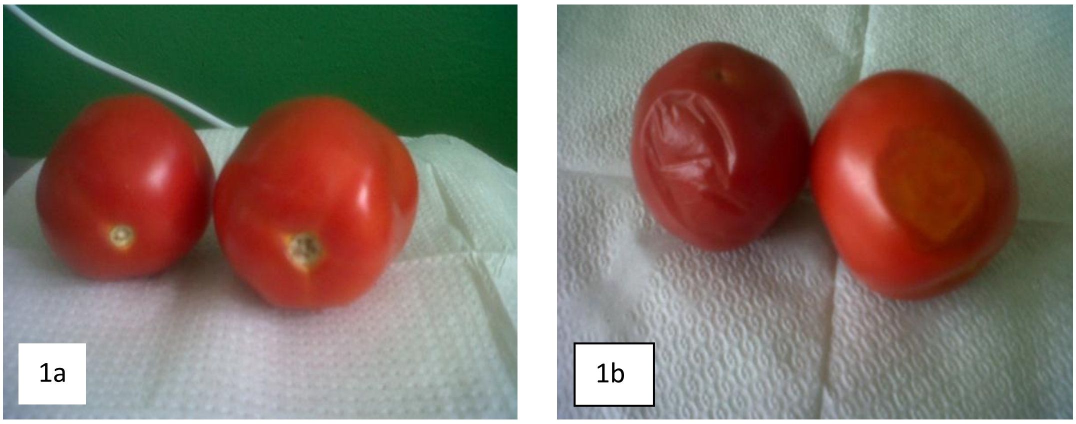

Plate 1: Control tomato fruits stored at ambient temperature (28±1°C).
(a) First day of storage (b) 7 days of storage.

Plate 2: Irradiated tomato fruits (3kGy) stored at ambient temperature (28±1°C).
(a) First day of storage (b) 12 days of storage.

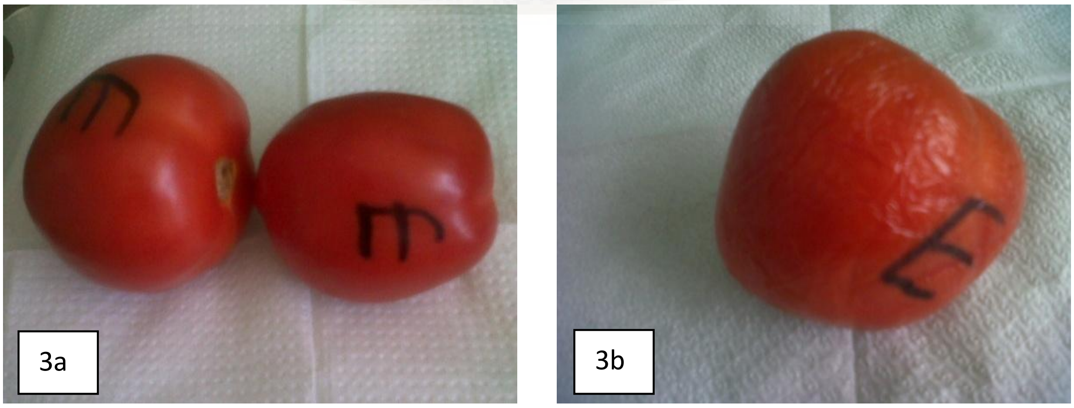

Plate 3: $CaCl_2$ treated tomato fruits (2.50%) stored at ambient temperature (10±1°C).
(a) First day of storage (b) 18 days of storage.

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4.1.2 Shelf Life Study of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

From Fig. 4.1.1(b), fruits treated with $CaCl_2$ showed the longer shelf life with 7-11 days longer than the control fruits which lasted for 7 days. After 14 days, $CaCl_2$ treated fruits started shrinking as seen in Plate 3(b).

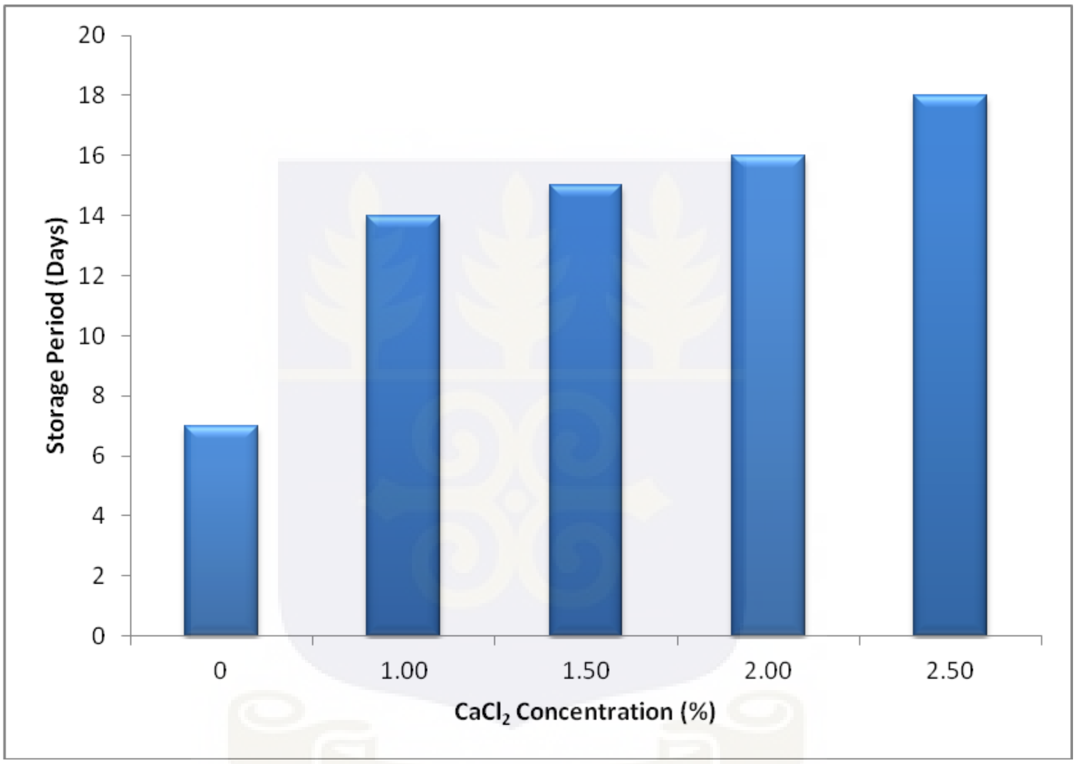

Fig. 4.1.1(b) Effect of $CaCl_2$ concentration on the shelf life of tomato fruits stored at ambient temperature (28±1°C).

Concentration at 1.00, 1.50, 2.00 and 2.50 % of $CaCl_2$ treatment extended shelf life of tomato fruit by 7, 8, 9 and 11 days respectively. The shelf life increased with increasing level of concentration. This confirms work by Nirupama *et al.* (2010) where treatment of 0.50%, 1.00%, 1.50% of $CaCl_2$ on tomato fruits caused the extension of storage life to 15, 17 and 18 days respectively, as compared to that of fruits of control set (7 days).

Comparatively, tomato fruits treated with $CaCl_2$ showed the longest shelf life with 7-11 days more above control fruits and 4-6 days more above irradiated fruits. Extension of the

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shelf life of the tomato fruit may be attributed mainly to the increased firmness and retarded ethylene production rates in $CaCl_2$ treated fruits as explained by Senevirathna and Daundasekera (2010). Gamma radiation was also able to extend the shelf life of tomato fruits by 3-4 days over control. This is as a result of its ability to prolong the shelf life of fruits and vegetables.

4.1.3 Shelf Life Study of Tomato Fruits Stored at Low Temperature (10±1°C) Following Irradiation.

Fig. 4.1.2(a) shows the effect of gamma radiation dose on the shelf life of tomato fruit stored at low temperature (10±1°C). Control fruits lasted for 25 days after which more than 50 % of the fruit showed signs of spoilage (Plate 4b).

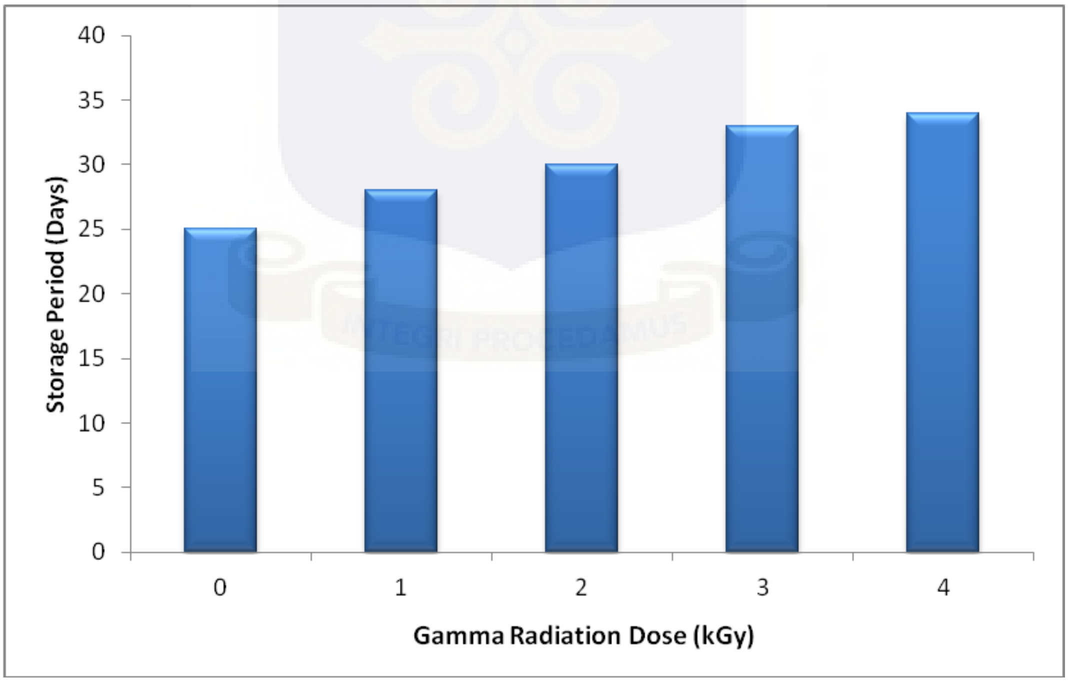

Fig. 4.1.2(a) Effect of irradiation dose on the shelf life of tomato fruits stored at low temperature (10±1°C).

Irradiated fruits lasted between 28-34 days. After 28 - 30 days, fruits treated with 1 and 2 kGy had more than 50% spoilage (Plate 5b) whilst fruits irradiated at 3 and 4 kGy lasted for 33-34 days as seen in Fig. 4.1.2(a). Therefore, the shelf life of tomato fruits increased with increasing dose.

4.1.4 Shelf Life Study of Tomato Fruits Stored at Low Temperature (10±1°C) following $CaCl_2$ Coating.

Fig. 4.1.2(b) shows the effect of $CaCl_2$ concentrations on the shelf life of tomato fruit stored at low temperature (10±1°C). Control fruits lasted for 25 days whilst fruits treated with $CaCl_2$ lasted between 38-43 days.

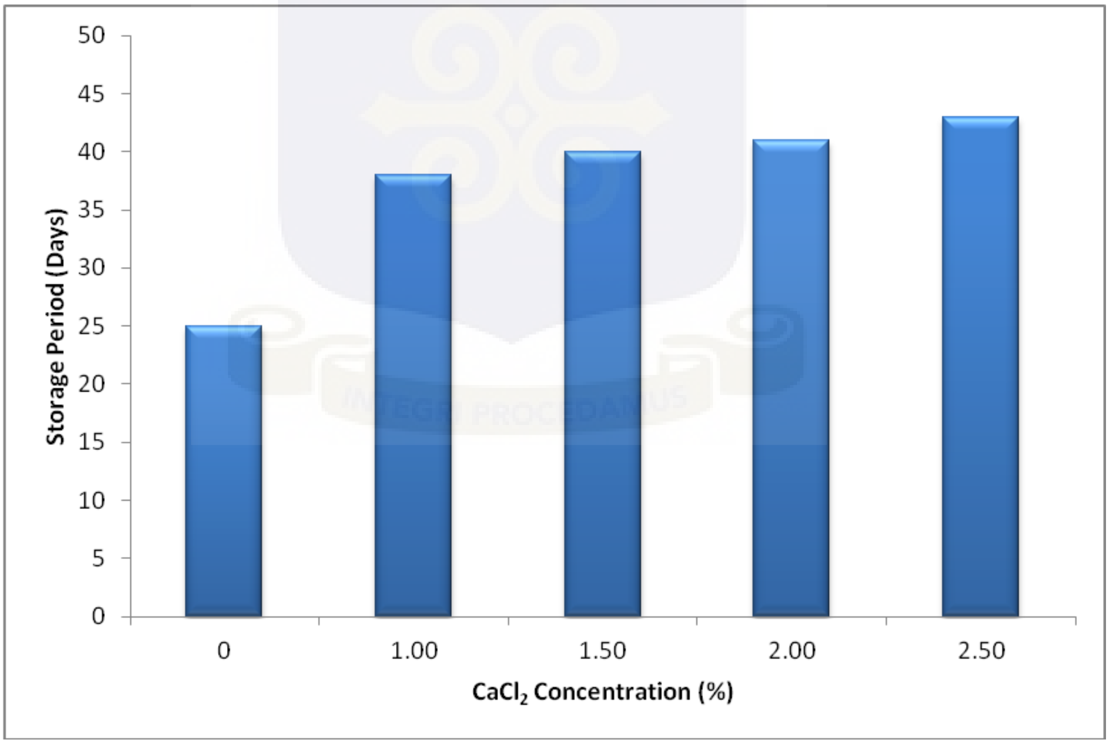

Fig. 4.1.2(b) Effect of $CaCl_2$ concentration on the shelf life of tomato fruits stored at low temperature (10±1°C).

$CaCl_2$ concentration of 1.00 and 1.50 % treated fruits lasted for 38 and 40 days respectively after which tomato fruits started showing signs of microbial infections (Plate

6b). Fruits treated with $CaCl_2$ at 1.00, 1.50, 2.00 and 2.50 % concentrations extended shelf life of tomato fruit by 13, 15, 16 and 18 days respectively over control which lasted for 25 days. These results supports the view of Cheour *et al*. (1990) who reported that the use of $CaCl_2$ prolonged the storage life of strawberries, as measured by a delay in accumulation of sugars (°Brix), decrease in organic acids and mould development.

In comparison with gamma radiation, fruits treated with $CaCl_2$ at concentrations of 1.00, 1.50, 2.00 and 2.50 % resulted in extended shelf lives of 10, 10, 8 and 9 days respectively over radiation treated fruits.

From the shelf life study, it could be observed that fruits stored at low temperature (10±1°C) generally experienced longer shelf life than at ambient temperature (28±1°C). For example, fruits in the control set which were kept under ambient temperature (28±1°C) were able to last for 7 days whilst the same set of fruits kept at low temperature (10±1°C) had an were able to last for 25 days. Fruits treated with gamma irradiation and stored at low temperature (10±1°C) extended shelf life of 18 days whilst fruits treated with $CaCl_2$ and stored at the same low temperature lasted 24-25 days over fruits stored at ambient temperature (28±1°C).

Gamma radiation extended the shelf life of tomato fruit by slowing down senescence making it possible to store the produce longer and in better conditions through preservation of nutrients, chemical and physical properties (Tiwari *et al*., 2009). The use of $CaCl_2$ was able to extend the shelf life as a result of its ability to maintain membrane integrity and delay membrane lipid catabolism (Martin-Diana *et al*., 2007).

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Plate 4: Control tomato fruits stored at low temperature (10±1°C). (a) First day of storage (b) 25 days of storage.

Plate 5: Irradiated tomato fruits (2 kGy) stored at low temperature (10±1°C). (a) First day of storage (b) 30 days of storage.

Plate 6: $CaCl_2$ treated tomato fruits (2.50%) stored at low temperature (10±1°C). (a) First day of storage (b) 41 days of storage.

4.2 PHYSICOCHEMICAL PROPERTIES OF BURKINA TOMATO FRUITS FOLLOWING GAMMA RADIATION AND $CaCl_2$ COATING.

4.2.1 Physiological Weight Loss of Tomato Fruit Stored at Ambient Temperature (28±1°C) Following Irradiation.

Fig. 4.2.1(a) shows the effect of irradiation dose (kGy) on the physiological weight of tomato fruit stored at ambient temperature (28±1°C). Weight loss in the control fruits ranged from 2.80 - 15.66 % (mean of 8.01%) whilst irradiated fruits showed between 2.48 – 14.55 % (mean of 6.24%) throughout storage period of 9 days.

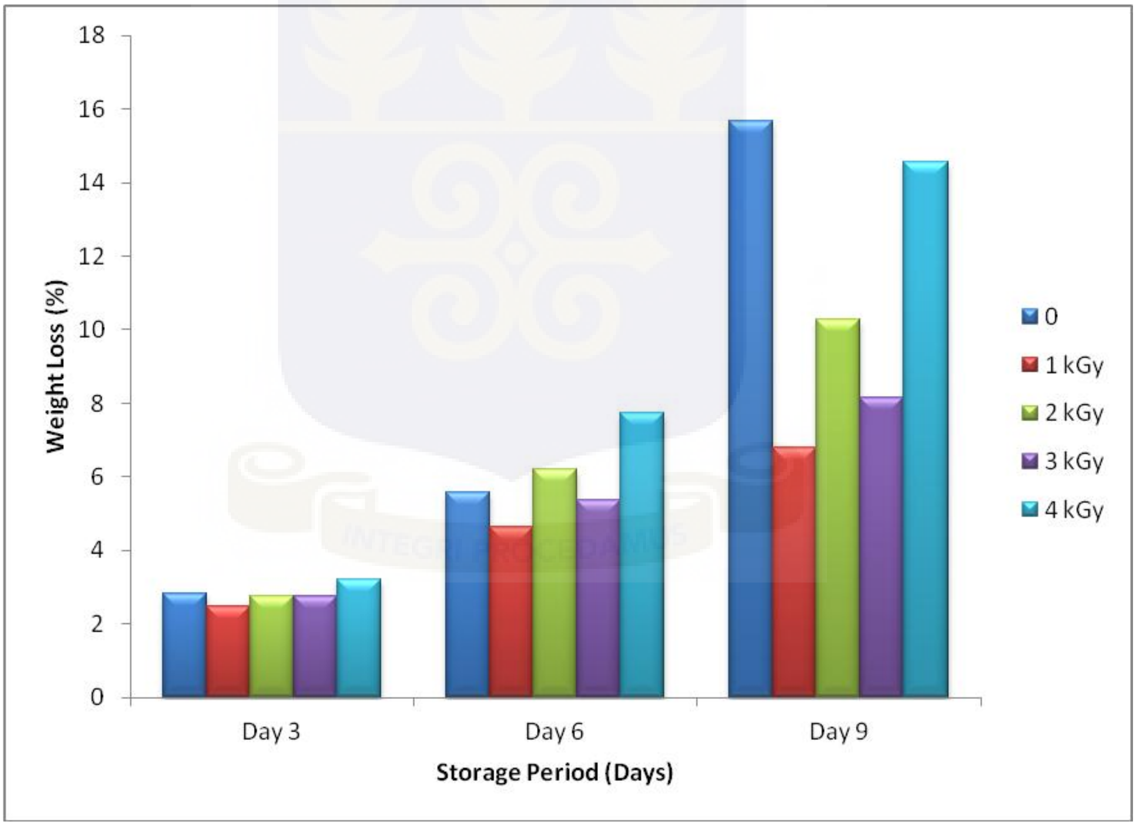

Fig. 4.2.1(a) Effect of irradiation dose (kGy) on physiological weight loss of tomato fruits stored at ambient temperature (28±1°C).

From Fig. 4.2.1(a), the control fruits showed the largest weight loss throughout the study with 15.66% weight loss on the final day. Control fruits also increased significantly ($P<0.05$) in weight loss with increasing storage days. Generally, weight loss increased

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significantly (Appendix 17a) in irradiated fruits with increasing radiation dose and also with advancement of storage. There were significant differences in weight loss of tomato fruits between storage days. With tomato fruits treated with radiation doses, 4kGy showed the largest weight loss throughout the storage period reaching 14.55 % on the final day whilst fruits treated with 1kGy showed the least weight loss (6.78 %) on the final day of assessment. These results confirm the work by Bhattarai and Gautam (2006) who observed that weight loss was larger in fruits without any treatment. This could be attributed to the fact that after harvest, climateric fruits like tomato generate heat which contributes to weight loss. The heat lost to the environment contributes to increased evaporation of water. Under ambient conditions, the heat generated is more rapid as a result of increased respiration rate. This leads to rapid weight loss of the fruit characterised by excessive softness making the fruit no longer marketable (Davies and Hobson, 1981; Padmini, 2006).

4.2.2 Physiological Weight Loss of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

Fig. 4.2.1(b) depicts tomato fruits treated with $CaCl_2$ and stored at ambient temperature (28±1°C) with weight loss ranging between 1.35 and 6.93 % (3.46% mean) whiles control fruits ranged from 2.80 - 15.66 % (8.01% mean). Weight loss in control fruits increased significantly ($P \leq 0.05$) with increasing storage days and showed the largest weight loss of 15.66 % on the final day. Weight loss increased with increasing $CaCl_2$ concentrations and also as storage days advanced. Tomato fruits treated with $CaCl_2$ at 2.50% concentration showed the largest weight loss at 2.57% on the 3rd day and 6.93% on the 9th day. Fruits treated with 1.50% concentration showed the least weight loss on the final day at 4.11%.

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Weight loss was larger in control fruits (8.01%) as compared to $CaCl_2$ treated fruits (3.46 %).

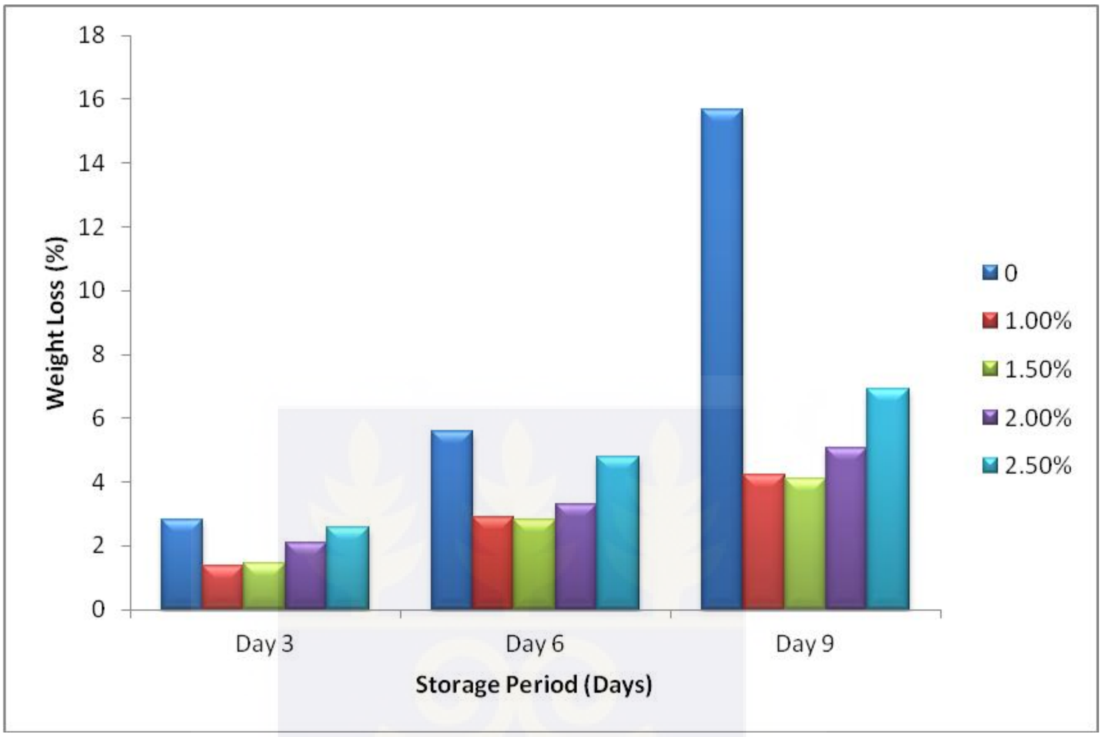

Fig. 4.2.1(b) Effect of $CaCl_2$ concentration on physiological weight loss of tomato fruits stored at ambient temperature (28±1°C).

In all treatments used, weight loss was larger in control fruits (8.01 %) than gamma radiation (6.24 %) and $CaCl_2$ treatments (3.46 %). This is in agreement with Bhattarai and Gautam (2006) who observed that weight loss was least in fruits treated with $CaCl_2$ and higher in fruits without any treatment. Physiological weight loss was greater in the irradiated samples than the $CaCl_2$ treated tomato fruits.

4.2.3 Physiological Weight Loss of Tomato Fruit Stored at Low Temperature (10±1°C) Following Irradiation.

Fig. 4.2.2(a) depicts the physiological weight loss of tomato fruits treated with gamma radiation dose. Weight loss in radiated fruits showed least weight loss as compared to

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fruits in the control set. Control fruits showed 22.93 % mean weight loss whilst irradiated fruits resulted in 1.85 % mean weight loss throughout the 25 day storage period.

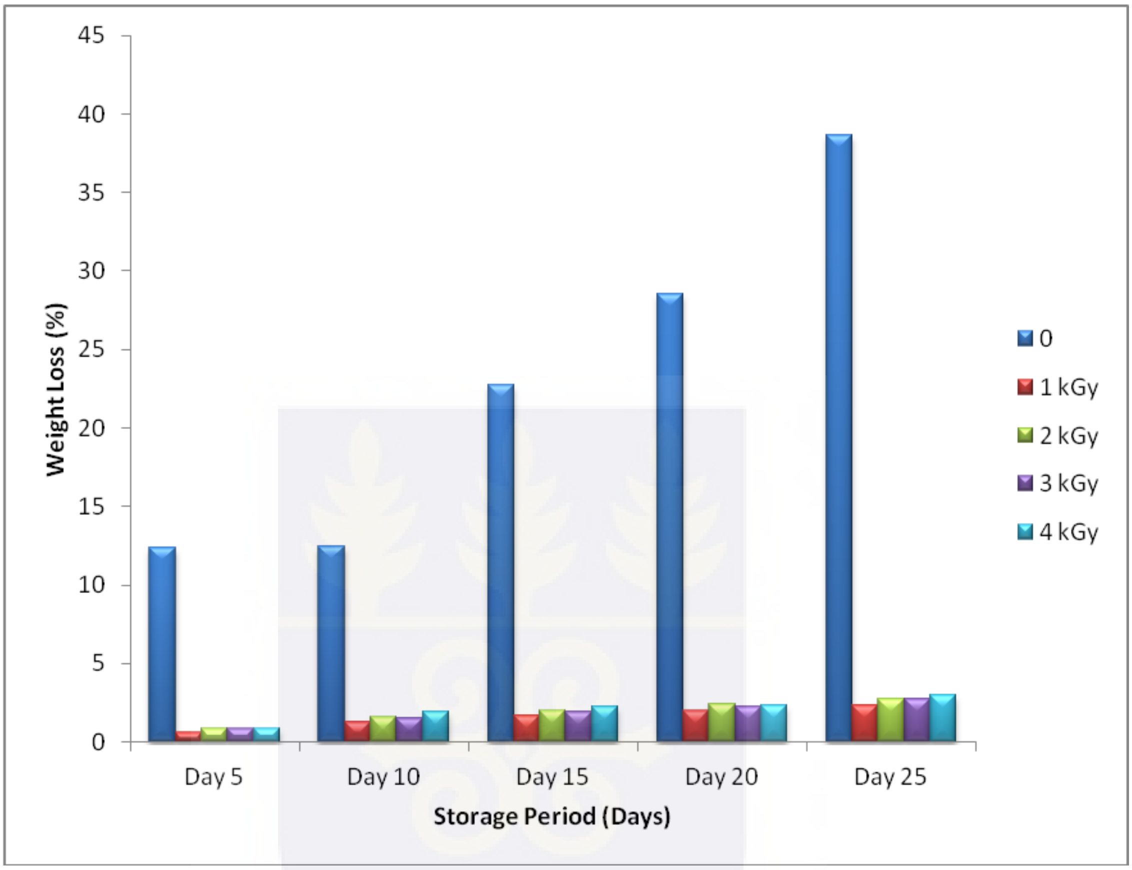

Fig. 4.2.2(a) Effect of irradiation doses (kGy) on physiological weight loss of tomato fruit stored at low temperature (10±1°C).

Weight loss for irradiated fruits increased significantly (Appendix 17b) throughout the storage period. Fruits treated with 1, 2, 3 and 4 kGy showed a percentage weight loss of 2.34, 2.76, 2.73 and 3.00 % respectively from the initial to the final day of evaluation. Thus, weight loss increased with increasing dose of gamma radiation. Fruits in the control set showed the largest percentage mean weight loss of 22.93 % with a significant increase ($P \leq 0.05$) in percentage weight loss throughout storage.

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4.2.4 Physiological Weight Loss of Tomato Fruit Stored at Low Temperature (10±1°C) Following $CaCl_2$ Coating.

Fig. 4.2.2(b) shows the effect of $CaCl_2$ concentration on physiological weight loss of tomato fruit stored at low temperature (10±1°C). Fruits in the control set showed the largest mean weight loss of 22.93%. Fruits treated with $CaCl_2$ showed the least percentage mean weight loss of 0.97 % throughout the 25 day storage period.

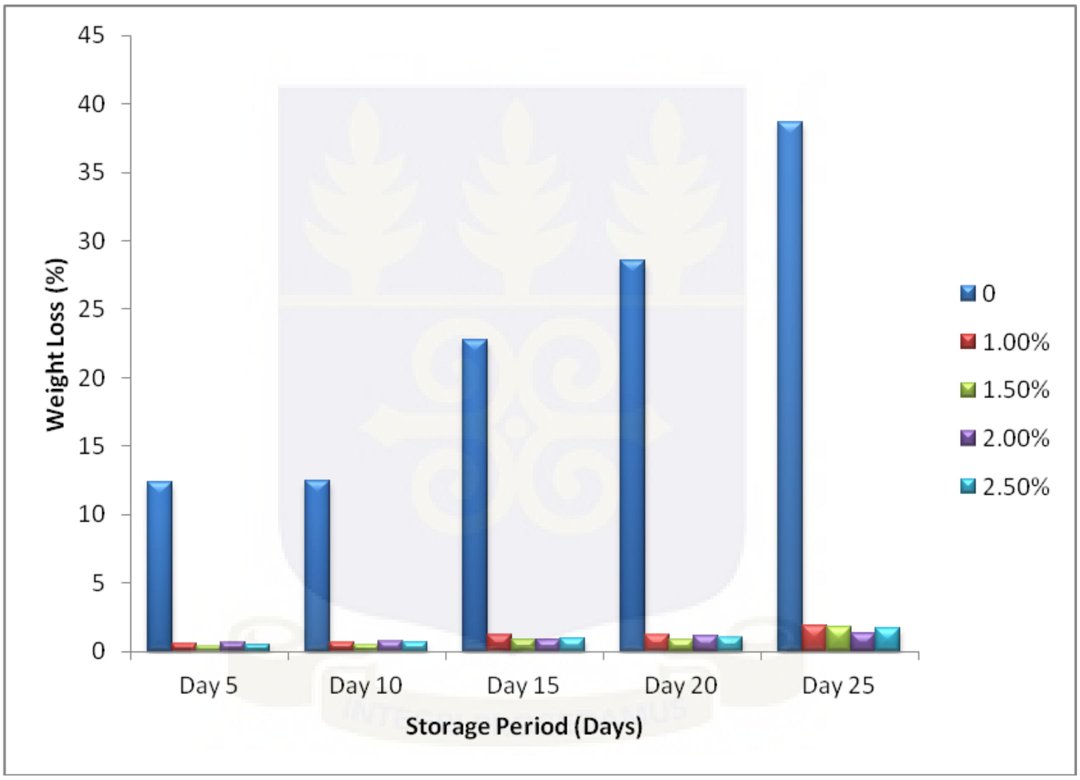

Fig. 4.2.2(b) Effect of $CaCl_2$ concentrations on physiological weight loss of tomato fruit stored at low temperature (10±1°C).

Weight loss increased significantly with 2.00 and 2.50 % $CaCl_2$ but not the other concentrations (1.00 and 1.50 %). Generally, weight loss increased with decreasing concentrations of $CaCl_2$ but increased with increasing storage days. There were significant differences (Appendix 18) in weight loss of tomato fruits among storage period.

In general, weight loss for all the treatments ranged between 0.41 – 38.67 % throughout the storage period as seen in Fig. 4.2.2(a) and Fig. 4.2.2(b). Percentage mean weight loss was greater in control fruits (22.93%) as compared to fruits treated with $CaCl_2$ (0.97%) and radiation treated (1.85%). The softening of tomato fruit after irradiation was as a result of biochemical and physiological processes like membrane damage, specific cell wall enzyme among others (Barka *et al*., 2000). This confirms the fact that irradiation affects the texture of some fruits as reported by Lee *et al*. (1968). The use of $CaCl_2$ on the other hand, improves the skin strength making the cell wall and tissues more resistant by controlling ripening and softening (Poovaiah, 1986), thus reducing loss in weight of the fruit.

Fruits stored at 28±1°C showed the largest percent weight loss as compared to those stored at 10±1°C for all treatments and their various levels throughout the storage period. For instance, control fruits showed percent weight loss of 15.66% after the 9th day when stored at ambient temperature whilst after 10 days weight loss was 12.47% for the same control fruits stored at 10°C. Postharvest recommendations indicate that tomatoes, including cherry and grape tomatoes, should be stored at 10°C or higher to avoid chilling injury (Roberts *et al*., 2002).

Nunes (2008) reported that maximum acceptable weight loss values before a tomato becomes unsalable ranges from 6-7%. With reference to the results, at ambient temperature, tomato fruits treated at 4kGy, 2kGy and control fruits experienced weight losses of 14.55%, 10.29% and 15.66% respectively on the 9th day, far in excess of 7.0%. Therefore, these fruits were beyond the salable range on the 9th day. At low temperature, fruits treated with gamma radiation and $CaCl_2$ are within the maximum acceptable weight loss range. However, control fruits throughout storage period were considered as fruits beyond the salable range.

Basically, evaporation and respiration are responsible for weight loss of fresh tomato fruits. In transpiration, water is lost due to differences in vapour pressure of water in the atmosphere and the transpiring surface. Respiration, on the other hand, causes a weight

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reduction because a carbon atom is lost from the fruit each time a carbon-dioxide molecule is produced from an absorbed oxygen molecule and evolved into the atmosphere (Bhowmik and Pan, 1992). High respiration rate of the fruit therefore results in higher evaporation of water from the fruit surface which leads to increase in percentage of weight loss.

4.2.5 pH of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following Irradiation.

Table 4.2.3(a) shows the effect of irradiation dose on pH of tomato fruit stored at ambient temperature (28±1°C). pH for control fruits ranged between 4.35 – 4.38 whilst that of irradiated fruits were between 4.26 – 4.62. The pH for control fruits reduced significantly after the 3rd day but increased on the 6th day.

Table 4.2.3(a) Effect of irradiation dose (kGy) on pH of tomato fruit stored at ambient temperature (28±1°C).

Storage Period	pH of Tomato Fruits				
(Days)	0	1 kGy	2 kGy	3 kGy	4 kGy
0	4.39^{Aa}	4.32^{Cb}	4.40^{Fc}	4.42^{Jd}	4.26^{Me}
3	4.35^{Bf}	4.33^{Cg}	4.43^{Gh}	4.44^{Jh}	4.37^{Ni}
6	4.38^{Aj}	4.38^{Dj}	4.47^{Hk}	4.57^{Kl}	4.59^{Om}
9	**ND	4.39^{En}	4.51^{Io}	4.52^{Lo}	4.62^{Pp}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

**ND – not determined.

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There was no significant difference between pH on the initial day and the final day of control fruits. However, there were significant differences in pH among storage days and irradiation doses (Appendix 1a and 1b).

It could be observed from the table (Table 4.2.3a) that fruits treated with gamma radiation generally showed an increase in pH throughout the storage period. For fruits irradiated at 2 and 4 kGy, the increase in pH was significant ($P<0.05$) with the advancement of days reaching 2.43 and 7.80 % respectively above the initial value by the final day (day 9). As fruits approach senescence or decay, the level of acidity reduces and this accounts for the reason why the pH increased after some few days of exposure to ambient conditions.

This result agress with Padmini (2006) who stated that pH increases with the advancement of storage days. Generally, there were significant differences in pH of tomato fruits in the radiation doses used among each storage day. Among storage days, pH of control fruits varied significantly from the irradiated fruits.

4.2.6 pH of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

Table 4.2.3(b) reveals the effect of $CaCl_2$ concentration (%) on pH of tomato fruit stored at ambient temperature (28±1°C). pH for control fruits ranged between 4.35 and 4.38 whilst that for fruits treated with $CaCl_2$ ranged between 4.10 and 4.41. pH reduced by the final day of evaluation (6th day) in control fruits, however, there was no significant difference between pH on the initial day and the final day for control fruits. The pH for tomato fruits treated with $CaCl_2$ ranged between 4.10 and 4.41 as depicted in table (4.2.3b).

Generally, there was no consistent relationship between $CaCl_2$ concentrations and pH. However, by the 9th day, pH of all treatment levels of $CaCl_2$ had reduced significantly. The decrease in pH could be attributed to the fact that pH increases to a maximum at or soon after the climacteric and then usually shows a slight fall as ripening progresses (Simmonds, 1969).

Table 4.2.3(b) Effect of $CaCl_2$ concentration (%) on pH of tomato fruit stored at ambient temperature (28±1°C).

Storage Period (Days)	pH of Tomato Fruits				
	0	1.00%	1.50%	2.00%	2.50%
0	4.39^{Aa}	4.29^{Cb}	4.37^{Ga}	4.27^{Ib}	4.27^{Lb}
3	4.35^{Bc}	4.33^{Dd}	4.34^{Gc}	4.41^{Je}	4.28^{Lf}
6	4.38^{Ag}	4.25^{Eh}	4.34^{Gi}	4.25^{Kh}	4.16^{Mj}
9	**ND	4.10^{Fk}	4.22^{Hl}	4.27^{Im}	4.24^{Nn}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

**ND – not determined.

There were significant differences in pH among storage days and irradiation doses (Appendix 2a and 2b). $CaCl_2$ treatment on pH of tomato fruits showed no consistency during storage and this confirms work by Bhattarai and Gautam (2006). This observation also agrees with reports on fruits like mango (Tirmazi and Wills, 1981) and strawberry (De Souza *et. al.*, 1999). Among storage days, there was no consistent relationship between pH for control fruits and $CaCl_2$ treated fruits.

Generally, fruits treated with $CaCl_2$ exhibited comparatively lower pH as compared to that of the fruits in the control set and radiation treated fruits. This may be attributed to the effect $CaCl_2$ has on obstructing enzymes such as polygalcturonase from reaching their

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active sites, thereby retarding tissue softening, limiting infection and delaying ripening (Scott and Wills, 1979; De-Souza *et al.*, 1999).

The tomato fruit is a commodity with a variably low pH (3.4 - 4.7) depending on variety and state of ripeness (Lund, 1992). The suitable range for fruits and vegetables according to Harris *et al*. (1991) is between 3.0 and 5.0. Hence, pH values of the tomato fruits obtained following various treatments fell within this range and would hinder the growth of microorganisms as most bacteria grow well over a range of pH range of 6 to 9 (Atlas, 1994).

4.2.7 pH of Tomato Fruits Stored at Low Temperature (10±1°C) Following Irradiation.

Table 4.2.4(a) displays pH of tomato fruits subjected to increasing doses of gamma radiation and stored at 10±1°C. pH of unirradiated tomato fruits fluctuated between 4.22 - 4.49 throughout the storage period whilst that of irradiated fruits ranged between 4.23 - 4.49 but did not reflect any consistent relationship with radiation doses. There were significant differences in pH among storage days and irradiation doses (Appendix 3a and 3b).

By the final day, pH had increased in all doses throughout the storage period. There were significant differences ($P<0.05$) in pH among each storage day at different doses at which tomato fruits were irradiated.

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Table 4.2.4(a) Effect of irradiation dose (kGy) on the pH of tomato fruit stored at low temperature (10±1°C).

Storage Period (Days)	pH of Tomato Fruits				
	0	1 kGy	2 kGy	3 kGy	4 kGy
0	4.22^{Aa}	4.23^{Fb}	4.30^{Jc}	4.35^{Nd}	4.36^{Qe}
5	4.40^{Bf}	4.32^{Gg}	4.34^{Jh}	4.44^{Pi}	4.42^{Rj}
10	4.35^{Ck}	4.40^{Hl}	4.38^{Km}	4.44^{Pn}	4.43^{Ro}
15	4.49^{Dp}	4.25^{Fq}	4.34^{Jr}	4.39^{Ns}	4.31^{St}
20	4.39^{Bu}	4.45^{Ivw}	4.39^{Mu}	4.42^{Ouv}	4.47^{Tw}
25	4.43^{Ex}	4.39^{Hy}	4.37^{Lz}	$4.41^{O\alpha}$	$4.49^{U\beta}$

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

Control fruits were also significantly different from irradiated fruit on all storage days. The results contradicts those obtained by Youssef *et al*. (2011) who reported that irradiating tomato fruits at 1.5, 3.0 and 4.5 kGy showed no significant effect on the acidity (pH) of tomato juice, working at a storage temperature of 4ºC. pH recorded for all irradiated fruits varied significantly but inconsistently over storage period.

4.2.8 pH of Tomato Fruits Stored at Low Temperature (10±1°C) Following $CaCl_2$ Coating.

Table 4.2.4(b) displays effect of $CaCl_2$ concentrations (%) on the pH of tomato fruit stored at 10±1°C. The pH of control fruits fluctuated between 4.22 - 4.49 throughout the storage period. Mean pH values for fruits treated with $CaCl_2$ ranged from 4.05 – 4.56 as depicted in Table 4.2.4(b).

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From the table, it could be observed that the fruits did not show any consistent relationship among the concentrations used although by the final day, pH values had increased significantly. $CaCl_2$ treated fruits at all concentrations increased in acidity from the initial to the 10th day whilst acidity reduced from the 15th to day 25. Generally, pH varied significantly within and among all $CaCl_2$ treated fruits and control fruits throughout storage.

The fluctuations in pH of the fruit could be due to maturity differences (Kirk and Sawyer, 1997). This is because, the more ripe a fruit the less acidic it becomes. The pH of climacteric fruits rises to a maximum and then usually shows a slight fall as ripening progresses (Simmonds, 1969). However, there were significant differences in pH among storage days and irradiation doses (Appendix 4a and 4b).

Table 4.2.4(b) Effect of $CaCl_2$ concentration (%) on the pH of tomato fruit stored at low temperature (10±1°C).

Storage Period	pH of Tomato Fruits				
(Days)	0	1.00%	1.50%	2.00%	2.50%
0	4.22^{Aa}	4.29^{Fb}	4.37^{Jc}	4.27^{Nab}	4.27^{Tab}
5	4.40^{Bd}	4.27^{Ge}	4.23^{Kf}	4.24^{Og}	4.12^{Uh}
10	4.35^{Ci}	4.27^{Gj}	4.24^{KLk}	4.13^{Pl}	4.05^{Vm}
15	4.49^{En}	4.33^{Ho}	4.28^{Lp}	4.34^{Qo}	4.45^{Wq}
20	4.39^{Br}	4.30^{Fs}	4.36^{Jt}	4.31^{Ru}	4.43^{Xv}
25	4.43^{Dw}	4.41^{Ix}	4.45^{My}	4.50^{Sz}	4.56^{Ya}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

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Simmonds (1969) explained further that the pH of a produce depends on the genotype, the soil type for cultivation and fertilizer application. For this study, though the same variety was used, there could have been a difference in the soil treatment the fruits received.

In all treatments used, irradiated fruits showed the highest pH range throughout the storage period. Mean pH values for fruits stored at low temperature ranged between 4.05 – 4.56 throughout the 25 days of storage whilst those stored at ambient temperature were between 4.10 – 4.62 for 9 days of analysis. Low temperature therefore reduced the pace at which ripening occur in the fruit which consequently showed in the mean pH values being lesser than those stored at ambient temperature.

4.2.9 Total Titratable Acidity (TTA) of Tomato Fruit Stored at Ambient Temperature (28±1°C) Following Irradiation.

Table 4.2.5(a) displays effect of radiation dose (kGy) on the TTA of tomato fruit stored at ambient temperature (28±1°C).

Table 4.2.5(a) Effect of irradiation dose (kGy) on the Total Titratable Acidity (TTA) of tomato fruit stored at ambient temperature (28±1°C).

Storage Period	Total Titratable Acidity (%) of Tomato Fruits				
(Days)	0	1 kGy	2 kGy	3 kGy	4 kGy
0	0.36^{Aa}	0.38^{Cb}	0.33^{Gc}	0.33^{Lc}	0.46^{Pd}
3	0.27^{Be}	0.33^{Df}	0.26^{Ig}	0.29^{JKh}	0.32^{Mi}
6	0.28^{Bj}	0.28^{Ek}	0.28^{Hl}	0.29^{Jm}	0.29^{Nn}
9	**ND	0.35^{Fo}	0.29^{Hp}	0.28^{Kp}	0.23^{Os}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

**ND – not determined.

TTA in control fruits reduced significantly from 0.36 – 0.28 % throughout the storage period resulting in 22.2 % reduction. TTA of irradiated tomato fruit also ranged between 0.23 – 0.46 % resulting in a mean of 0.32%.

Generally, fruits treated with gamma radiation reduced in TTA during the first 6 days but increased on the final day in all doses. The result confirms the findings of De Castro *et al.* (2006) who observed that titratable acidity decreased in the first 7 days storage period. The rise in TTA after the 6th day could be related to the increase of titratable acidity caused by the gaseous conditions (elevation of CO_2 concentration and reduction of O_2) during storage as period reported by De Souza *et al.* (1999). There were significant differences in pH among storage days and irradiation doses (Appendix 5a and 5b).

Fruits treated with 4kGy however, reduced significantly in TTA throughout the storage period. This confirms the fact that the amounts of organic acids usually decrease during maturity, because organic acids are substrates of respiration (Wills *et al.*, 1981). Generally, TTA among storage days differed significantly in all irradiated fruits and control fruits.

4.2.10 Total Titratable Acidity (TTA) of Tomato Fruit Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

Table 4.2.5(b) displays the effect of $CaCl_2$ concentration (%) on Total Titratable Acidity (TTA) of tomato fruit stored at ambient temperature (28±1°C). TTA in control fruits resulted in a mean of 0.30% whilst that for fruits treated with $CaCl_2$ is 0.41%. Control fruits showed a decrease in %TTA during storage. In general, TTA of tomato fruits increased with increasing concentration of $CaCl_2$ but only up to the 6th day of storage. By the 9th day, however, TTA decreased in all $CaCl_2$ treatments. This result confirms work done by Senevirathna and Daundasekera (2010). However, there were significant differences in pH among storage days and irradiation doses (Appendix 6a and 6b).

Table 4.2.5(b) Effect of $CaCl_2$ concentration (%) on Total Titratable Acidity (TTA) of tomato fruit stored at ambient temperature (28±1°C).

Storage Period (Days)	Total Titratable Acidity (%) of Tomato Fruits				
	0	1.00%	1.50%	2.00%	2.50%
0	0.37^{Aa}	0.42^{Cb}	0.41^{Fb}	0.47^{Ic}	0.48^{Md}
3	0.28^{Be}	0.43^{Df}	0.38^{Gg}	0.36^{Ji}	0.44^{Nh}
6	0.28^{Bj}	0.40^{Ek}	0.41^{Fk}	0.37^{Kl}	0.49^{Mm}
9	**ND	0.41^{En}	0.35^{Ho}	0.33^{Lp}	0.36^{Oo}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

**ND – not determined.

Comparatively, irradiated tomato samples and control fruits showed lower TTA throughout the storage period than $CaCl_2$ treatment. This may be attributed to the obstructing effect $CaCl_2$ has on enzymes such as polygalcturonase from reaching their active sites, thereby retarding tissue softening and delaying ripening which leads to slowing down the reduction of acidity in the fruit (De Souza *et al.*, 1999; Scott and Wills, 1979).

4.2.11 Total Titratable Acidity (TTA) of Tomato Fruit Stored at Low Temperature (10±1°C) Following Irradiation.

Table 4.2.6(a) shows effect of gamma radiation doses (kGy) on the TTA of tomato fruit stored at low temperature (10±1°C). Control fruits showed mean of 0.33% TTA

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throughout the storage period and displayed significant differences (P≤ 0.05) among storage days. For irradiated fruits, mean TTA ranged was 0.32% as in table 4.2.6(a).

Table 4.2.6(a) Effect of irradiation dose (kGy) on the TTA of tomato fruit stored at low temperature (10±1°C).

Storage Period (Days)	Total Titratable Acidity (%) of Tomato Fruits				
	0	1 kGy	2 kGy	3 kGy	4 kGy
0	0.51^{Aa}	0.47^{Gb}	0.34^{Mc}	0.36^{Qd}	0.37^{Ud}
5	0.28^{Be}	0.28^{Ff}	0.28^{Kg}	0.28^{Rh}	0.28^{STi}
10	0.33^{Cj}	0.28^{Fl}	0.29^{Lk}	0.31^{Om}	0.29^{Tjk}
15	0.25^{Dn}	0.38^{Ho}	0.35^{Np}	0.32^{Pq}	0.38^{Vo}
20	0.32^{Er}	0.26^{Is}	0.29^{KLt}	0.31^{Or}	0.31^{Wr}
25	0.31^{Eu}	0.32^{Ju}	0.34^{Mv}	0.32^{OPu}	0.28^{Sw}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

Generally, there were significant differences in %TTA among radiation doses used on each storage day though the differences were not consistent (Appendix 7a and 7b). Similarly, there were significant differences among storage days which reduced %TTA at all levels. Control fruits represented a greater percentage of TTA as compared to irradiated fruits.

The reason for reduction in TTA during storage was due to the amount of organic acids which usually decreases during maturity. This is because organic acids are substrates for respiration (Wills *et al.*,1981) and the acids are converted into salts and sugars by enzymes especially invertase (Deka, 2000).

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4.2.12 Total Titratable Acidity (TTA) of Tomato Fruit Stored at Low Temperature (10±1°C) Following $CaCl_2$ Coating.

Table 4.2.6(b) shows the effect of $CaCl_2$ concentration (%) on the TTA of tomato fruit stored at 10±1°C. Control fruits showed a decrease in %TTA and among storage days, there were significant differences ($P \leq 0.05$) in TTA (Appendix 8a and 8b). Fruits treated with $CaCl_2$ showed mean TTA of 0.41% as seen in Table 4.2.6(b).

Table 4.2.6(b) Effect of $CaCl_2$ concentration (%) on the TTA of tomato fruit stored at low temperature (10±1°C).

Storage Period (Days)	%Total Titratable Acidity of Tomato Fruits				
	0	1.00%	1.50%	2.00%	2.50%
0	0.51^{Aa}	0.42^{Fb}	0.41^{Jb}	0.47^{PRc}	0.48^{TUc}
5	0.28^{Bd}	0.45^{Ge}	0.44^{Ke}	0.41^{Qf}	0.49^{Tg}
10	0.33^{Ch}	0.42^{Fi}	0.34^{Lh}	0.46^{Pi}	0.47^{Ui}
15	0.25^{Dj}	0.37^{Hk}	0.41^{Jl}	0.48^{Rm}	0.31^{Vn}
20	0.32^{Eo}	0.35^{Ip}	0.31^{Mo}	0.39^{Sq}	0.38^{Wr}
25	0.31^{Es}	0.42^{Ft}	0.47^{Nu}	0.32^{Ts}	0.41^{Xt}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly ($P>0.05$) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different ($P>0.05$) from each other.

Generally, there were significant differences ($P \leq 0.05$) in %TTA among $CaCl_2$ concentrations during storage as %TTA generally increased with increasing concentration. Similarly, among storage days, %TTA showed significant differences as %TTA decreased though not consistently. These fluctuations have also been confirmed by Senevirathna and Daundasekera (2010) when tomato fruits were treated with $CaCl_2$.

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In all treatments used, fruits treated with gamma radiation showed the least mean TTA of 0.31% throughout the study period whilst control fruits and fruit treated with $CaCl_2$ showed 0.33 and 0.41% respectively.

The %TTA from fruits stored at ambient temperature was least (0.23 – 0.49%) as compared to those stored in the low temperature (0.26 – 0.51%).

Fluctuations in the %TTA in all treatments used with respect to advancement in storage could be related to differences in maturity stage of the fruits (Kirk and Sawyer, 1997). This is because, as the fruit matures, pH increases which results in a corresponding reduction in %TTA. Therefore, %TTA of tomato was expected to reduce parallel to advancement in storage. Salunkhe *et al.* (1974) explained further that the inconsistencies in %TTA in tomato fruits may also be related to the acidity declining after the first appearance of yellow colour in normal ripening. The %TTA then starts to increase again but after that increase, acidity starts to decrease, probably due to disappearance of citric acid.

According to Bhattacharya (2004), acidity is often used as an indication of maturity, as acid decreases on ripening of fruit. He reported further that during the ripening of tomatoes, acids such as malic and citric acid disappear which may be the main factor responsible for the reduction in titratable acidity during the storage. The microorganisms use citric acid as a carbon source, resulting in reduction in the titratable acidity. Comparatively, as pH increases, %TTA reduces as the acids are converted to sugars as the fruit ripens. Therefore, the lower the acidity the more riped the fruit.

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4.2.13 Total Soluble Solids (%, °Brix) of Tomato Fruit Stored at Ambient Temperature (28±1°C) Following Irradiation.

Table 4.2.7(a) displays effect of gamma radiation doses (kGy) on Total Soluble Solids (TSS) of tomato fruits stored at ambient temperature (28±1°C). Control fruits showed significant differences in TSS as storage days advanced. TSS reduced on the 3rd day and increased on the 6th day in control fruits. In irradiated fruits, TSS ranged from 4.03 - 5.00 %.

Table 4.2.7(a) Effect of Irradiation Dose (kGy) on Total Soluble Solids (TSS, %) of Tomato Fruit Stored at Ambient Temperature (28±1°C).

Storage Period (Days)	Total Soluble Solids (%) of Tomato Fruits				
	0	1 kGy	2 kGy	3 kGy	4 kGy
0	4.10^{Aa}	4.29^{Cb}	4.37^{Ec}	4.27^{Gb}	4.27^{Ib}
3	3.50^{Ba}	4.33^{Cb}	4.34^{Ec}	4.41^{Hd}	4.28^{Ie}
6	4.00^{Cg}	4.30^{Cgh}	4.27^{Egh}	4.40^{Hgh}	4.40^{Jgh}
9	**ND	4.87^{Di}	5.00^{Fj}	4.17^{Gk}	4.03^{Kl}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

**ND – not determined.

Tomato samples treated with gamma radiation showed no significant differences in TSS on days 0 and 6, however, there were significant differences on days 3 and 9. Similarly, there were no significant differences within each dose during storage. Fruits treated with gamma radiation increased in TSS from day 0 to day 9 whilst from day 3 to day 6, TSS reduced in fruits treated with 1, 2 and 3 kGy. On days 0 and 9, TSS increased with decreasing concentration radiation dose whilst on days 3 and 6, it increased with

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increasing dose. Fruits treated with gamma radiation showed the higher TSS content as compared to control (Table 4.2.7a).

The increase in TSS agrees with results obtained by Salunkhe *et al.* (1974) who stated that the sugar content of tomato fruit juices increases after the first appearance of yellow colour in normal ripening. Also, TSS have been shown to increase during ripening then remain constant with over-maturity (Gautier *et al.*, 2008). The results confirm those of Akter and Khan (2012), Prakash *et al.* (2002) that there were no significant differences in TSS as a result of irradiation as observed in this research. The significant changes in TSS in control fruits however, contradicts results by Akter and Khan (2012) in control tomato fruits stored at 25°C.

4.2.14 Total Soluble Solids (%, °Brix) of Tomato Fruit Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

Table 4.2.7(b) shows effect of $CaCl_2$ concentration (%) on Total Soluble Solids (TSS) of tomato fruit stored at ambient temperature (28±1°C). Control fruits showed between 3.50 – 4.10 % whilst that of fruits treated with $CaCl_2$ ranged from 3.30 - 4.17 %.

Control fruits showed significant differences in TSS as storage days advanced and reduced significantly. Fruits treated with $CaCl_2$ decreased insignificantly in TSS as storage days progressed. Generally, within each storage day, there were no significant differences among $CaCl_2$ concentrations.

Fruits treated with $CaCl_2$ showed lower TSS percentages as compared to the irradiated and control fruits. According to Sammi and Masud (2007), the significantly low TSS contents in treated fruits were the result of delayed ripening by the action of $CaCl_2$ treatment.

Table 4.2.7(b) Effect of $CaCl_2$ Concentration (%) on Total Soluble Solids (TSS, %) of Tomato Fruit Stored at Ambient Temperature (28±1°C).

Storage Period (Days)	Total Soluble Solids (%) of Tomato Fruits 0	1.00%	1.50%	2.00%	2.50%
0	4.1^{Aa}	4.00^{Eb}	4.00^{Hb}	4.00^{Kb}	4.17^{Nc}
3	3.50^{Bd}	3.90^{Ef}	3.67^{He}	3.60^{Kde}	4.00^{Mf}
6	4.00^{Ch}	3.50^{Fg}	3.30^{Ii}	3.73^{Kj}	3.57^{Og}
9	**ND	4.00^{Dk}	4.00^{Gk}	4.00^{Jk}	4.00^{Mk}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

**ND – not determined.

$CaCl_2$ treatment had little or no effect on TSS content as it did not show any significant differences in tomato fruits, this observation agrees with reports on fruits like mango (Tirmazi and Wills, 1981) and strawberry (De Souza *et al*., 1999).

4.2.15 Total Soluble Solids (%, °Brix) of Tomato Fruit Stored at Low Temperature (10±1°C) Following Irradiation.

Table 4.2.8(a) shows effect of gamma radiation doses (kGy) on Total Soluble Solids (TSS, °Brix) of tomato fruit stored at low temperature (10±1°C). TSS of control fruits showed between 3.90 and 4.33 % whilst irradiated fruits were between 4.00 and 5.13 % TSS.

Control fruits showed no significant differences in TSS during storage, however, TSS reduced slightly as storage progressed. Irradiated fruits showed no significant differences within the storage days.

Table 4.2.8(a) Effect of Irradiation Dose (kGy) on Total Soluble Solids (TSS, %) of Tomato Fruit Stored at Low Temperature (10±1°C).

Storage Period (Days)	Total Soluble Solids (%) of Tomato Fruits				
	0	1 kGy	2 kGy	3 kGy	4 kGy
0	4.33^{Aa}	4.29^{Ca}	4.37^{Ha}	4.27^{La}	4.27^{Pa}
5	3.93^{Cb}	4.27^{Cc}	4.23^{Hc}	4.24^{Lc}	4.12^{Qd}
10	4.13^{Be}	5.00^{Dg}	4.20^{Hef}	4.90^{Mg}	4.33^{Pf}
15	4.00^{Ch}	4.43^{Ek}	5.13^{Ji}	5.00^{Ni}	4.00^{Rh}
20	4.00^{Co}	4.00^{Fo}	4.00^{Ko}	4.00^{Oo}	4.00^{Ro}
25	3.90^{Cm}	4.50^{Gq}	4.50^{Iq}	4.00^{Or}	4.00^{Rr}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

Generally, during storage there were no significant differences in TSS within the doses throughout storage. Gamma radiation therefore did not have any effect on TSS. Similar results were found in tomato fruits stored at 12°C (Akter and Khan, 2012; Prakash *et al.*, 2002) and dragon fruits stored at 10°C (Wall and Khan, 2008).

4.2.16 Total Soluble Solids (%, °Brix) of Tomato Fruit Stored at Low Temperature (10±1°C) $CaCl_2$ Coating.

Table 4.2.8(b) shows the effect of $CaCl_2$ concentrations (%) on Total Soluble Solids (TSS) of tomato fruit stored at low temperature (10±1°C). Control fruits ranged between 3.90 - 4.33 % and did not show any significant difference in TSS as storage progressed though it reduced slightly. Fruits treated with $CaCl_2$ had TSS of 3.43 - 4.07% throughout storage period.

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Table 4.2.8(b) Effect of $CaCl_2$ Concentrations (%) on Total Soluble Solids (TSS, %) of Tomato Fruit Stored at Low Temperature (10±1°C).

Storage Period	Total Soluble Solids (%) of Tomato Fruits				
(Days)	0	1.00%	1.50%	2.00%	2.50%
0	4.33^{Aa}	4.00^{Db}	4.00^{Gb}	4.00^{Hb}	4.00^{Kb}
5	3.93^{Cc}	4.07^{Dc}	4.00^{Gc}	3.90^{Hc}	3.50^{Jd}
10	4.13^{Be}	3.53^{Ef}	4.00^{Gg}	4.00^{Hg}	4.00^{Kg}
15	4.00^{Ch}	3.77^{Fj}	4.00^{Gh}	3.53^{Ii}	4.00^{Kh}
20	4.00^{Cl}	3.77^{Fk}	4.00^{Gl}	4.00^{Hl}	4.00^{Kl}
25	3.90^{Cm}	3.50^{En}	3.93^{Gm}	4.00^{Hn}	3.43^{Jn}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

Fruits treated with $CaCl_2$ also showed no significant differences during storage among the concentrations. A similar trend showed within the $CaCl_2$ concentrations of each day of storage, thus no significant differences were observed.

These results agree with reports on fruits like mango (Tirmazi and Wills, 1981) and strawberry (De Souza *et al*., 1999) where $CaCl_2$ treatment had little or no effect on TSS content as it did not show any significant differences. Comparing all treatments used, irradiated fruits displayed the highest TSS (3.90 - 5.13%) throughout storage as seen in the Table 4.2.8(a) followed by control fruit (3.90 - 4.33 %) whilst $CaCl_2$ treated fruits showed the least (3.50 – 4.00 %). The TSS for all treatments used for fruits stored at low temperature ranged between 3.43 - 5.13 % which recorded the largest TSS whilst those stored at ambient temperature ranged from 3.30 – 5.00%.

The total soluble solids content (TSS) shows high positive correlation with sugars content, and therefore is generally accepted as an important quality trait of fruits. About 50 to 65% of soluble solids contents are sugars (glucose and fructose) and their amounts and proportions influences the organoleptic quality of tomatoes (Adedeji *et al*., 2006).

The TSS content in fruits is an important criterion in determining the suitability of varieties for processing. High TSS is desirable to yield higher recovery of processed products. Guold and Berry (1972) worked on tomatoes for canning and formulated that for varieties suitable for processing, TSS content should be more than 5%. In the results obtained, however, the fruits can be said to be not suitable for canning purposes because the TSS readings were all less than 5 % on the initial day.

4.2.17 Moisture Content of Tomato Fruit Stored at Ambient Temperature (28±1°C) Following Irradiation.

Fig. 4.2.9(a) shows the moisture contents of tomato fruits stored at ambient temperature (28±1°C) following gamma radiation of varying doses (kGy). Control fruits ranged between 94.49 – 95.45 % moisture content. Irradiated tomato fruits showed between 94.62 – 96.53 % moisture content.

Control fruits showed no difference in moisture content on day 0 to day 3. However, % moisture content decreased significantly on the 6th day in control fruits. Generally, during storage, there were no significant differences in % moisture content within radiation doses. However, days 0 and 9 differed significantly in fruits treated with 2 and 4 kGy.

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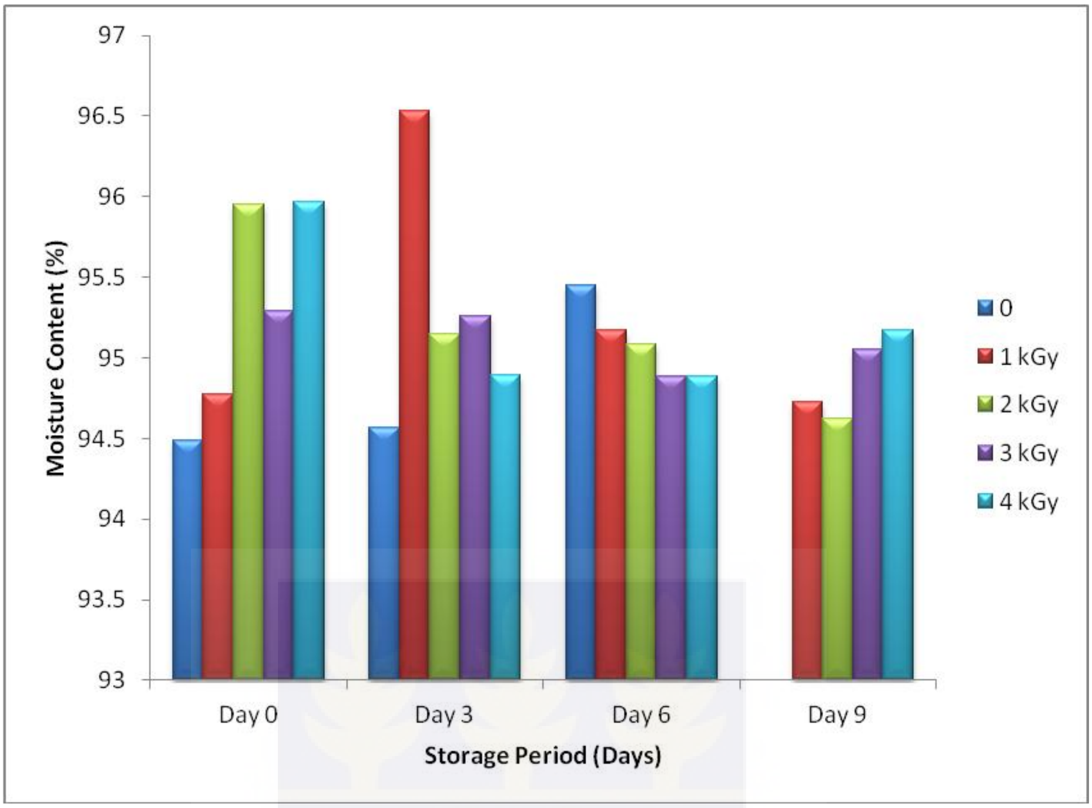

Fig. 4.2.9(a) Effect of Irradiation Dose (kGy) on Moisture Content of Tomato Fruit Stored at Ambient Temperature (28±1°C).

From the figure above (Fig. 4.2.9a) it can be observed that on day 0, tomato fruits irradiated at 2 and 4 kGy resulted in significantly higher % moisture content than those treated with 1 and 3 kGy both of which were different from that of control fruits. On the 3rd day, tomato fruits treated at 1 kGy showed a significantly higher % moisture content than the other doses including the control. On the 6th day, irradiated tomato fruits treated at all doses did not differ from each other including control fruits. On the 9th day, tomato fruits treated at 1 and 2 kGy resulted in lower % moisture content than tomato fruits treated at 3 and 4 kGy.

The highest moisture content was recorded by 1 kGy on the 3rd day whilst the least was shown by 2 kGy on day 9.

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4.2.18 Moisture Content of Tomato Fruit Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

Fig. 4.2.9 (b) displays effect of $CaCl_2$ concentration on moisture content of tomato fruit stored at ambient temperature (28±1°C). Control fruits displayed between 94.49 – 95.45 % Moisture Content which was comparatively higher than that of irradiated tomato fruits (94.62 – 96.53 %).

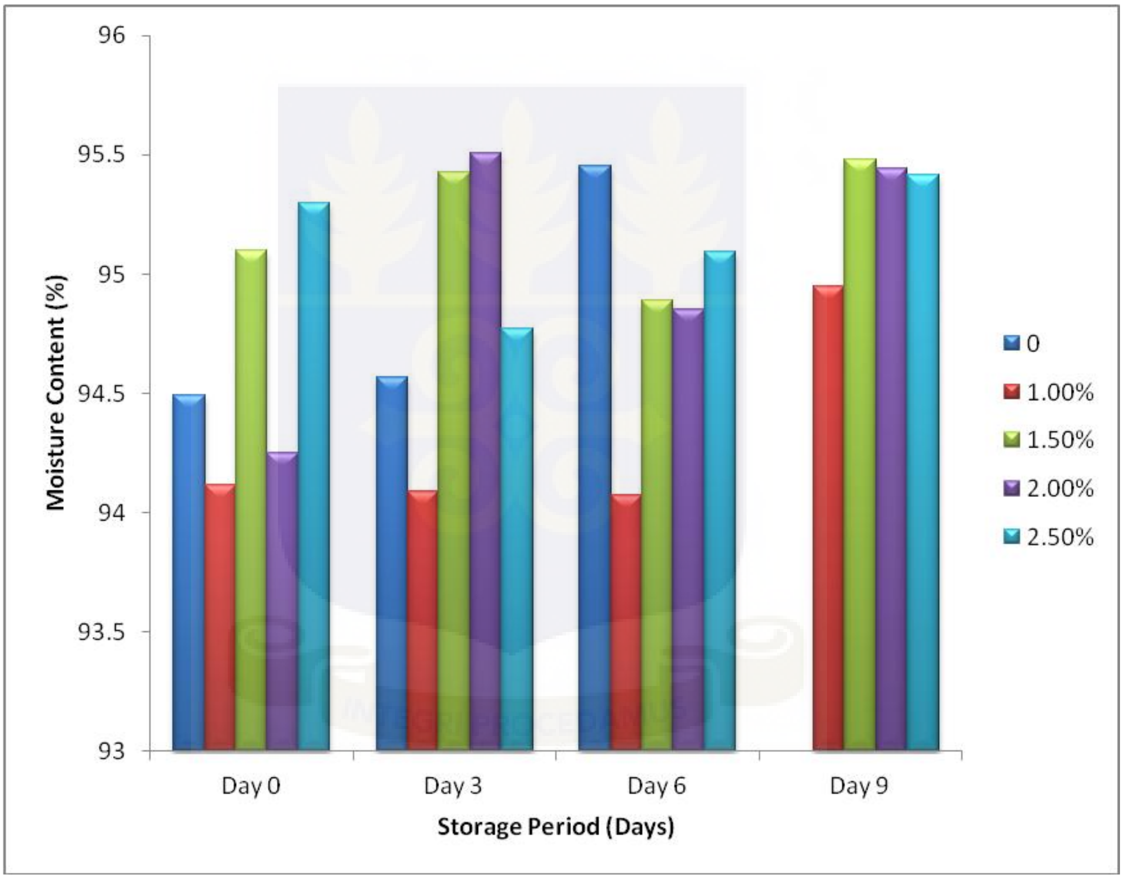

Fig. 4.2.9(b) Effect of $CaCl_2$ concentration on moisture content of tomato fruit stored at ambient temperature (28±1°C).

Control fruits showed no difference in moisture content between day 0 and day 3, however, % moisture content increased significantly on the 6th day. From the figure (Fig. 4.2.9b), tomato fruits treated with 1.50 and 2.50 % $CaCl_2$ concentration resulted in significantly higher % moisture content than those treated with 1.00 and 2.00 %, but did not differ from that of control fruits on day 0.

On the 3rd day, tomato fruits treated at 1.50, 2.00 and 2.50 % $CaCl_2$ concentration resulted in significantly higher % moisture content than those treated at 1.00% as well control fruits. On the 6th day, tomato fruits treated at 1.50, 2.00 and 2.50 % $CaCl_2$ concentration resulted in significantly higher % moisture content and did not differ from control fruits than those treated at 1.00% concentration. On the 9th day, tomato fruits treated at 1.00% concentration resulted in significantly lower % moisture content than tomato fruits treated at 1.50, 2.00 and 2.50 % $CaCl_2$ concentration. Tomato fruits treated at 2.00 % showed the highest moisture content on day 3 whilst the least was 1.00 % on day 6.

The mean moisture content varied from 94.09 to 96.53 % and this falls within the ranges reported by Amanat *et al.* (2009) on other tomato varieties. Tomato fruits irradiated showed between 94.62 – 96.53 % moisture content which was comparatively higher than that of $CaCl_2$ treated fruits (94.09 to 95.51 %) and control fruits (94.49 – 94.57 %).

The use of $CaCl_2$ interacts with pectic acid to form calcium pectate, which has a firming effect on cell walls (Poovaiah, 1986). This prevents the loss of moisture from fruits which accounted for the reduction in moisture loss of $CaCl_2$ treated fruits. Irradiation on the other hand causes softening to fruits (Barka *et al.*, 2000) and the softening gives the fruit less total solids.

4.2.19 Moisture Content of Tomato Fruit Stored at Low Temperature (10±1°C) Following Irradiation.

Fig. 4.2.10(a) shows the effect of gamma radiation doses on moisture content of tomato fruit stored at low temperature (10±1°C). Moisture content of control fruits ranged between 94.49 and 95.60 % which resulted in no significant differences during storage. Moisture content of irradiated fruits ranged between 94.32 - 95.97 %.

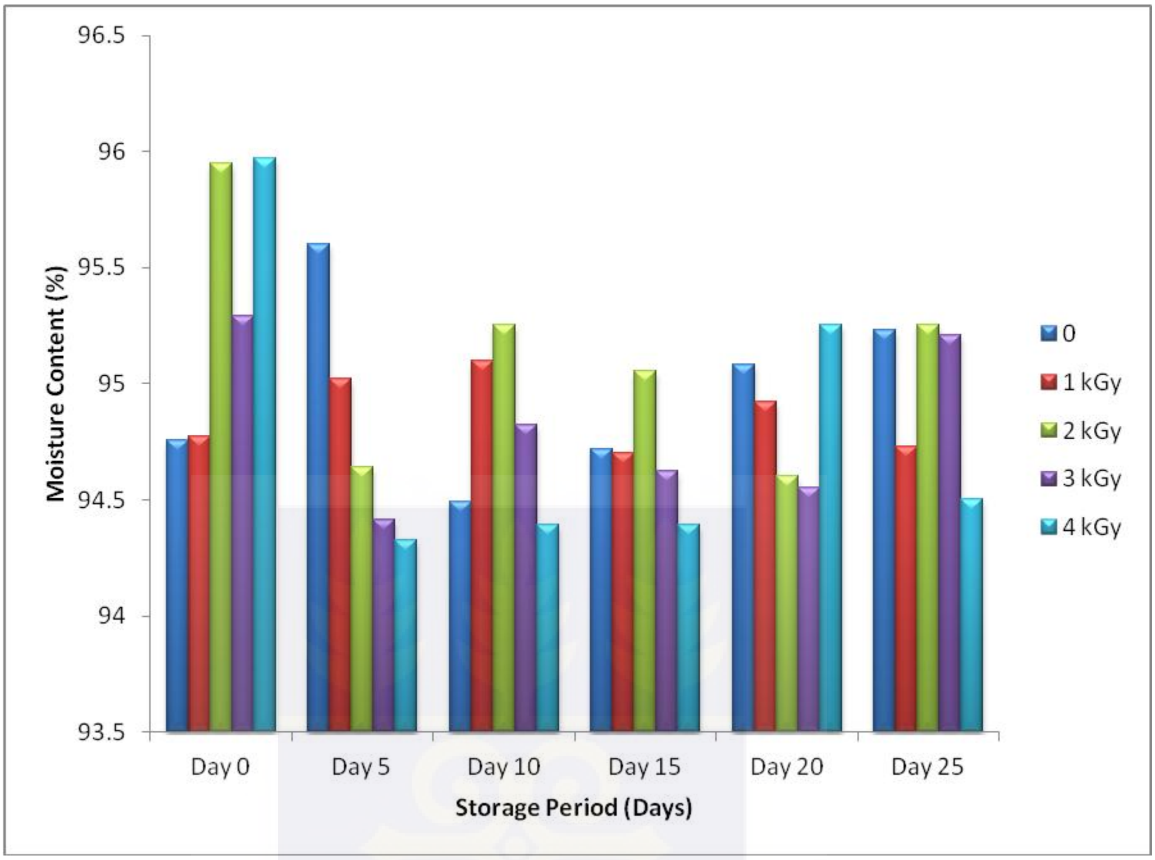

Fig. 4.2.10(a) Effect of Radiation Dose (kGy) on Moisture Content of Tomato Fruit Stored at Low Temperature (10±1°C).

Among radiation doses, there were no significant differences in % moisture content throughout the storage period. On day 0, tomato fruits treated with 3kGy gamma radiation showed a significant difference in % moisture content. However, 2 and 4 kGy were not significantly different and this was the same case for 1kGy and control fruits. On day 5, fruits treated with 2, 3 and 4 kGy showed no significant differences in moisture content. On day 10, fruits treated with 1, 2 and 3 kGy showed no significant changes and did not differ from 3 and 4 kGy and control fruits. On day 15, fruits treated with 4kGy were significantly different from all the other treatments including the control fruits. On day 20, all treatments showed no significant differences. On day 25, 1 and 4 kGy were not significantly different. Similarly, 2 and 3 kGy and control fruits were also not different.

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4.2.20 Moisture Content of Tomato Fruit Stored at Low Temperature (10±1°C) Following $CaCl_2$ Coating.

Fig. 4.2.10(b) depicts the effect of $CaCl_2$ concentration on the moisture content of tomato fruit stored at 10±1°C over a period of 25 days. Control fruits ranged between 94.49 to 95.60 % moisture content. Moisture content for $CaCl_2$ treated fruits ranged from 94.16 and 95.85 %. Generally, during storage, no significant differences resulted in control fruits. All fruits treated with of calcium chloride did not show any significant difference in % moisture content of tomato fruits during storage.

On day 0, fruits treated with 1.00, 2.00 and 2.50 % $CaCl_2$ concentration resulted in no significant differences but all were different from the control and 1.50% treated fruits. On day 5, all treatments showed significant differences. Day 10 resulted in no significant differences in all treatments. On day 15, fruits treated with 1.00, 1.50 and 2.00 % $CaCl_2$ concentrations were the same whilst 2.50% and control fruits were not significantly different. However, 1.50% treated fruits were not significantly different from 2.50% and the control fruits. On day 20, all fruits subjected $CaCl_2$ treatment were not significantly different from each other. Day 25 resulted in no significant differences in 1.00, 1.50 and 2.50 % $CaCl_2$ concentration. However, control fruits did not differ from fruits treated with 2.00 % on day 20 and 25. $CaCl_2$ application on tomato fruits therefore did not show any effect on % moisture content during storage.

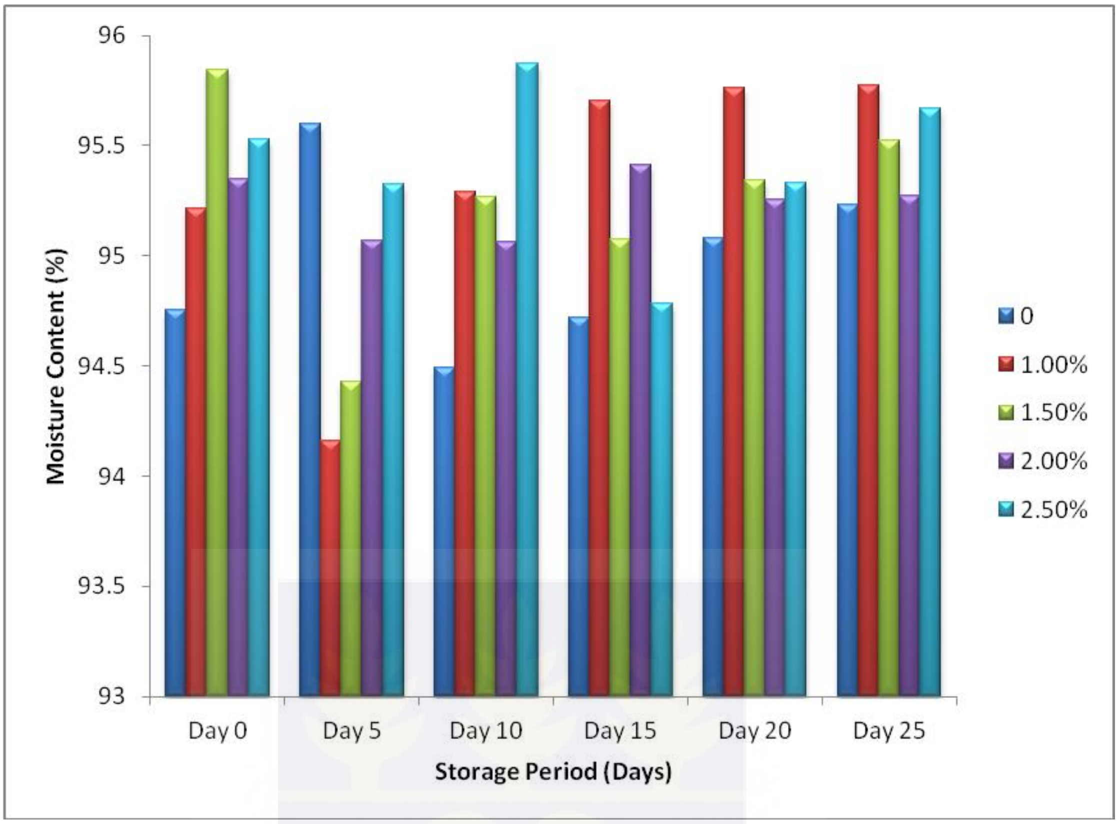

Fig. 4.2.10(b) Effect of $CaCl_2$ Concentration on Moisture Content of Tomato Fruit Stored at Low Temperature (10±1°C).

Generally, % moisture was greater in irradiated fruits (94.14 – 95.85 %) than $CaCl_2$ treated fruits (94.32 – 95.97 %) and control (94.49 – 95.60 %). Irradiation causes softening to fruits as a result of biochemical processes like cell wall enzyme and membrane damage (Barka *et al.*, 2000) which gives the fruit a greater moisture content and a lesser amount of total solids. On the other hand, the use $CaCl_2$ has a firming effect on cell walls (Poovaiah, 1986). This prevents the loss of moisture from fruits which accounted for the high content in total solids of $CaCl_2$ treated fruits. High total solids is a desirable characteristic for the canned tomato industry since it improves the quality of the processed product and consequently reduces processing cost (DePascale *et al.*, 2001).

Among storage conditions, % moisture content was greater at ambient temperature than low temperature storage due to the minimal ripening of fruits upon exposure of to low temperature. This has been confirmed by Shewfelt *et al.*, (1986) and De Castro *et al.*,

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(2005) that for longer period, ripe tomato can be stored at a temperature of 10-15°C as chilling injury and ripening are minimal.

The quality of most fruits and vegetables is affected by water loss during storage, which depends on the temperature and relative humidity conditions (Perez *et al*., 2003). Irradiation did not have any significant effect on the moisture content among storage days. Yaman and Bayoindril (2002) reported the changes in firmness diffusion driven by a gradient of water vapour pressure at different locations as the reason for primary mechanism of moisture loss from fresh fruits and vegetables.

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4.3 NUTRITIONAL CONTENT OF BURKINA TOMATO FRUITS FOLLOWING GAMMA RADIATION AND $CaCl_2$ COATING.

4.3.1 Vitamin C Content of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following Irradiation.

Fig. 4.3.1(a) displays effect of irradiation dose on vitamin C content of tomato fruit stored at ambient temperature (28±1°C). From the figure, it can be observed that vitamin C content in control fruits ranged from 19.11 – 19.80 mg/100 g whilst that of irradiated fruits ranged from 8.65 to 15.24 mg/100g.

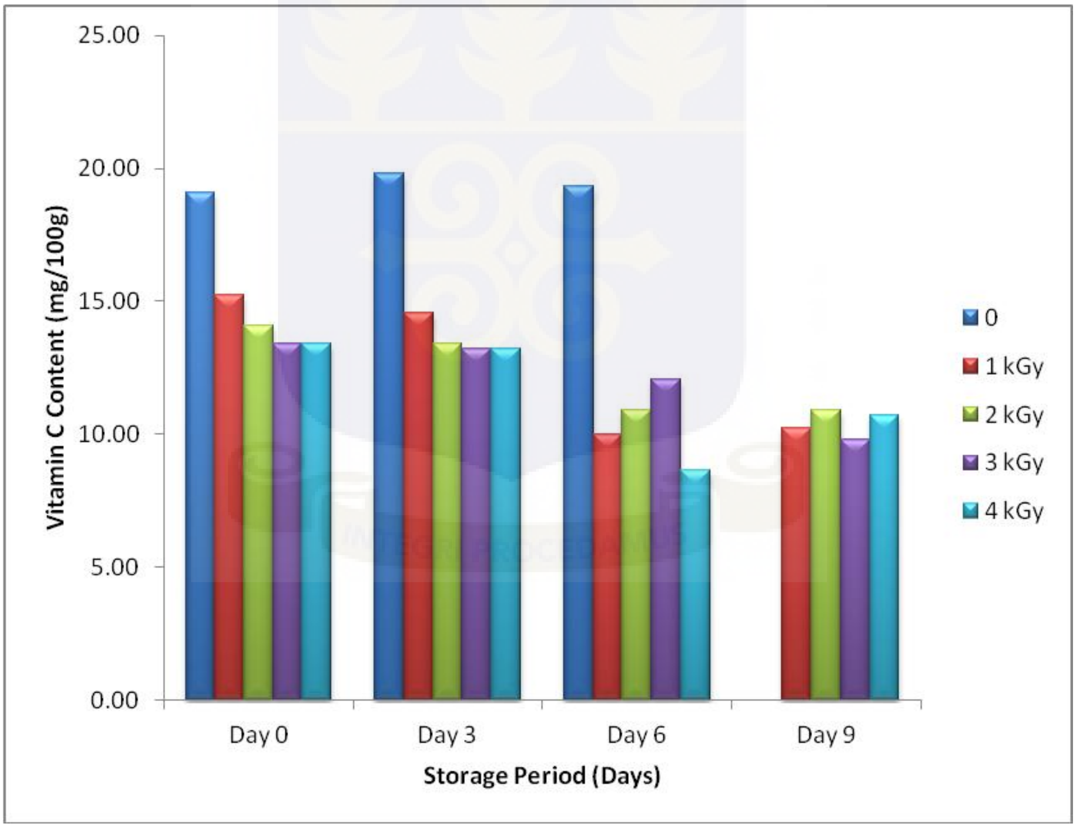

Fig. 4.3.1(a) Effect of irradiation dose on vitamin C content of tomato fruits stored at ambient temperature (28±1°C).

Vitamin C content of fruits in the control set increased on the 3rd day from 19.11 to 19.80 mg/100g but decreased on the 6th day. The same result has been shown by Pamplona-Roger (2003) who found out that the vitamin C level for tomato is 19.10mg/100g. The

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initial increase in vitamin C in control fruit is due to an increase in vitamin C during ripening then a decrease during senescence (Selvaraj *et al*., 1982, Lazan *et al*. 1990). Vitamin C content of irradiated fruits ranged between 8.65 to 15.24 mg/100g as seen in Fig. 4.3.1(a) above. There were no significant differences in vitamin C content among all doses used on days 0 and 3. Similarly, on days 6 and 9, vitamin C content for 1 and 2 kGy did not differ. However, there were significant differences in vitamin C content of fruits irradiated at 3 and 4 kGy.

Unlike fruits in the control set, irradiation caused a decrease in vitamin C of tomato fruit as depicted in Fig. 4.3.1(a). However, fruits in the control set increased in vitamin C content on the 3^{rd} day but reduced significantly on the 6^{th} day though the amount of vitamin C was not significantly different from that of the initial day. Generally, all the radiation treatments used significantly ($p < 0.05$) decreased vitamin C content of tomato fruits. However, vitamin C content of fruits in the control set was significantly higher than irradiated fruits. This was expected because vitamin C is sensitive to oxidation but gamma radiation causes water radiolysis of tomato juice producing free radicals which are strong oxidizing agent (Variyar *et al*., 2004). During storage, Fig. 4.3.1(a) illustrated that vitamin C content of irradiated tomato fruits significantly decreased ($p < 0.05$) but at different levels among various treatments.

4.3.2 Vitamin C Content of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

Fig. 4.3.1 (b) displays the effect of $CaCl_2$ concentration on the vitamin C content of tomato fruit stored at ambient temperature (28±1°C) for 9 days. Control fruit ranged from 19.11 –

19.80 mg/100 g vitamin C. For fruits treated with $CaCl_2$, vitamin C content ranging from 14.79 to 23.21 mg/100 g as depicted in Fig. 4.3.1 (b).

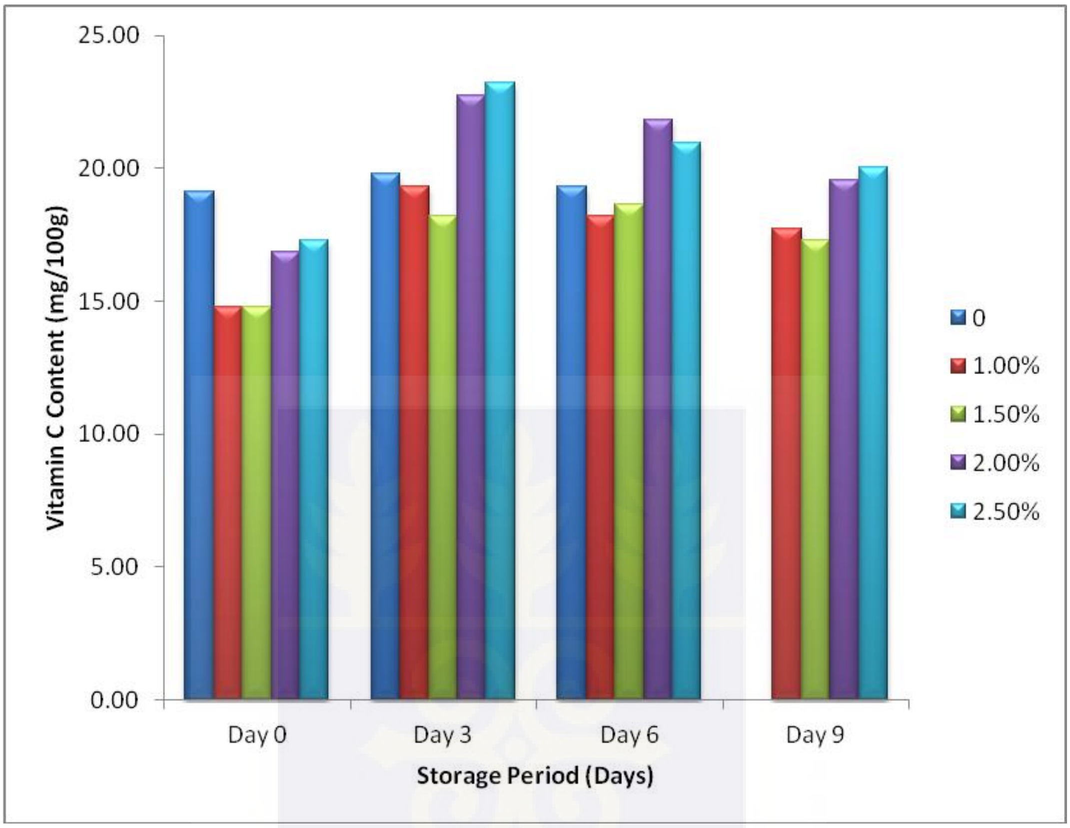

Fig. 4.3.1 (b) Effect of $CaCl_2$ concentration on the vitamin C content of tomato fruits stored at ambient temperature (28±1°C).

For all concentrations of $CaCl_2$ applied, vitamin C content of the fruits increased from day 0 to day 3 but reduced gradually though not significantly by the final day. Vitamin C content of fruits in the control set was highest (19.11 mg/100 g) at the onset of the storage but dropped slightly with storage period, though not significantly. This initial value was statistically higher than values recorded for fruits subjected to the various concentrations of $CaCl_2$ coating tested. However, fruits subjected to 2.00 and 2.50 % $CaCl_2$ coating recorded significantly higher levels of vitamin C compared to the control and lower levels of $CaCl_2$ coating by the 3rd and 6th day of storage. The use of $CaCl_2$ coating appears to have stimulated vitamin C production in the fruits but this waned with storage time.

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The results agree with those obtained by Sammi and Masud (2007) who stated that fruits treated with calcium chloride showed the highest vitamin C content. The slowing down of vitamin loss in $CaCl_2$ treated fruits is attributed to the low oxygen permeability of the coating film formed on the surface of the fruit (Ayranci and Tune, 2003).

On the whole, vitamin C content of the tomato fruit used ranged from 8.65 to 23.21 mg/100 g fruit and this falls outside the range obtained by Grierson and Kader (1986) who observed that the vitamin C content of ripe tomato ranges from 15 to 23 mg/100 g fruit. It must, however, be noted that the content of vitamin C in tomato could vary according to the variety of tomato, plant origin, condition of planting, harvesting, and maturity stage of the fruit among others.

4.3.3 Vitamin C Content of Tomato Fruits Stored at Low Temperature (10±1°C) Following Irradiation.

Fig. 4.3.2(a) shows the effect of irradiation dose on vitamin C content of tomato fruit stored at low temperature (10±1°C) for 25 days. Control fruits recorded between 9.33 – 22.07 mg/100g vitamin C content throughout the storage period. Vitamin C content of irradiated fruits ranged between 7.85 – 20.25 mg/100 g.

Generally, vitamin C reduced significantly in control fruits during storage though there was an increase on the 5th day of storage. Vitamin C content of irradiated tomato fruit ranged between 7.85 – 20.25 mg/100g. Similar results were obtained by Purkayastha and Mahanta (2010) who also found out that the vitamin C levels in five tomato cultivars ranged from 12.68 mg/100 g - 21.54 mg/100g.

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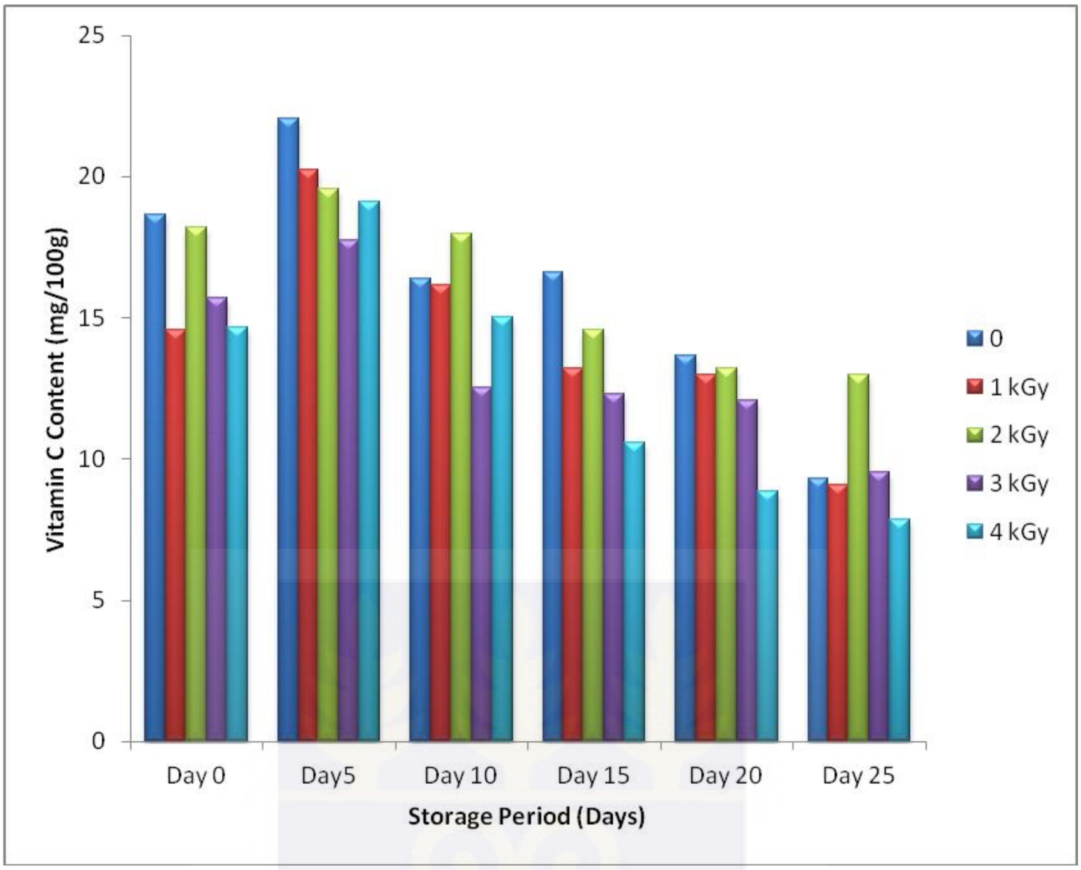

Fig. 4.3.2(a) Effect of irradiation dose on vitamin C content of tomato fruits stored at low temperature (10±1°C).

After day 0, vitamin C increased significantly in all doses used but then decreased gradually throughout the storage period. The initial increase in vitamin C can be related to ongoing ripening process in the fruits after which vitamin C content started to decline (Selvaraj *et al*., 1982).

The eventual decrease in vitamin C during storage with advancement of storage period was probably due to the sensitivity of vitamin C to oxygen, light and heat as well as being easily oxidized in the presence of oxygen by both enzymatic and non-enzymatic catalysts of oxidation process in tomato (Mapson, 1970; Moore *et al*., 1995).

4.3.4 Vitamin C Content of Tomato Fruits Stored at Low Temperature (10±1°C) following $CaCl_2$ Coating.

Fig. 4.3.2(b) shows effect of $CaCl_2$ concentration on the vitamin C content of tomato fruit stored at 10±1°C. Vitamin C content of fruits treated with $CaCl_2$ ranged from 10.47 – 23.66 mg/100g and 9.33 – 22.07 mg/100g in fruits in the control set.

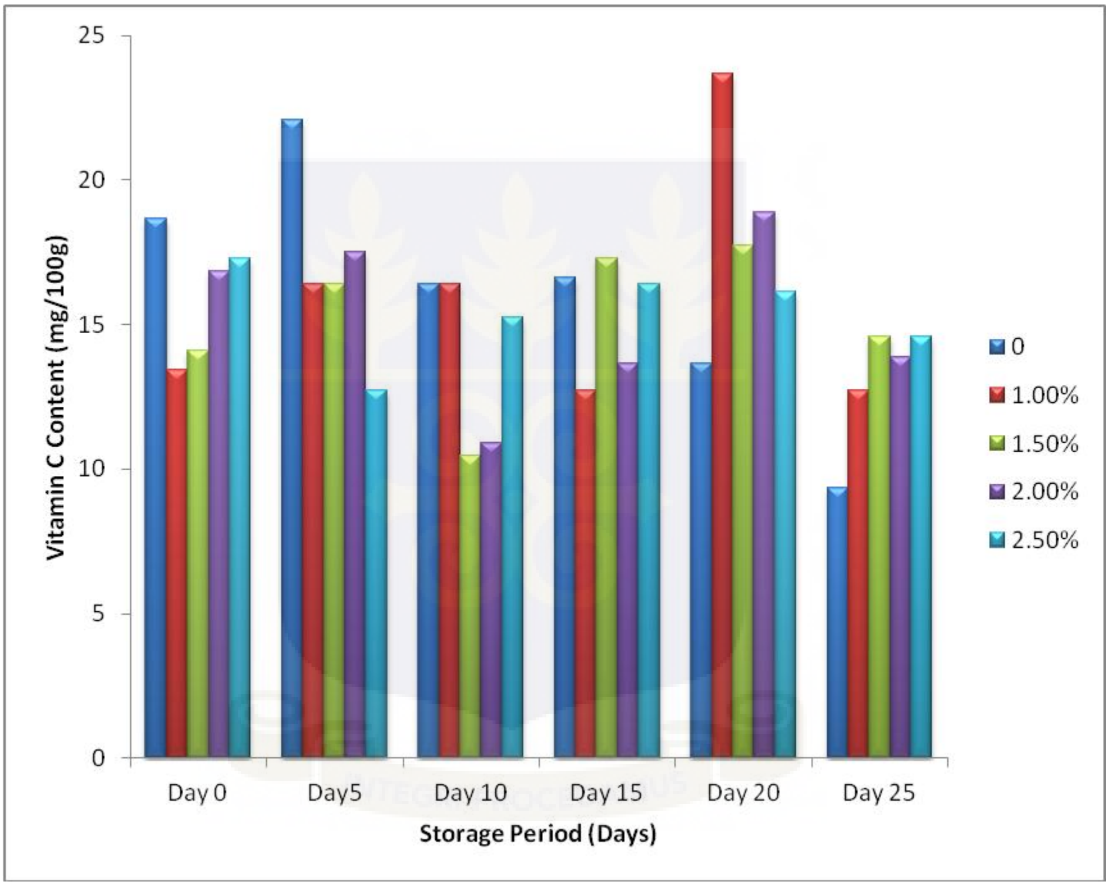

Fig. 4.3.2(b) Effect of $CaCl_2$ concentration on the vitamin C content of tomato fruits stored at low temperature (10±1°C).

Generally, all fruits decreased in vitamin C significantly by the final day of analysis as compared to the vitamin C content on day 0 at 50.00, 5.07, 17.58 and 15.79 % in control fruits and fruits treated at 1.00, 2.00, and 2.50 % $CaCl_2$ concentrations respectively. It was clear that the percentage loss of vitamin C content during storage of samples treated with $CaCl_2$ was much lower than that of samples in the control group. However, after the initial day, vitamin C increased significantly in all $CaCl_2$ concentrations used except for 2.50 %

which increased after day 10. The increase in vitamin C content in $CaCl_2$ treated fruits could probably be due to the slowing down of the ripening process by $CaCl_2$, hence keeping vitamin C out of the oxidation that occurs during normal ripening. Generally, the different levels of $CaCl_2$ concentrations used did not cause any significant changes in the vitamin C content of tomato fruits including control samples throughout the storage period.

Comparatively, fruits treated with radiation showed the least vitamin C content (7.85 – 20.25 mg/100g) as compared to fruits treated with $CaCl_2$ (10.47 – 23.66 mg/100g) and control fruits (9.33 – 22.07 mg/100g).

In all treatments used and at both storage temperatures, vitamin C content reduced with the advancement of storage days and this could be attributed to its sensitivity to oxygen, light and heat (Moore *et al.*, 1995). All fruits treated with $CaCl_2$ showed the higher vitamin C content under all storage conditions as compared to the other treatments used. The use of $CaCl_2$ in fruits leads to the favourable effect of reduction of antioxidants such as vitamin C loss in horticultural commodities such as strawberries (Luna-Guzman and Barrett, 2000) and an increase in vitamin C content in $CaCl_2$ treated fruits like pineapples and guavas (Mohammed *et al*., 1993) and papayas (Poovaiah, 1986). Loss of ascorbic acid in radiated fruits and vegetables could be due to irradiation-induced oxidation of ascorbic acid to dehydroascorbic acid (Fan and Sommers, 2013).

Preservation of vitamin C content during storage is a difficult task since it undergoes oxidation. The presence of higher oxygen concentrations in the storage atmosphere hastens this process (Okolie and Sannie, 2012). However in the present investigation, the ascorbic acid content of fruits was significantly influenced by various post - harvest treatments and storage conditions.

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4.3.5 Lycopene Content of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following Irradiation.

Fig. 4.3.3(a) displays effect of irradiation dose on lycopene contents of tomato fruits stored at ambient temperature (28±1°C) for 9 days. . Lycopene content of irradiated fruits ranged between 15.10 and 71.01 mg/kg whiles control fruits ranged between 55.85 and 115.63 mg/kg.

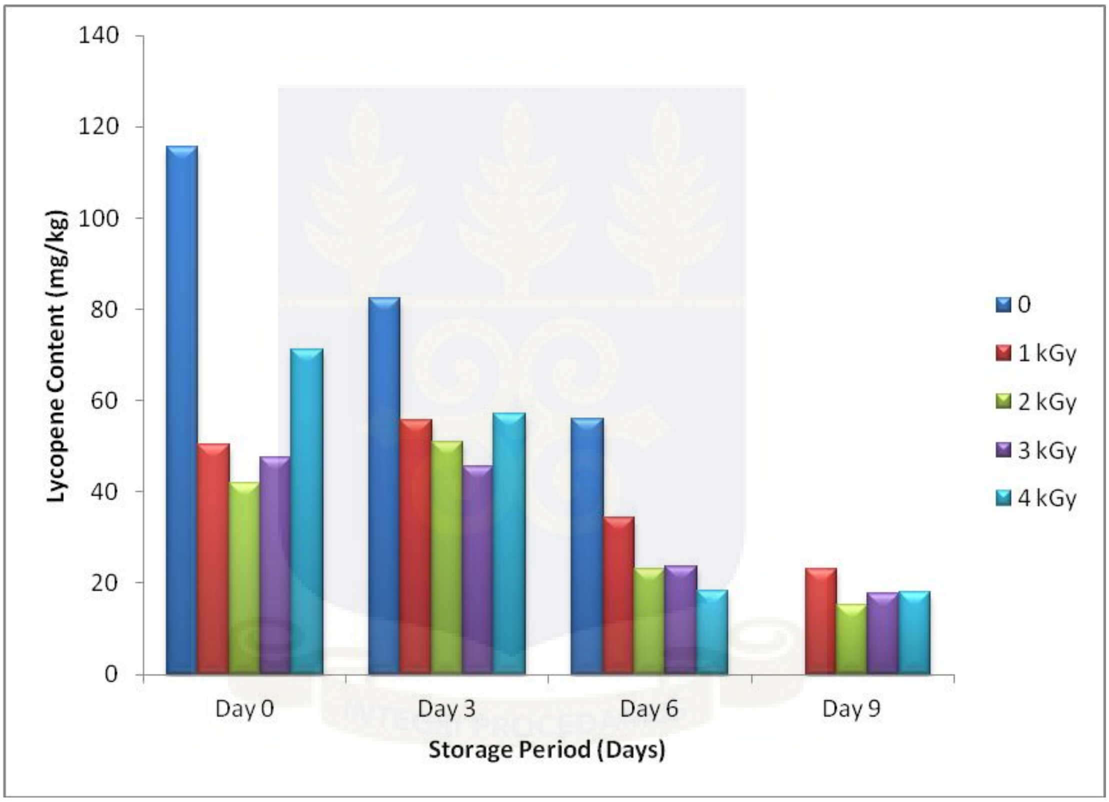

Fig. 4.3.3(a) Effect of irradiation dose on lycopene content of tomato fruits stored at ambient temperature (28±1°C).

Lycopene content was highest in control fruits but decreased significantly throughout the storage period. Similarly, lycopene content reduced in all doses as storage days progressed. In each radiation dose used, days 0 and 3 did not differ significantly in lycopene content. In like manner, days 6 and 9 were also not significantly different from each other in all doses except for fruits irradiated with 1kGy.

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Generally, among storage days, lycopene content in tomato fruits at all doses did not differ significantly. The results indicated that gamma radiation at doses of 1, 2, 3 and 4 kGy did not show significant effect on the total lycopene content in tomato. These results confirm that of Youssef *et al*., (2011) that gamma irradiation at doses of 1.5, 3.0 and 4.5 kGy did not have any significant effect on the total lycopene content in tomato juice. However, in a few cases there were significant differences and this may be related to the maturity differences of the fruit (Kirk and Sawyer, 1997).

On the whole, irradiated fruits showed lower reduction in lycopene content than control fruits.

4.3.6 Lycopene Content of Tomato Fruits Stored at Ambient Temperature (28±1°C) Following $CaCl_2$ Coating.

Fig. 4.3.3(b) shows effect of $CaCl_2$ concentration on the lycopene content of tomato fruit stored at ambient temperature (28±1°C) for 9 days. Lycopene content in $CaCl_2$ treated samples ranged between 38.56 and 125.45 mg/kg whiles that of control fruits ranged between 55.85 and 115.63 mg/kg.

Generally, changes in lycopene content at the end of the storage period were proportional to the $CaCl_2$ concentration used. By the 9th day, lycopene had reduced significantly by 53.31, 55.72, 59.53 and 57.51 % for fruits treated with 1.00, 1.50, 2.00 and 2.50 % $CaCl_2$ concentrations respectively. Lycopene content of fruits in the control set ranged between 55.85 and 115.63 mg/kg showing a significant decrease (51.70 %) throughout the 6 days of storage which was higher compared to 40.60, 41.64, 20.88 and 30.73 % for fruits treated with 1.00, 1.50, 2.00 and 2.50 % $CaCl_2$ concentrations respectively.

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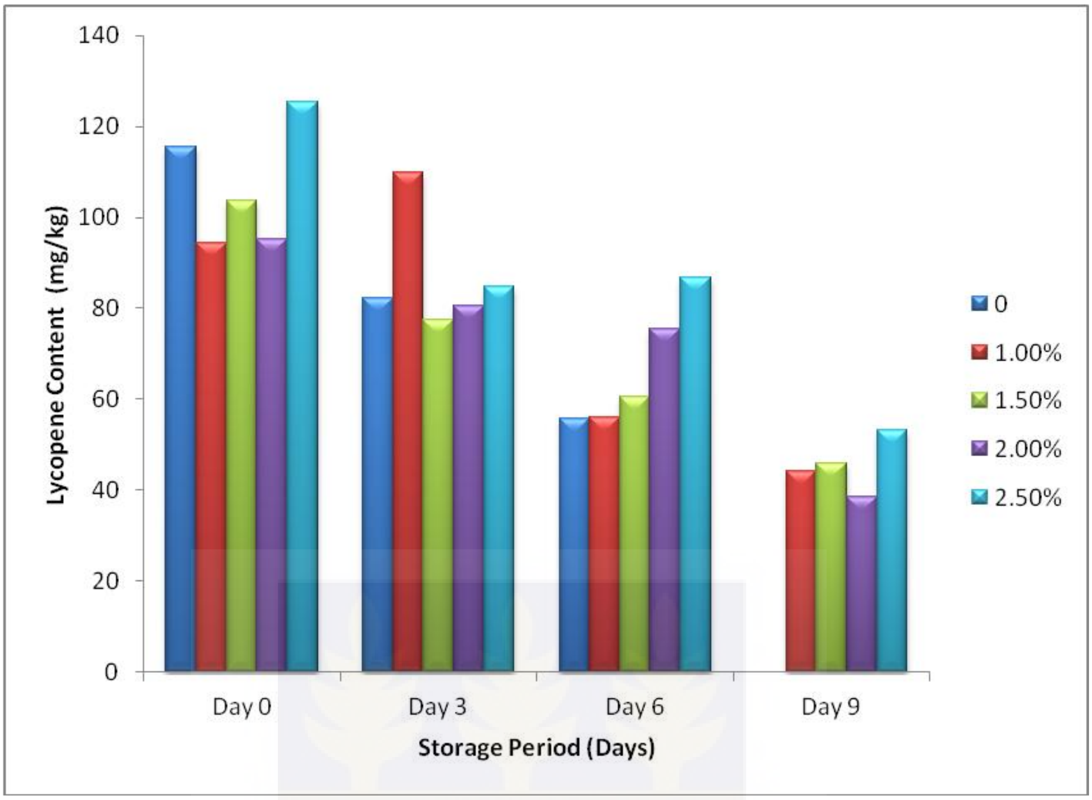

Fig. 4.3.3(b) Effect of $CaCl_2$ concentration on the lycopene content of tomato fruit stored at ambient temperature (28±1°C).

Generally, there were significant differences in lycopene content as storage days progressed within the different $CaCl_2$ concentrations used. In contrast, within each storage day, lycopene content did not show any significant difference in all $CaCl_2$ concentration.

Lycopene content of irradiated fruits ranged between 15.10 – 71.01 mg/kg as depicted in Fig. 4.3.3(a) whilst $CaCl_2$ treated samples showed between 38.56 – 125.45 mg/kg (Fig. 4.3.3b). Control fruits ranged between 55.85 – 115.63 mg/kg. It is clear that lycopene content was high in $CaCl_2$ treated samples than control and irradiated fruits. The lycopene content in all treatment used falls within the results obtained by Quartey (2010) for tomato lines ranging from 148 – 0.6 mg/kg. The use of $CaCl_2$ was able to reduce loss of lycopene in tomato fruits because $CaCl_2$ prevents the loss of antioxidants in fruits as a result of low permeability of oxygen of the coating formed on the fruit surface (Luna-Guzman and Barrett, 2000).

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4.3.7 Lycopene Content of Tomato Fruits Stored at Low Temperature (10±1°C) Following Irradiation.

Fig. 4.3.4(a) depicts the effect of irradiation dose on vitamin C content of tomato fruit stored at low temperature (10±1°C) for 25 days. Lycopene content in control fruits ranged from 30.07 – 86.20 mg/kg whiles irradiated fruits also ranged from 24.44 – 99.92 mg/kg in lycopene content.

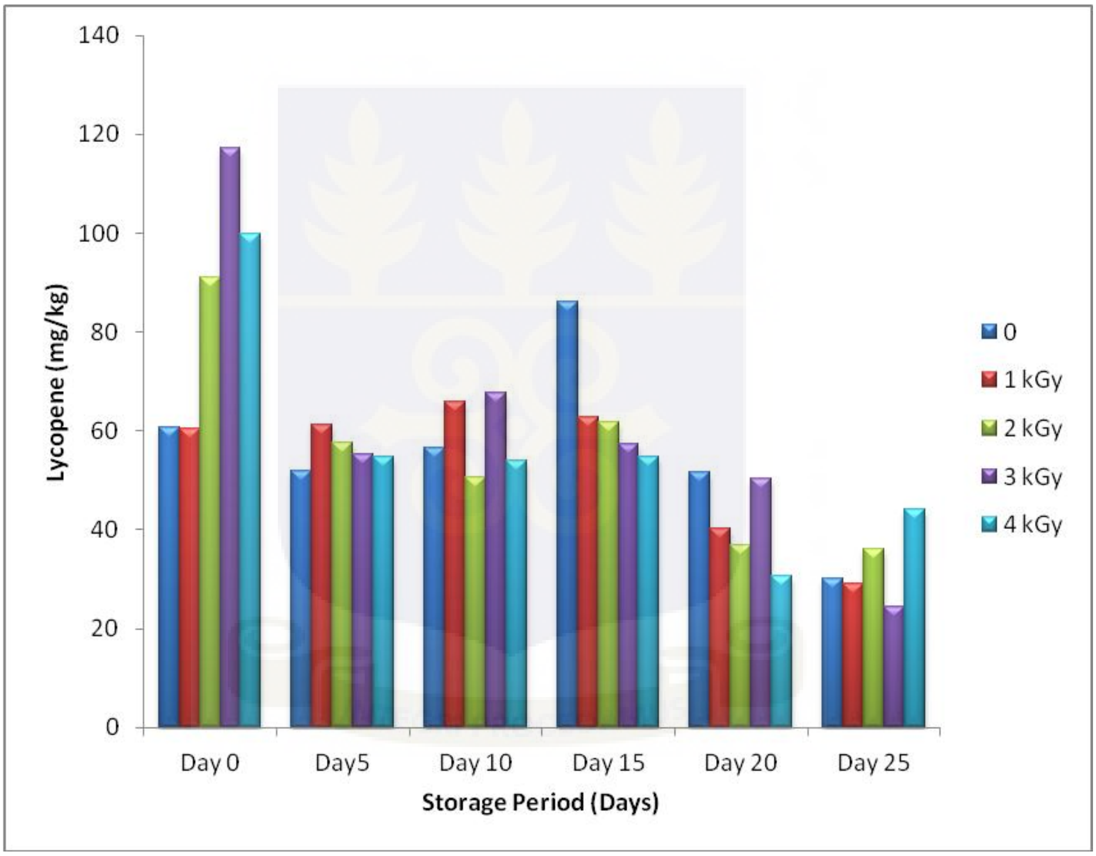

Fig. 4.3.4(a) Effect of Irradiation Dose on Lycopene Content of Tomato Fruit Stored at Low Temperature (10±1°C).

Generally, there were no significant differences in lycopene content in control fruits during storage except for days 15 and 25. Fruits treated with 1 and 4 kGy showed no significant difference except in a few cases which differed. However, fruits treated with 2 and 3 kGy differed significantly during storage. Among the storage days, lycopene content was at par with each other among the doses used.

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Lycopene content had reduced significantly by 50.45, 51.75, 61.29, 79.15 and 55.76 % in 0, 1, 2, 3 and 4 kGy by the final day. Therefore, loss of lycopene content was generally proportional to the dose used. Loss of lycopene in control fruits was lower than in irradiated fruits and this result contradicts result by Youssef *et al*. (2011) who stated that loss in total lycopene content of irradiated tomato samples was lower than non irradiated samples.

4.3.8 Lycopene Content of Tomato Fruits Stored at Low Temperature (10±1°C) Following $CaCl_2$ Coating.

Fig. 4.3.4(b) shows effect of $CaCl_2$ concentration on the lycopene content of tomato fruit stored at low temperature (10±1°C) for 25 days. Control fruits recorded 30.07 and 86.20 mg/kg lycopene content with about 50.45% reduction on the final day. Fruits treated with $CaCl_2$ ranged between 51.71 and 97.03 mg/kg lycopene content.

At 1.00, 1.50 and 2.00 % $CaCl_2$ concentration, lycopene content showed no significant differences as storage progressed. Generally, lycopene content in all doses did not differ significantly from each other within each storage day except for day 0.

However, by the 25th day, all concentrations used reduced by 14.93, 42.62, 35.95 and 37.27 % in 1.00, 1.50, 2.00 and 2.50 % respectively. It was clear that reduction in lycopene content was greater in control fruits (50.45%) than in samples treated with $CaCl_2$. However, lycopene content was greater in fruits treated with $CaCl_2$ than control fruits as seen in Fig. 4.3.4(b).

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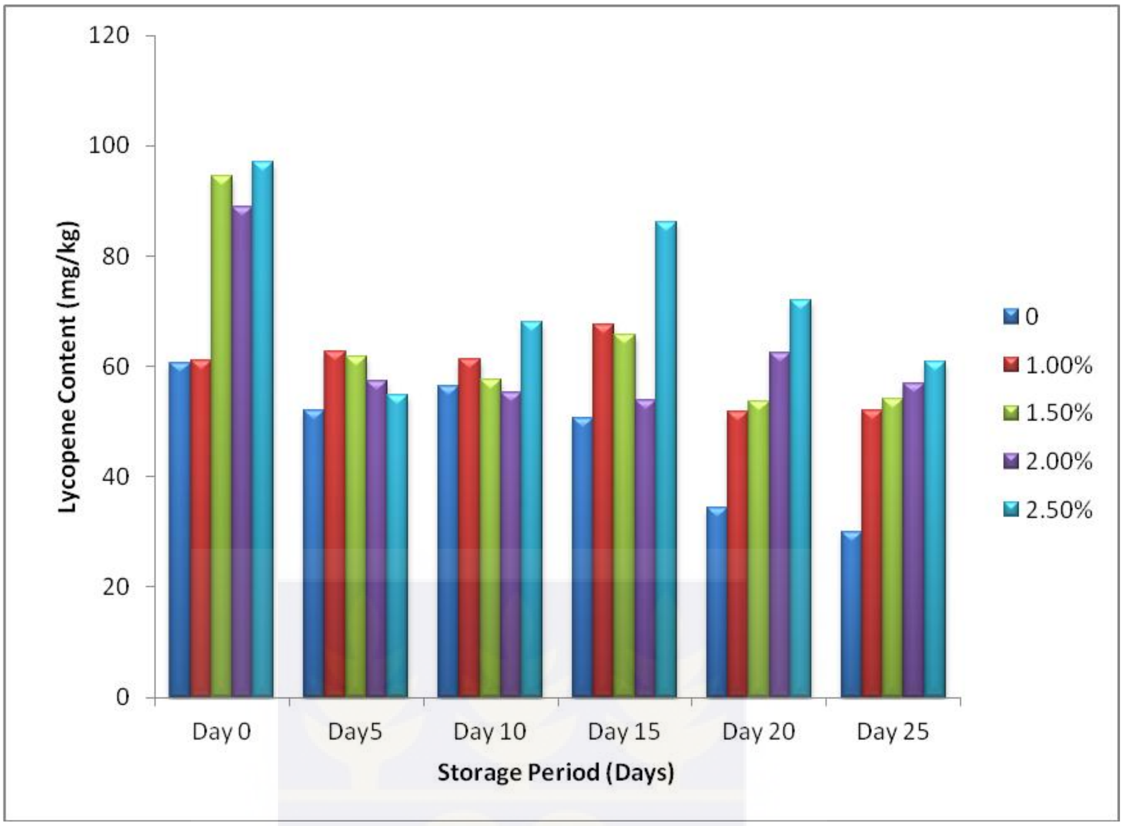

Fig. 4.3.4(b) Effect of $CaCl_2$ Concentration on the Lycopene Content of Tomato Fruit Stored at Low Temperature (10±1°C).

Comparatively, fruits treated with $CaCl_2$ effectively maintained lycopene content (51.71 – 97.03 mg/kg) as seen in Fig. 4.3.4(b) compared to irradiated fruits which reduced significantly from 99.92 - 24.44 mg/kg (Fig. 4.3.4a) and control fruits (30.07 – 86.20 mg/kg) which also reduced. However, the highest lycopene content was redored by 3kGy irradiated fruits on the initial day. The use of $CaCl_2$ produces a low oxygen permeability coating on the surface of the fruit which prevents loss of antioxidants (Luna-Guzman and Barrett, 2000). This was earlier noted by Subbiah and Perumal (1990) who stated that calcium chloride increases the lycopene contents in tomatoes.

Decrease in lycopene content with time may be related to lycopene degradation as a result of storage (Nguyen and Schwartz, 1999). The main causes of lycopene degradation are isomerization and oxidation. The reversible isomerization of all-trans-lycopene to less

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coloured, more oxidizable cis isomers is the first stage of lycopene degradation (Boskovic, 1979).

Generally, all samples stored at low temperature showed higher lycopene content than those in ambient temperature. This is because lycopene is sensitive to light, heat and oxygen (Nguyen & Schwartz, 1999) and since at ambient temperature the fruit is exposed to these elements more readily than those kept in refrigerator at low temperature, loss in lycopene would be greater at ambient temperature.

4.3.9 Effect of Irradiation (kGy) on Elemental Composition of Tomato Fruits Stored at Ambient Temperature (28±1°C) for 9 days.

Table 4.3.1a depicts the elemental composition (Na, K, Zn, Cu and Mn) of irradiated tomato fruits stored at ambient temperature and observed on the initial and final days (after 9 days of storage) of the study. In general, Na, K, Zn, and Cu concentrations in the fruits decreased with time over the storage period while that of Mn increased across irradiation doses. Na contents reduced by 93, 97, 87 and 86 % for 1, 2, 3 and 4 kGy respectively and 97 % for the control over the nine day storage period. Similarly, K concentration in the fruits reduced by 35, 29, 10 and 30 % for 1, 2, 3 and 4 kGy respectively and 44% for the control over the storage period. In like manner, Zn concentration in the fruits decreased by 23, 24, 18 and 19 % for 1, 2, 3 and 4 kGy respectively and 46% for the control and irradiation doses 1, 2, 3 and 4 kGy respectively over the storage period. Also the concentration of Cu in the tomato fruits reduced by 7, 67, 65 % for 1, 3 and 4 kGy respectively and 97 % for the control. However, 2kGy treated fruits increased by 12%. By contrast, the concentration on Mn in the tomato fruits

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increased by 44, 4, 18 % for 2, 3 and 4 kGy respectively and 57 % for the control while it decreased by 5.83% for irradiation dose 1 kGy the over storage period.

The composition of Zn, Cu and Mn in irradiated tomato fruits showed the lower content as seen in table 4.3.1(a) as compared to Na and K. Zn element was the least composition in tomato fruits ranging from 0.37 – 1.07 mg/kg whilst Cu and Mn ranged from 3.33 – 14.58 mg/kg and 2.03 – 2.87 mg/kg respectively. The greatest reduction in elemental composition was observed in Cu and Na by 97% in control fruits over a nine day storage period. On the other hand, control fruits illicited the highest increase in Mn element by 57% over the storage period.

Na concentration in radiated tomato ranged from 2.67 – 118 mg/kg throughout the storage period whilst K ranged between 1881.67 and 3696.67 mg/kg. These results confirm those obtained by Quartey (2010) where Na and K content in tomato were 170.77 and 32600 mg/kg respectively. The results for Cu also confirm that obtained by Quartey (2010) which ranged from 2.39 – 21.89 mg/kg.

Table 4.3.5(a) Effect of radiation dose (kGy) on the elemental composition of tomato fruits stored at ambient temperature (28±1°C) for 9 days.

GAMMA RADIATION DOSES (kGy)	Na (mg/kg)		K (mg/kg)		Zn (mg/kg)		Cu (mg/kg)		Mn (mg/kg)	
	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
0	102.67^{Aa}	3.00^{Eb}	2298.33^{Aa}	1292.33^{Ab}	0.87^{Aa}	0.47^{Ab}	4.82^{ABa}	0.13^{Ab}	0.47^{Aa}	1.10^{Ab}
1	116.33^{Bc}	8.33^{Fd}	2888.33^{Bc}	1881.67^{Bd}	0.66^{Bc}	0.51^{Bd}	5.71^{Bc}	4.55^{Bd}	2.06^{Bc}	1.94^{Bc}
2	103.00^{Ae}	2.67^{Ef}	3516.67^{Ce}	2511.67^{Cf}	0.37^{Ce}	0.49^{Ce}	1.11^{Ae}	3.33^{Cf}	1.30^{Cd}	2.34^{Be}
3	108.67^{Cg}	14.67^{Gh}	3271.67^{Dg}	2928.33^{Dh}	0.77^{ABf}	0.63^{Dg}	14.58^{Cg}	5.13^{Dh}	1.94^{Bf}	2.03^{Bf}
4	118.67^{Dj}	16.67^{Hi}	3696.67^{Ej}	2598.67^{Ei}	1.07^{Dh}	0.87^{Eh}	1.91^{ABi}	1.77^{Ej}	2.87^{Dg}	3.50^{Cg}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

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4.3.10 Effect of $CaCl_2$ Concentration (%) on Elemental Composition of Tomato Fruits Stored at Ambient Temperature (28±1°C) for 9 days.

Table 4.3.2(b) shows the concentrations of Na, K, Zn, Cu and Mn elements in tomato fruits treated with $CaCl_2$ at different concentrations and stored at ambient temperature for analysis on the initial and final days (9 day storage period). K showed the higher concentration in tomato (1281.00 - 3503.33 mg/kg). Generally, there were no significant differences among treatment concentrations on both the initial and final days including control fruits. However, storage caused a significant reduction in K concentration by 44, 63, 30, 43 and 52 % for the control and $CaCl_2$ concentrations of 1.00, 1.50, 2.00 and 2.50 % respectively over the storage period. Na concentration reduced significantly on the final day and also varied significantly among treatment levels as in Table 4.3.2(b). Na reduced by 97, 56, 48, 40 and 56 % for the control and $CaCl_2$ concentrations of 1.00, 1.50, 2.00 and 2.50 % respectively over the storage period. Generally, the concentration of Zn reduced significantly for all concentrations by 46, 45, 63 and 7 % for the control and for the control and $CaCl_2$ concentrations of 1.00, 1.50 and 2.00 % respectively over the storage period, however, at 2.50%, Zn concentration increased by only 6%. In like manner, Cu concentration reduced significantly by 97, 32, 54 and 12 % for the control and $CaCl_2$ concentrations of 1.00, 1.50, 2.00 and 2.50 % respectively over the storage period but increased by 7% at 2.50%. Mn concentration reduced by 6, 63 and 11 % for $CaCl_2$ concentrations of 1.00, 1.50 and 2.00 % respectively over the storage period but increased by 57 and 30 % for control and 2.50%.

The greatest reduction in elemental composition was recorded in Na (97%) in control fruits over the nine day storage period. On the other hand, control fruits recorded the largest increase in Mn element by 57% over the storage period.

Table 4.3.5(b) Effect of $CaCl_2$ Concentration (%) on the elemental composition of tomato fruits stored at ambient temperature (28±1°C) for 9 days.

$CaCl_2$ CONCENTRATIONS (%)	Na (mg/kg)		K (mg/kg)		Zn (mg/kg)		Cu (mg/kg)		Mn (mg/kg)	
	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
0	102.67^{Aa}	3.00^{Fb}	2298.33^{Aa}	1292.33^{Db}	0.87^{Ca}	0.47^{Ab}	4.82^{Aa}	0.13^{Ab}	0.47^{Ba}	1.10^{Db}
1.00	55.97^{Bc}	24.43^{Gd}	3460.00^{Bc}	1281.00^{Dd}	2.05^{Bc}	1.13^{BCd}	4.47^{Ac}	3.05^{Bd}	5.27^{Ac}	4.97^{ABd}
1.50	47.77^{Ce}	24.87^{Hf}	2386.67^{Ae}	1676.33^{Ef}	1.87^{Ae}	0.70^{ABf}	4.49^{Ae}	2.06^{Cf}	5.29^{Af}	1.94^{Ce}
2.00	48.87^{Dg}	29.20^{Ih}	2726.33^{Cg}	1566.33^{Fh}	1.49^{Dg}	1.39^{Ch}	3.78^{Bh}	3.33^{Dg}	5.39^{Ah}	4.79^{Ag}
2.50	60.80^{Ei}	26.33^{Jj}	3503.33^{Bi}	1693.33^{Ej}	1.97^{ABi}	2.10^{Dj}	4.57^{Aj}	4.91^{Ei}	3.73^{Cj}	5.33^{Bi}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

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4.3.11 Effect of Irradiation dose (kGy) on Elemental Composition of Tomato Fruits Stored at Low Temperature (10±1°C) for 25 days.

Table 4.3.2(a) depicts the elemental composition (Na, K, Zn, Cu and Mn) of radiated fruits stored at 10±1°C for 25 days and analysed day 0 and day 25. K showed the higher mean content of 2997 mg/kg. At 0 and 1 kGy, K concentration increased by 16 and 20 % whilst decreasing insignificantly by 14, 21 and 12 % at 2, 3 and 4 kGy on the final day. Among the doses used, there were significant differences ($p<0.05$) in K content on both the initial and final days. Generally, K increased with increasing dose. Gamma radiation therefore significantly affected concentration of K. Na concentration was between 16 and 118 mg/kg and decreased significantly by 84, 68, 64, 85 and 79 % for the control fruits and irradiation doses of 1, 2, 3 and 4 kGy respectively over storage period.

Zn content ranged between 0.37 and 1.51 mg/kg whilst Cu and Mn ranged from 1.06 – 14.58 and 0.47 – 2.90 mg/kg respectively throughout the storage period. Zn content increased significantly at 37, 41, 76 and 9 % for the control fruits and irradiation doses of 1, 2 and 3 kGy respectively but decreased at 20% for fruits treated with irradiation dose of 4kGy. In contrast, Cu content decreased significantly by 76, 81, 79 % for the control fruits and irradiation doses of 1 and 3 kGy respectively but increased at 38 and 51 % for irradiation doses of 2 and 4 kGy respectively. Mn also decreased by 32 and 3 % for irradiation doses 1 and 4 kGy respectively while increasing by 84, 69 and 3 % for control and irradiation doses 2 and 3 kGy respectively. Storage period generally affected concentrations of Zn, Na, K, Mn and Cu significantly.

The greatest reduction in elemental composition was observed in Na by 85% at 3 kGy irradiation dose. On the other hand, control fruits illicited the largest increase in Mn element by 84% over the storage period.

Table 4.3.6(a) Effect of irradiation doses (kGy) on the elemental composition of tomato fruit stored at low temperature (10±1°C) for 25 days.

GAMMA RADIATION DOSES (kGy)	Na (mg/kg)		K (mg/kg)		Zn (mg/kg)		Cu (mg/kg)		Mn (mg/kg)	
	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
0	102.67^{Aa}	16.00^{Ab}	2298.33^{Aa}	2750.00^{Ab}	0.87^{Aa}	1.37^{Ab}	4.82^{ABa}	1.18^{Ab}	0.47^{Aa}	2.90^{Ab}
1	116.33^{Bc}	37.33^{Bc}	2888.33^{Bc}	3620.33^{Bc}	0.66^{Bc}	1.11^{Bd}	5.71^{Bd}	1.06^{Bc}	2.06^{Bc}	1.41^{Bd}
2	103.00^{Ae}	37.00^{Bd}	3516.67^{Ce}	3029.67^{Cd}	0.37^{Ce}	1.51^{Af}	1.11^{Ae}	1.79^{Cf}	1.30^{Ce}	4.20^{Cf}
3	108.67^{Cg}	16.00^{Af}	3271.67^{Dg}	2590.00^{De}	0.77^{ABg}	0.85^{Ch}	14.58^{Ch}	3.10^{Dg}	1.94^{Ag}	2.62^{Bh}
4	118.67^{Dj}	25.33^{Dg}	3696.67^{Ej}	3268.33^{Ef}	1.07^{Di}	0.86^{Cj}	1.91^{ABi}	3.92^{Ej}	2.87^{Di}	2.78^{ABi}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

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4.3.12 Effect of $CaCl_2$ Concentrations (%) on the Elemental Composition of Tomato Fruit Stored at Low Temperature (10±1°C) for 25 days.

Table 4.3.2 (b) shows the concentrations of Na, K, Zn, Cu and Mn in tomato fruits treated with $CaCl_2$ at different concentrations and stored at 10±1°C. K recorded the largest mean of 2761mg/kg in treated fruits whilst fruits in the control set showed 2524 mg/kg. K concentration decreased significantly by 27 and 35 % for 2.00 and 2.50 % $CaCl_2$ concentrations respectively while increasing by 16, 2 and 8 % for the control fruits and 1.00 and 1.50 % $CaCl_2$ concentration respectively. On day 25 and 0 day, there were significant differences in K and Na concentrations respectively at all levels of $CaCl_{2.}$ Na concentration reduced significantly in all concentrations by 84, 23, 40, 38 % of 1.00, 1.50, 2.00 and 2.50 % respectively and 13 % for the control and $CaCl_2$ concentrations.

Zn concentration in tomato fruits reduced by 46, 14 and 8 % for the control and $CaCl_2$ concentrations of 1.00 and 1.50 % respectively but increased by 35 and 18 % of 2.00 and 2.50 % $CaCl_2$ concentrations respectively over the storage period. In contrast, Cu content reduced significantly in all concentrations by 97, 20, 40, 8 and 19 % in the control and 1.00, 1.50, 2.00 and 2.50 % $CaCl_2$ concentrations respectively. In like manner, Mn reduced significantly by 57, 49, 40 and 22 % for the control and 1.00, 1.50 and 2.00 % $CaCl_2$ concentrations respectively but increased by 21% at 2.50% $CaCl_2$ concentration over the storage period.

Generally, from the study, fruits treated with radiation and control fruits showed a greater loss in the elements studied than those treated with $CaCl_2$. Also, fruits stored at ambient temperature showed greater loss of the elements than those stored in low temperature.

Table 4.3.6(b) Effect of $CaCl_2$ concentrations (%) on the elemental composition of tomato fruit stored at low temperature (10±1°C) for 25 days.

$CaCl_2$ CONCENTRATIONS (%)	Na (mg/kg)		K (mg/kg)		Zn (mg/kg)		Cu (mg/kg)		Mn (mg/kg)	
	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL
0	102.67^{Aa}	16.00^{Ab}	2298.33^{Aa}	2750.00^{Ab}	0.87^{Ca}	0.47^{Ab}	4.82^{Aa}	0.13^{Ab}	0.47^{Ba}	1.10^{Db}
1.00	55.97^{Bc}	43.33^{Bd}	3460.00^{Bc}	3520.00^{Bd}	2.05^{Ba}	1.76^{Aa}	4.47^{Aa}	3.57^{Ab}	5.27^{Aa}	2.69^{Bb}
1.50	47.77^{Ce}	28.67^{Cf}	2386.67^{Ae}	2602.00^{Cf}	1.87^{Aa}	1.74^{Aa}	4.49^{Aa}	2.71^{Bb}	5.29^{Aa}	3.17^{Cb}
2.00	48.87^{Dg}	30.33^{Ch}	2726.33^{Cg}	2002.33^{Dh}	1.49^{Da}	2.28^{Bb}	3.78^{Bb}	3.47^{Ab}	5.39^{Aa}	4.18^{Db}
2.50	60.80^{Ei}	52.67^{Dj}	3503.33^{Bi}	2278.67^{Ej}	1.97^{ABa}	2.39^{Bb}	4.57^{Aa}	3.71^{Ab}	3.73^{Ca}	4.73^{Eb}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

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The mineral content of tomatoes is important for both the conservation and the nutritional value of the product. The major mineral element studied in this research include Potassium and Sodium. Potassium is a major intracellular cation in the human body and it facilitates the transmission of nerve impulses. Its deficiency causes nerve irritability, cardiac and mental disorder, muscular weakness and paralysis. Sodium is a primary extra–cellular cation in humans. Sodium together with Potassium are electrolytes that maintain normal fluid balance inside and outside cells and a proper balance of acids and bases in the body. Deficiency of this element may result in muscle cramp and hypertension (Adotey *et al*., 2009).

Trace metals play an essential biological role in plant and human metabolism. Trace metals like Cu, and Mn together with Fe are considered as essential elements for normal life processes. Copper and zinc are activators and coenzymes and are considered as good source of protein (Durdana *et al*., 2007). Dara, (1993) stated that the recommended daily dietary intake of Zn and Cu is about 15 and 2 - 3 mg respectively. From this research, Zn ranged between 0.37 and 1.51 mg/kg which shows that tomato when included in ones diet can contribute to providing about 10 - 40% of the recommended daily intake when the fruit is taken with other food items. Ingestion of 15-75 mg of copper causes gastrointestinal disorders. From the study, it could be seen that Cu ranged between 0.13 -14.58 mg/kg which is within the acceptable range of Cu consumption by humans.

Magnesium is an essential element and its main functions in the body include bone mineralization, building of proteins and maintenance of teeth. A daily dietary intake of 2.5 to 5 mg of manganese by human contributes to the well being of the cells

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(Dara, 1993). The result obtained in this research revealed a concentration of 0.47 – 3.50 mg/kg Mn in all the treatments which is within the range of daily dietary intake.

4.4 MICROBIAL LOAD OF BURKINA TOMATO FRUITS FOLLOWING GAMMA RADIATION AND $CaCl_2$ COATING.

4.4.1 Total Aerobic Mesophilic Bacteria Count (log cfu/ml) of Tomato Fruit at Ambient Temperature (28°C±1) Storage Following Irradiation.

Table 4.4.1a shows counts of total aerobic mesophiles bacteria on irradiated tomato stored for 9 days at ambient temperature. Fruits irradiated at 1, 2, 3 and 4 kGy showed no or below detectable count (<10 cfu/ml) through days 0 – 3 whiles control fruits showed detectable counts (>10 cfu/ml) throughout the storage period.

Table 4.4.1a. Effect of gamma radiation and storage (28°C±1) on total aerobic mesophiles (log cfu/ml) of tomato fruit.

Storage Period (Days)	Gamma Radiation Dose (kGy)				
	0	1	2	3	4
0	0.44^{Ab}	<1	<1	<1	<1
3	1.61^{Ba}	<1	<1	<1	<1
6	1.74^{Ca}	1.65^{Eb}	0.86^{Gc}	0.48^{Id}	<1
9	3.85^{Da}	3.19^{Fb}	1.04^{Hc}	0.82^{Jd}	<1

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

Fruits irradiated at 4kGy showed growth that was below the detectable limit throughout the storage period of 9 days. By contrast, control fruits showed a progressive and continuous increase in total microbial count from 0.44 log cfu/ml on the initial day to 3.85 log cfu/ml on the 9th day. As storage period increased, total

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aerobic mesophiles increased in counts in all doses and the increase was inversely proportional to dose applied. Counts of total aerobic mesophiles in irradiated fruits at ambient temperature storage were significantly different ($P \leq 0.05$) from each other among doses and storage periods (Appendix 9). Gamma radiation significantly reduced microbial counts by inactivating spoilage micro organisms compared to control which showed increasing growth. Higher radiation doses (3 and 4 kGy) significantly reduced microbial counts to no counts or below detectable counts while the lower doses (1 and 2 kGy) showed fewer counts throughout storage period.

4.4.2 Total Aerobic Mesophilic Bacteria Count (log cfu/ml) of Tomato Fruit at Ambient Temperature (28°C±1) Storage Following $CaCl_2$ Coating.

Table 4.4.1b shows counts of total aerobic mesophiles on tomato fruits treated with varying concentrations of calcium chloride and stored for 9 days at ambient temperature. Fruits treated with $CaCl_2$ at all concentrations showed no or below detectable counts (<10 cfu/ml) through days 0 – 3 unlike control fruits.

Fruits treated with 2.50% showed below detectable count throughout the storage period. However, control fruits showed increasing total aerobic mesophilic bacteria throughout the study. On days 6 and 9, total aerobic mesophilic bacteria counts decreased with increasing concentration of $CaCl_2$. Fruits treated at 1.00 and 2.00 % showed an increase in total aerobic mesophilic bacteria from 1.03 – 1.15 and 0.85 – 0.90 log cfu/ml respectively on days 6 and 9. Counts of total aerobic mesophiles in treated fruits at ambient temperature storage were significantly different ($P \leq 0.05$) from each other among concentrations and storage periods (Appendix 10).

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Table 4.4.1b. Effect of $CaCl_2$ concentration (%) and storage (28°C±1) on total aerobic mesophiles (log cfu/ml) of tomato fruit.

Storage Period (Days)	$CaCl_2$ Concentration (%)				
	0	1.00	1.50	2.00	2.50
0	0.44^{Aa}	<1	<1	<1	<1
3	1.61^{Ba}	<1	<1	<1	<1
6	1.74^{Ca}	1.03^{Eb}	0.85^{Gc}	<1	<1
9	3.85^{Da}	1.15^{Fb}	0.90^{Hc}	0.48^{Id}	<1

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

In comparison with irradiated fruits, calcium chloride treated fruits showed a reduced count of total aerobic mesophilic bacteria throughout storage. The highest count for irradiated samples was 3.19 log cfu/ml at 1kGy whilst the highest for $CaCl_2$ treatment was 1.15 log cfu/ml at 1% concentration. Irradiation of fruits could affect the tissue of the fruit causing softening (De Costa, 2000) and consequently, easy access by microorganisms. $CaCl_2$ treatment reduced contamination of the fruits as its use enhanced tissue resistance to fungal or bacterial attack by stabilizing or strengthening cell walls (Bolin and Huxsoll, 1989) while the control showed for increasing growth. Higher temperature could have enhanced growth of the microorganisms.

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4.4.3 Total Aerobic Mesophilic Bacteria Count (log cfu/ml) of Tomato Fruit at Low Temperature (10°C±1) Storage Following Irradiation.

Table 4.4.2a shows counts of total aerobic mesophilic bacteria in irradiated tomato stored for 25 days at low temperature. Fruits that were irradiated showed reduced count of total aerobic mesophilic bacteria of between 0.43 – 3.50 log cfu/ml whiles control fruits showed counts of between 0.44 – 4.10 log cfu/ml.

Table 4.4.2a. Effect of gamma radiation and storage (10°C±1) on total aerobic mesophilic bacteria (log cfu/ml) of tomato fruit.

	Gamma Radiation Dose (kGy)				
Storage Period (Days)	0	1	2	3	4
0	0.44^{A}	<1	<1	<1	<1
5	1.05^{Ba}	0.43^{Gb}	<1	<1	<1
10	1.69^{Ca}	0.80^{Hb}	1.50^{Lc}	<1	<1
15	2.96^{Da}	1.50^{Ib}	0.68^{Mc}	1.01^{Pd}	0.92^{Sd}
20	3.43^{Ea}	2.92^{Jb}	2.84^{Nb}	1.75^{Qc}	4.37^{Td}
25	4.10^{Fe}	3.50^{Kf}	2.93^{Og}	2.79^{Rh}	2.40^{Ui}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

On day 0, irradiated fruits showed no or below detectable microbial count (<10 cfu/ml). Fruits irradiated at 3 and 4 kGy did not show any bacterial count from day 0 to 10, thus, total aerobic mesophiles increased with decreasing radiation doses. These results coincide with previous finding by Prakash *et al*. (2002) that tomato fruits

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irradiated at 3.70 kGy showed no microbial count from day 0 to day 9. Total aerobic mesophiles in irradiated fruits at 10°C±1 were significantly different ($P \leq 0.05$) from each other among doses and storage periods (Appendix 11). In all doses used, total aerobic count increased with advancement in days except for 4kGy treated fruits whose changes fluctuated with an increase on the 20th day and a reduction on the 25th day. Among radiation doses, total aerobic mesophiles decreased with increasing dose. The bacterial count in control fruit increased from 0.44 log cfu/ml (1.70×10^{2}) to 4.10 log cfu/ml (4.90×10^{6}) throughout storage. On the 15th day, the dose with the largest mean total aerobic counts was in control fruits at 3.50 log cfu/ml followed by 1kGy with 2.64 log cfu/ml whilst 4kGy showed the least with 2.56 log cfu/ml.

4.4.4 Total Aerobic Mesophilic Bacteria Count (log cfu/ml) of Tomato Fruit at Low Temperature (10°C±1) Storage Following $CaCl_2$ Coating.

The table (4.4.2b) shows total aerobic mesophilic bacteria of tomato fruits treated with calcium chloride and stored for 25 days at 10°C±1. Unlike control fruits which showed counts of between 0.44 – 4.10 log cfu/ml, fruits treated with $CaCl_2$ showed no detectable count (<10 cfu/ml) on the initial day.

Generally, all concentrations increased in total aerobic counts throughout storage period except the 2.5% concentration. There were significant differences ($P \leq 0.05$) in total aerobic counts throughout the storage period and between concentrations (Appendix 12). Control fruits showed the highest count with 4.10 log cfu/ml as compared to treated fruits which decreased in counts with increasing concentration. This can be attributed to the ability of $CaCl_2$ to provide an inhibitory effect on microbial growth while control allowed for spore spreading, increasing counts.

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Table (4.4.2b) Effect of $CaCl_2$ concentration (%) and storage (10°C±1) on total aerobic mesophilic bacteria (log cfu/ml) contaminating tomato fruit.

Storage Period (Days)	$CaCl_2$ Concentration (%)				
	0	1.00	1.50	2.00	2.50
0	0.44^{A}	<1	<1	<1	<1
5	1.05^{Ba}	0.67^{Gb}	0.41^{Lc}	0.31^{Qc}	0.85^{Vd}
10	1.69^{Ca}	0.12^{Hb}	1.28^{Mc}	0.79^{Rd}	0.81^{VWd}
15	2.96^{Da}	2.07^{Ib}	0.28^{Nc}	1.30^{Sd}	0.89^{We}
20	3.43^{Ef}	2.97^{Jg}	0.48^{Lh}	0.56^{Th}	2.62^{Xj}
25	4.10^{Fa}	3.21^{Kb}	0.87^{Pc}	0.61^{Ud}	0.27^{Ye}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

Compared to irradiated samples which recorded between 0.43-4.37 log cfu/ml compared to 0.12-3.31 log cfu/ml in fruits treated with $CaCl_2$, $CaCl_2$ reduced microbial load more than fruits that were irradiated. However, growth started on day 5 in all concentrations in fruits treated with $CaCl_2$ whiles fruits treated with 1kGy gamma irradiation recorded bacterial count on day 5 as displayed in Tables 4.4.2a and 4.4.2b. $CaCl_2$ reduces the availability of moisture in the fruits which prevents the activities of microbes (Luna-Guzman and Barrett, 2000). Low temperature is also an important factor in maintaining quality and extending the shelf-life of fruits and vegetables after harvest due to its effects on reducing respiration rate, ripening, senescence and rot development (Majidi *et al.*, 2011) in contrast to ambient temperature which hastens these processes.

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4.4.5 Moulds and Yeasts Count (log cfu/ml) of Tomato Fruits at Ambient Temperature (28°C±1) Storage following Irradiation.

Table 4.4.3a shows the growth of moulds and yeasts in irradiated tomato fruits stored for 9 days at ambient temperature. Generally, moulds and yeasts increased after the 6th day in control fruits whiles irradiated fruits increased on the final day. Control fruits recorded the highest moulds and yeasts growth of 3.16 log cfu/ml. There were significant differences in moulds and yeasts growth on day 9 among all doses (Appendix 13).

Table (4.4.3a): Effect of gamma radiation and storage (28°C±1) on moulds and yeasts count (log cfu/ml) of tomato fruit.

Storage Period (Days)	Gamma Radiation Dose (kGy)				
	0	1	2	3	4
0	<1	<1	<1	<1	<1
3	<1	<1	<1	<1	<1
6	0.80^{Aa}	<1	<1	<1	<1
9	3.16^{Ba}	1.50^{Cb}	1.04^{Dc}	0.44^{Ed}	<1

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

Generally, irradiation caused a significant (P ≤ 0.05) decrease in moulds and yeasts count on the final day which was proportional to irradiation doses.

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However, 4kGy did not record any moulds and yeasts through all the storage days. Thus, the higher doses (3 and 4 kGy) were more effective in controlling moulds and yeasts than the lower doses (1 and 2 kGy) This is in accordance with studies by Prakash *et al*. (2002), which indicated no detection for moulds and yeasts growth when tomato was irradiated at 3.75 kGy on the 6^{th}, 9^{th} and 12^{th} day of analysis contrary to samples treated with 0.5 and 1.24 kGy. Previous work by Youssef *et al*., (2011) demonstrates that moulds and yeasts growth increased with reducing radiation doses.

4.4.6 Moulds and Yeasts Count (log cfu/ml) of Tomato Fruits at Ambient Temperature (28°C±1) Storage following $CaCl_2$ Coating.

Table 4.4.3b shows the moulds and yeasts growth in tomato fruits treated with calcium chloride and stored for 9 days at 28°C±1. Fruits treated with $CaCl_2$ showed reduction in moulds and yeasts of between 0.30 and 0.94 log cfu/ml over storage period whilst control fruits recorded between 0.80 and 3.16 log cfu/ml.

Generally, moulds and yeasts remained at low levels up to day 9^{th} day when they increased which agrees with the findings by Luna-Guzman and Barrett (2000). However, the control fruits started increasing after the 6^{th} day and recorded the highest growth of moulds and yeasts with 3.16 log cfu/ml as compared to concentrations of 1.00 and 1.50 % which recorded 0.94 and 0.30 log cfu/ml respectively. Yeasts and moulds counts on the final day were significantly different from each $CaCl_2$ concentrations (Appendix 14). Concentrations of 2.00 and 2.50 % did not show any detectable count of moulds and yeasts throughout the storage days.

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Table (4.4.3b): Effect of $CaCl_2$ concentration (%) and storage (28°C±1) on moulds and yeasts count (log cfu/ml) of tomato fruit.

Storage Period (Days)	$CaCl_2$ Concentration (%)				
	0	1.00	1.50	2.00	2.50
0	<1	<1	<1	<1	<1
3	<1	<1	<1	<1	<1
6	0.80^{Aa}	<1	<1	<1	<1
9	3.16^{Ba}	0.94^{Cb}	0.30^{Dc}	<1	<1

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

From Table 4.4.3a and 4.4.3b, fruits treated with $CaCl_2$ showed lower counts of moulds and yeasts than irradiated fruits, however, control fruits showed the highest population. The reason for the lower counts in fruits treated with $CaCl_2$ could be related to the effect $CaCl_2$ has on tomato fruits by reducing the availability of moisture in the fruit which prevents the activities of microbes (Luna-Guzman and Barrett, 2000).

4.4.7 Moulds and Yeasts Count (log cfu/ml) of Tomato Fruits at Low Temperature (10°C±1) Storage Following Irradiation.

Table 4.4.4a shows the growth of moulds and yeasts in irradiated tomato fruits stored for 25 days at low temperature.

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Table (4.4.4a): Effect of gamma radiation and storage (10°C±1) on moulds and yeasts count (log cfu/ml) of tomato fruit.

Storage Period (Days)	Gamma Radiation Dose (kGy)				
	0	1	2	3	4
0	<1	<1	<1	<1	<1
5	<1	<1	<1	<1	<1
10	2.32^{Aa}	0.61^{Db}	1.28^{Fc}	0.79^{Id}	0.79^{Ld}
15	3.61^{Be}	3.18^{Eef}	3.03^{Gf}	2.81^{Jf}	0.31^{Mg}
20	3.55^{Bh}	3.84^{Ehi}	2.84^{Hhi}	2.84^{Jhi}	2.57^{Ni}
25	4.15^{Cj}	3.87^{Ek}	3.61^{Il}	3.24^{Km}	2.90^{On}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

Fruits treated with gamma radiation showed reduced count of moulds and yeasts of between 0.61 – 3.87 log cfu/ml whiles control fruits increased from 2.32 – 4.15 log cfu/ml counts during the storage period.

At all radiation doses, the few spores which remained after irradiation began to grow and increase during storage but the counts were lower in the higher doses 3 and 4 kGy. Control fruits however, showed the highest growth with 4.15 log cfu/ml by the end of the storage period compared to 3.87, 3.61, 3.24 and 2.90 log cfu/ml for 1, 2, 3 and 4 kGy respectively. This trend confirms the work by Prakash *et al*. (2002) and Youssef *et al*., (2011) that tomato fruits irradiated at high doses reduced counts of moulds and yeasts. There were no significant differences in irradiated fruits on day

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20, however, significant differences were portrayed throughout the other storage days as seen in Appendix 15.

4.4.8 Moulds and Yeasts Count (log cfu/ml) of Tomato Fruits at Low Temperature (10°C±1) Storage Following $CaCl_2$ Coating.

The table (Table 4.4.4b) shows the growth of moulds and yeasts in tomato fruits treated with calcium chloride and stored for 25 days at 10°C±1.

Table (4.4.4b): Effect of $CaCl_2$ concentration (%) and storage (10°C±1) on moulds and yeasts count (log cfu/ml) of tomato fruit.

Storage Period (Days)	$CaCl_2$ Concentrations (%)				
	0	1.00	1.50	2.00	2.50
0	<1	<1	<1	<1	<1
5	<1	<1	<1	<1	<1
10	2.32^{Aa}	<1	<1	<1	<1
15	3.91^{Da}	1.27^{Gb}	1.08^{Jc}	3.91^{Da}	1.27^{Gb}
20	3.55^{Ea}	2.77^{Hb}	1.75^{Kc}	3.55^{Ea}	2.77^{Hb}
25	4.15^{Fa}	1.61^{Ib}	2.46^{Lc}	4.15^{Fa}	1.61^{Ib}

Least Significant Difference. Means with the same letters (upper cases, days) in the same column are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses) are not significantly different (P>0.05) from each other.

<1 = below detectable limit (<10 cfu/ml).

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Moulds and yeasts growth started on day 15 in fruits treated with $CaCl_2$ at all concentrations used. However, growth of moulds and yeast started increasing in control fruits on the 10th day of observation.

In all concentrations, there were significant increases in population of moulds and yeast throughout storage. Control fruits and 2.00% $CaCl_2$ treated fruits recorded the same values on day 25 and the count was the highest (4.15 log cfu/ml) as compared to the other concentrations; 2.46 log cfu/ml for 1.50 % and 1.61 log cfu/ml for both 1.00 and 2.50 %). There were significant differences in moulds and yeasts counts from days 15 to 25 (Appendix 16).

In comparison with irradiated fruits, growth of moulds and yeasts started on the 10th day in contrast with $CaCl_2$ samples which started increasing on day 15. Notwithstanding, irradiated samples recorded the least counts of moulds and yeasts of 3.87 log cfu/ml compared to 4.15 log cfu/ml for $CaCl_2$ samples though both results were below 10^7 cfu/ml.

Microbial counts from this study did not exceed 10^7 and were almost similar to those obtained in other fresh products (Nguyen-the and Carlin, 1994) which did not exceed 10^9. The International Commission on Microbiological Specifications for Foods (ICMSF, 1974), recommends that the microbiological criterion of aerobic plate count for salad vegetables or fruits must not exceed 10^6 (Microbiological Reference Criteria for Food, 1995). From the study, none of the samples showed counts exceeding 10^6 cfu/ml and therefore are considered as microbiologically safe.

At low temperature storage, the treatment that showed the least total aerobic count and moulds and yeasts count by the end of the 25 day storage period was at 2.50 %

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$CaCl_2$ concentration. At ambient temperature storage, the treatments that showed the least total aerobic count were at 4kGy and 2.50 %. Similarly, tomato fruits treated at 4kGy, 2.00 and 2.50 % showed the least moulds and yeasts count by the end of the 25 day storage period at low temperature storage.

The comparatively high contamination levels of microorganisms in untreated tomato fruits (control) was expected and could be due to the high natural microflora of the raw tomato, that come from soil, water or the hands of workers, as well as the contamination during blending and packaging. The results also indicate that moulds and yeasts are relatively more resistance to gamma irradiation than aerobic mesophilic bacteria as confirmed by Youssef *et al*., (2011) and Fan and Sokorai (2008).

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CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The versatility of the tomato fruit as well as its nutritional properties makes it an important horticulture crop in the diets or many people world-wide. This study has provided information on the appropriate and effective means of preserving fresh tomato fruits to prevent post - harvest losses without compromising on physico – chemical and nutritional properties. The use of different temperatures (28±1°C and 10±1°C) and different levels of the two treatments used (gamma radiation and $CaCl_2$ coating) in this study helped to bring out the effects of the treatment combinations on the shelf life as well as the physicochemical and nutritional properties of tomato fruits.

The following conclusions were drawn based on results obtained.

1. Shelf Life Extension

a) Gamma radiation at 4kGy followed by low temperature storage (10°C±1) extended shelf life of tomato fruits by 9 and 5 days compared to unirradiated fruits stored at same temperature and ambient temperature (28°C±1) respectively. Similarly, fruits irradiated at 3kGy also extended shelf life by 7 and 5 days compared to unirradiated fruits stored at low (10°C±1) and ambient (28°C±1) temperature storage respectively.

b) Similarly, 2.50% calcium chloride concentrations followed by low temperature storage (10°C±1) also extended shelf life of tomato fruits by 18

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and 11 days over untreated fruits stored at same temperature and ambient temperature (28°C±1) respectively.

c) In general, storage at low temperature (10±1°C) increased the storage life of tomato fruits by a maximum of 18 and 25 days in control and treated fruits respectively.

d) The use of gamma radiation and $CaCl_2$ coating greatly extended the shelf life of tomato fruits more than control fruits. However, $CaCl_2$ coating extended the shelf life of tomato fruits better than gamma radiation.

2. Physicochemical properties

a) Weight loss was greatest in untreated fruits (2.80 – 15.66 %) followed by those subjected to gamma irradiation (2.48 – 14.55 %) with $CaCl_2$ coating showing the least (1.30 – 6.93 %) at ambient temperature storage (28±1°C). Similarly, at low temperature storage, irradiated fruits and fruits treated with $CaCl_2$ showed weight loss ranging between 0.59 – 3.00 and 0.41 – 1.77 % respectively compared to 12.33 – 38.67 % in untreated fruits.

b) In general, weight loss was significantly low in all treated fruits at low temperature storage compared to high temperature storage. However, weight loss exhibited by $CaCl_2$ treatments was significantly lower than irradiation or no treatment.

c) pH of fruits treated with $CaCl_2$ exhibited comparatively inceased pH from 4.10 – 4.41 compared to that of the fruits in the control set (4.35 – 4.39) and irradiated fruits (4.26 – 4.62) at ambient temperature storage (28±1°C). In contrast, irradiated fruits (4.22 –

4.49) and control fruits (4.23 – 4.49) were at par and showed the longest pH range than $CaCl_2$ treated fruits (4.05 – 4.56) at low temperature storage (10±1°C).

d) Generally, fruits stored at 10±1°C were a more acidic state as compared to those stored at 28±1°C in all treatments.

e) Total Titratable Acidity (TTA) in irradiated tomato fruits (0.23 – 0.46 %) and control fruits (0.36 – 0.28 %) were lower throughout the storage period than $CaCl_2$ coating (0.33 – 0.49) at ambient temperature storage (28±1°C). At low temperature storage (10±1°C), fruits treated with gamma radiation showed the least %TTA (0.26 – 0.47 %) compared to control fruits (0.25 – 0.51 %) and fruits treated with $CaCl_2$ (0.31 – 0.49 %).

f) Generally, TTA was larger in all treatments at low temperature storage as compared to high temperature storage.

g) At ambient temperature (28±1°C), control fruits (3.50 – 4.10 %) exhibited lower Total Soluble Solids (TSS) as compared to the irradiated fruits (4.03 – 5.00 %) and fruits treated with $CaCl_2$ (3.30 - 4.17 %). Similarly, at low temperature storage (10±1°C), irradiated fruits displayed the largest TSS (4.00 - 5.13%) as compared to $CaCl_2$ treated fruits showed the least (3.90 – 4.33 %) and control fruits (3.43 – 4.07).

h) Control fruits displayed between 94.49 – 95.45 % moisture content which was comparatively larger than that of irradiated tomato fruits (94.62 – 96.53 %) and $CaCl_2$ treated fruits (94.11 to 95.51 %) at ambient temperature storage (28±1°C). In contrast, at

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low temperature storage (10±1°C), moisture content was greater in irradiated fruits (94.43 – 95.87 %) than $CaCl_2$ treated fruits (94.32 – 95.97 %) and control (94.49 – 95.60 %).

3. Nutritional Properties

a) At ambient temperature storage (28±1°C), tomato fruits treated with $CaCl_2$ coating at 2.50% showed the highest vitamin C content of 20.02 mg/100 g over storage period. Similarly, at low temperature storage (10±1°C), vitamin C content of fruits treated with $CaCl_2$ showed the largest content 14.56 mg/100 g compared to 12.96 mg/100 g (2.5 and 1.5 %) in irradiated fruits over storage period.

b) In general, fruits treated with $CaCl_2$ showed the largest content at both temperatures over the storage period.

c) Lycopene content was high in $CaCl_2$ treated fruits at 2.50% (53.30 mg/kg) by the final day of storage than irradiated fruits at 1kGy (23.05 mg/kg) at ambient temperature storage (28±1°C). Similarly, at low temperature storage (10±1°C), $CaCl_2$ coating at 2.5% showed the largest lycopene content of 60.87 mg/kg.

d) In general, contents of Na, K, Zn, and Cu in irradiated tomato fruits decreased with time over the storage period while that of Mn increased across irradiation doses at ambient temperature storage (28±1°C). In like manner, contents of Na, K, Zn, Mn and Cu in fruits treated with $CaCl_2$ decreased with time over the storage period.

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e) In general, Na and Cu showed a greater reduction in content in irradiated fruits than $CaCl_2$ treated fruits at both temperatures over storage period. K and Zn content also exhibited more reductions in $CaCl_2$ treated fruits than irradiated fruits at ambient temperature storage (28±1°C). However, at low temperature storage (10±1°C), there were fluctuations in the content of K and Mn in both treatments.

4. Microbial Load

a) Total aerobic mesophilic bacteria counts at ambient temperature (28±1°C) reduced with increasing radiation doses and $CaCl_2$ concentrations. However, fruits treated with $CaCl_2$ showed a reduced count (0.48 – 1.15 log cfu/ml) over the storage period than irradiated fruits (0.48 - 3.19 log cfu/ml) whilst control fruits showed the largest counts (0.44 - 3.85 log cfu/ml). Similarly, at low temperature (10±1°C), total aerobic mesophilic counts reduced with increasing radiation doses and $CaCl_2$ concentrations.

Treatment of fruits with $CaCl_2$ at 2.50% concentration was best able to reduce microbial load (0.27 log cfu/ml) more than fruits that were irradiated (2.40 log cfu/ml) when stored at 10±1°C for 25 days which were all acceptable by The International Commission on Microbiological Specifications for Foods (ICMSF, 1974).

b) Mould and yeast counts reduced with increasing radiation doses or $CaCl_2$ concentration throughout storage at both temperatures (28±1°C and 10±1°C). At low temperature (10±1°C), fruits treated with $CaCl_2$ at all concentrations reduced growth of moulds

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and yeasts below an acceptable level of 10^6 by ICMSF (1974) standards.

c) In general, fruits treated at 2.50% and 4kGy were best able to reduce microbial load in tomato fruits at both temperatures. However, fruits treated with $CaCl_2$ exhibited a reduced microbial load at both storage temperatures.

In summary, it appears that doses of 3 and 4 kGy significantly extends shelf life of tomato by inactivating spoilage micro organisms, however, it caused a reduction in the nutritional properties of fresh tomato fruits and also changes in appearance (softening) of the fruit which affected the fruits' physicochemical properties. Similarly, $CaCl_2$ coating at 2.00 and 2.50 % also extended the shelf life of tomato longer than gamma radiation and reduced microbial content as well. $CaCl_2$ coating is also better able to maintain the nutritional properties as well as physicochemical properties of fresh tomato fruits than gamma irradiation or no treatment. Based on the results from this study, $CaCl_2$ application is a feasible solution for farmers, retailers and consumers to reduce post - harvest losses.

5.2 RECOMMENDATIONS

The following recommendations are made following results obtained from this research;

1. Gamma radiation should be combined with calcium chloride to determine the effects of the combination treatments on tomato preservation.

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2. Other postharvest treatments like applications of Chitosan, Sodium Hypochlorite, Potassium Permanganate and their combination with gamma radiation should be investigated.
3. Research into the combined use of various post - harvest treatments and packaging materials on storage properties of fresh tomato fruits should be undertaken. This would provide information to retailers who package tomato fruits using Modified Atmosphere Packaging.
4. $CaCl_2$ coating is an approved processing aid for organic food production and is relatively inexpensive, and easily accessible.
5. Sensory evaluation should be conducted on the effects of these post - harvest treatments on the organoleptic properties (taste, texture, colour, sweetness) of fresh tomato fruits.

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APPENDICES

Appendix 1a: ANOVA Table for pH of Tomato Fruits Following Gamma Radiation Application and Storage at Ambient Temperature (28±1°C).

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0536933	4	0.0134233	335.58	0.0000
Within groups	0.0004	10	0.00004		
Total (Corr.)	0.0540933	14			

DAY 3

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.026	4	0.0065	195.00	0.0000
Within groups	0.000333333	10	0.0000333333		
Total (Corr.)	0.0263333	14			

DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.12516	4	0.03129	586.69	0.0000
Within groups	0.000533333	10	0.0000533333		
Total (Corr.)	0.125693	14			

DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0778667	3	0.0259556	283.15	0.0000
Within groups	0.000733333	8	0.0000916667		
Total (Corr.)	0.0786	11			

Appendix 1b: Multifactor ANOVA Table for pH of Tomato Fruits Following Gamma Radiation Application and Storage at Ambient Temperature (28±1°C) - Type III Sums of Squares

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A: DOSE - 0kGy	0.00295556	2	0.00147778	26.60	0.0010
RESIDUAL	0.000333333	6	0.0000555556		
TOTAL (CORRECTED)	0.00328889	8			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A: DOSE - 1 kGy	0.00886667	3	0.00295556	118.22	0.0000
RESIDUAL	0.0002	8	0.000025		
TOTAL (CORRECTED)	0.00906667	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A: DOSE - 2 kGy	0.0204667	3	0.00682222	136.44	0.0000
RESIDUAL	0.0004	8	0.00005		
TOTAL (CORRECTED)	0.0208667	11			

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Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A: DOSE - 3 kGy	0.0427583	3	0.0142528	171.03	0.0000
RESIDUAL	0.000666667	8	0.0000833333		
TOTAL (CORRECTED)	0.043425	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A: 4 kGy	0.269492	3	0.0898306	1796.61	0.0000
RESIDUAL	0.0004	8	0.00005		
TOTAL (CORRECTED)	0.269892	11			

Appendix 2a: ANOVA Table for pH of Tomato Fruits Following $CaCl_2$ Coating and Storage at Ambient Temperature (28±1°C).

DAY 3

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0285733	4	0.00714333	357.17	0.0000
Within groups	0.0002	10	0.00002		
Total (Corr.)	0.0287733	14			

DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0895067	4	0.0223767	839.13	0.0000
Within groups	0.000266667	10	0.0000266667		
Total (Corr.)	0.0897733	14			

DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0483667	3	0.0161222	322.44	0.0000
Within groups	0.0004	8	0.00005		
Total (Corr.)	0.0487667	11			

Appendix 2b: Multifactor ANOVA Table for pH of Tomato Fruits Following $CaCl_2$ Coating and Storage at Ambient Temperature (28±1°C) - Type III Sums of Squares.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 0 %	0.00295556	2	0.00147778	26.60	0.0010
RESIDUAL	0.000333333	6	0.0000555556		
TOTAL (CORRECTED)	0.00328889	8			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 1.0 0%	0.0891	3	0.0297	1188.00	0.0000
RESIDUAL	0.0002	8	0.000025		
TOTAL (CORRECTED)	0.0893	11			

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Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 1.50%	0.0428917	3	0.0142972	13.40	0.0017
RESIDUAL	0.00853333	8	0.00106667		
TOTAL (CORRECTED)	0.051425	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.00%	0.0524667	3	0.0174889	419.73	0.0000
RESIDUAL	0.000333333	8	0.0000416667		
TOTAL (CORRECTED)	0.0528	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.50%	0.026825	3	0.00894167	268.25	0.0000
RESIDUAL	0.000266667	8	0.0000333333		
TOTAL (CORRECTED)	0.0270917	11			

Appendix 3a: ANOVA Table for pH of Tomato Fruits Following Gamma Radiation Application and Storage at Low Temperature (10±1°C).

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0501733	4	0.0125433	470.38	0.0000
Within groups	0.000266667	10	0.0000266667		
Total (Corr.)	0.05044	14			

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0295333	4	0.00738333	369.17	0.0000
Within groups	0.0002	10	0.00002		
Total (Corr.)	0.0297333	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.01664	4	0.00416	208.00	0.0000
Within groups	0.0002	10	0.00002		
Total (Corr.)	0.01684	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.09764	4	0.02441	135.61	0.0000
Within groups	0.0018	10	0.00018		
Total (Corr.)	0.09944	14			

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DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0158267	4	0.00395667	8.02	0.0036
Within groups	0.00493333	10	0.000493333		
Total (Corr.)	0.02076	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0274667	4	0.00686667	206.00	0.0000
Within groups	0.000333333	10	0.0000333333		
Total (Corr.)	0.0278	14			

Appendix 3b: Multifactor ANOVA Table for pH of Tomato Fruits Following Gamma Radiation Application and Storage at Low Temperature (10±1°C) - Type III Sums of Squares.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSE 0 kGy	0.113783	5	0.0227567	163.85	0.0000
RESIDUAL	0.00166667	12	0.000138889		
TOTAL (CORRECTED)	0.11545	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSE 1 kGy	0.120583	5	0.0241167	54.95	0.0000
RESIDUAL	0.00526667	12	0.000438889		
TOTAL (CORRECTED)	0.12585	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSE 2 kGy	0.00657778	5	0.00131556	78.93	0.0000
RESIDUAL	0.0002	12	0.0000166667		
TOTAL (CORRECTED)	0.00677778	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A: DOSE 3 kGy	0.0125111	5	0.00250222	112.60	0.0000
RESIDUAL	0.000266667	12	0.0000222222		
TOTAL (CORRECTED)	0.0127778	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A: DOSES 4 kGy	0.0998944	5	0.0199789	719.24	0.0000
RESIDUAL	0.000333333	12	0.0000277778		
TOTAL (CORRECTED)	0.100228	17			

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Appendix 4a: ANOVA Table for pH of tomato fruits following $CaCl_2$ coating and storage at low temperature (10±1°C).

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0332267	4	0.00830667	9.58	0.0019
Within groups	0.00866667	10	0.000866667		
Total (Corr.)	0.0418933	14			

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.115307	4	0.0288267	2162.00	0.0000
Within groups	0.000133333	10	0.0000133333		
Total (Corr.)	0.11544	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.176307	4	0.0440767	300.52	0.0000
Within groups	0.00146667	10	0.000146667		
Total (Corr.)	0.177773	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0931067	4	0.0232767	91.88	0.0000
Within groups	0.00253333	10	0.000253333		
Total (Corr.)	0.09564	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0333067	4	0.00832667	624.50	0.0000
Within groups	0.000133333	10	0.0000133333		
Total (Corr.)	0.03344	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.04324	4	0.01081	540.50	0.0000
Within groups	0.0002	10	0.00002		
Total (Corr.)	0.04344	14			

Appendix 4b: Multifactor ANOVA Table for pH of Tomato Fruits Following $CaCl_2$ Coating and Storage at Low Temperature (10±1°C) - Type III Sums of Squares.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL- 0	0.110978	5	0.0221956	99.88	0.0000
RESIDUAL	0.00266667	12	0.000222222		
TOTAL (CORRECTED)	0.113644	17			

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Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL – 1.00%	0.0431111	5	0.00862222	517.33	0.0000
RESIDUAL	0.0002	12	0.0000166667		
TOTAL (CORRECTED)	0.0433111	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.00%	0.228778	5	0.0457556	457.56	0.0000
RESIDUAL	0.0012	12	0.0001		
TOTAL (CORRECTED)	0.229978	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.5%	0.594733	5	0.118947	3058.63	0.0000
RESIDUAL	0.000466667	12	0.0000388889		
TOTAL (CORRECTED)	0.5952	17			

Appendix 5a: ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following Gamma Radiation Application and Storage at Ambient Temperature (28±1°C).

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0375007	4	0.00937516	311.73	0.0000
Within groups	0.000300749	10	0.0000300749		
Total (Corr.)	0.0378014	14			

DAY 3

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0107675	4	0.00269187	67.62	0.0000
Within groups	0.000398082	10	0.0000398082		
Total (Corr.)	0.0111655	14			

DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.000375225	4	0.0000938063	490.14	0.0000
Within groups	0.00000191386	10	1.91386E-7		
Total (Corr.)	0.000377139	14			

DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0202698	3	0.0067566	197.70	0.0000
Within groups	0.000273408	8	0.000034176		
Total (Corr.)	0.0205432	11			

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Appendix 5b: Multifactor ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following Gamma Radiation Application and Storage at Ambient Temperature (28±1°C) – Type III Sums of Squares

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSE - 0 kGy	0.0154378	2	0.0077189	257.83	0.0000
RESIDUAL	0.000179629	6	0.0000299382		
TOTAL (CORRECTED)	0.0156174	8			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 1 kGy	0.0163847	3	0.00546157	200.01	0.0000
RESIDUAL	0.000218453	8	0.0000273067		
TOTAL (CORRECTED)	0.0166032	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 2 kGy	0.00835371	3	0.00278457	90.43	0.0000
RESIDUAL	0.000246341	8	0.0000307926		
TOTAL (CORRECTED)	0.00860005	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 3 kGy	0.00429251	3	0.00143084	52.07	0.0000
RESIDUAL	0.00021982	8	0.0000274775		
TOTAL (CORRECTED)	0.00451233	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 4 kGy	0.0886045	3	0.0295348	2155.11	0.0000
RESIDUAL	0.000109637	8	0.0000137046		
TOTAL (CORRECTED)	0.0887141	11			

Appendix 6a: ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following $CaCl_2$ Coating and Storage at Ambient Temperature (28±1°C) - Type III Sums of Squares.

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0226273	4	0.00565681	172.42	0.0000
Within groups	0.00032809	10	0.000032809		
Total (Corr.)	0.0229553	14			

DAY 3

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0514003	4	0.0128501	491.63	0.0000
Within groups	0.000261378	10	0.0000261378		
Total (Corr.)	0.0516617	14			

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DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0684279	4	0.017107	195.47	0.0000
Within groups	0.000875179	10	0.0000875179		
Total (Corr.)	0.0693031	14			

DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.00991104	3	0.00330368	80.56	0.0000
Within groups	0.00032809	8	0.0000410112		
Total (Corr.)	0.0102391	11			

Appendix 6b: Multifactor ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following $CaCl_2$ Coating and Storage at Ambient Temperature (28±1°C)

- Type III Sums of Squares.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 0	0.0169744	2	0.00848718	334.39	0.0000
RESIDUAL	0.000152288	6	0.0000253814		
TOTAL (CORRECTED)	0.0171266	8			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 1.00%	0.00110389	3	0.000367962	17.94	0.0007
RESIDUAL	0.000164045	8	0.0000205056		
TOTAL (CORRECTED)	0.00126793	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 1.50%	0.00854059	3	0.00284686	83.30	0.0000
RESIDUAL	0.000273408	8	0.000034176		
TOTAL (CORRECTED)	0.00881399	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.00%	0.0333934	3	0.0111311	465.29	0.0000
RESIDUAL	0.000191386	8	0.0000239232		
TOTAL (CORRECTED)	0.0335848	11			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.50%	0.0324535	3	0.0108178	85.55	0.0000
RESIDUAL	0.00101161	8	0.000126451		
TOTAL (CORRECTED)	0.0334652	11			

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Appendix 7a: ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following Gamma Radiation Application and Storage at Low Temperature (10±1°C).

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.069566	4	0.0173915	334.79	0.0000
Within groups	0.000519475	10	0.0000519475		
Total (Corr.)	0.0700854	14			

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.00012112	4	0.0000302799	369.17	0.0000
Within groups	8.20224E-7	10	8.20224E-8		
Total (Corr.)	0.00012194	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.00527678	4	0.00131919	37.12	0.0000
Within groups	0.000355431	10	0.0000355431		
Total (Corr.)	0.00563221	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0357344	4	0.00893361	217.83	0.0000
Within groups	0.000410112	10	0.0000410112		
Total (Corr.)	0.0361446	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.00640869	4	0.00160217	58.60	0.0000
Within groups	0.000273408	10	0.0000273408		
Total (Corr.)	0.00668209	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.00674224	4	0.00168556	205.50	0.0000
Within groups	0.0000820224	10	0.00000820224		
Total (Corr.)	0.00682427	14			

Appendix 7b: Multifactor ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following Gamma Radiation Application and Storage at Low Temperature (10±1°C) - Type III Sums of Squares.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 0 kGy	0.1261	5	0.0252199	737.45	0.0000
RESIDUAL	0.000410386	12	0.0000341988		
TOTAL (CORRECTED)	0.12651	17			

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Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 1 kGy	0.0973853	5	0.0194771	711.79	0.0000
RESIDUAL	0.000328363	12	0.0000273636		
TOTAL (CORRECTED)	0.0977137	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 2 kGy	0.0158805	5	0.0031761	137.10	0.0000
RESIDUAL	0.000278	12	0.0000231667		
TOTAL (CORRECTED)	0.0161585	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 3 kGy	0.00894603	5	0.00178921	56.05	0.0000
RESIDUAL	0.000383045	12	0.0000319204		
TOTAL (CORRECTED)	0.00932907	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:DOSES 4 kGy	0.0323843	5	0.00647686	315.86	0.0000
RESIDUAL	0.000246067	12	0.0000205056		
TOTAL (CORRECTED)	0.0326303	17			

Appendix 8a: ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following $CaCl_2$ Coating and Storage at Low Temperature (10±1°C)

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0208228	4	0.00520569	105.78	0.0000
Within groups	0.000492135	10	0.0000492135		
Total (Corr.)	0.0213149	14			

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0739182	4	0.0184795	482.44	0.0000
Within groups	0.000383045	10	0.0000383045		
Total (Corr.)	0.0743012	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0503454	4	0.0125863	270.79	0.0000
Within groups	0.000464794	10	0.0000464794		
Total (Corr.)	0.0508102	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0881194	4	0.0220299	619.81	0.0000
Within groups	0.000355431	10	0.0000355431		
Total (Corr.)	0.0884749	14			

DAY 20

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Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0156225	4	0.00390563	158.72	0.0000
Within groups	0.000246067	10	0.0000246067		
Total (Corr.)	0.0158686	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.0554089	4	0.0138522	266.66	0.0000
Within groups	0.000519475	10	0.0000519475		
Total (Corr.)	0.0559284	14			

Appendix 8b: Multifactor ANOVA Table for TOTAL TITRATABLE ACIDITY of Tomato Fruits Following $CaCl_2$ Coating and Storage at Low Temperature (10±1°C) - Type III Sums of Squares.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL- 0	0.1261	5	0.0252199	737.45	0.0000
RESIDUAL	0.000410386	12	0.0000341988		
TOTAL (CORRECTED)	0.12651	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 1.00%	0.0204714	5	0.00409429	224.63	0.0000
RESIDUAL	0.000218726	12	0.0000182272		
TOTAL (CORRECTED)	0.0206902	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL -1.50%	0.0581926	5	0.0116385	243.25	0.0000
RESIDUAL	0.000574157	12	0.0000478464		
TOTAL (CORRECTED)	0.0587668	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.00%	0.0525057	5	0.0105011	158.93	0.0000
RESIDUAL	0.000792884	12	0.0000660736		
TOTAL (CORRECTED)	0.0532986	17			

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:LEVEL 2.50%	0.0702385	5	0.0140477	362.68	0.0000
RESIDUAL	0.000464794	12	0.0000387328		
TOTAL (CORRECTED)	0.0707033	17			

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Appendix 9: ANOVA Table for TOTAL AEROBIC MESOPHILES of Tomato Fruits Following Gamma Radiation Application and Storage at Ambient Temperature (28±1°C)

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.471732	4	0.117933	637.97	0.0000
Within groups	0.00184857	10	0.000184857		
Total (Corr.)	0.473581	14			

DAY 3

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	6.20351	4	1.55088	31569.61	0.0000
Within groups	0.000491256	10	0.0000491256		
Total (Corr.)	6.204	14			

DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	6.77479	4	1.6937	2337.98	0.0000
Within groups	0.00724429	10	0.000724429		
Total (Corr.)	6.78203	14			

DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	89.6818	4	22.4204	7099.68	0.0000
Within groups	0.0315795	10	0.00315795		
Total (Corr.)	89.7133	14			

Appendix 10: ANOVA Table for TOTAL AEROBIC MESOPHILES of Tomato Fruits Following $CaCl_2$ Coating Application and Storage at Ambient Temperature (28±1°C)

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.471732	4	0.117933	637.97	0.0000
Within groups	0.00184857	10	0.000184857		
Total (Corr.)	0.473581	14			

DAY 3

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	6.20351	4	1.55088	31569.61	0.0000
Within groups	0.000491256	10	0.0000491256		
Total (Corr.)	6.204	14			

DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	6.59181	4	1.64795	7842.07	0.0000
Within groups	0.00210142	10	0.000210142		
Total (Corr.)	6.59391	14			

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DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	27.0748	4	6.76869	18056.03	0.0000
Within groups	0.00374871	10	0.000374871		
Total (Corr.)	27.0785	14			

Appendix 11: ANOVA Table for TOTAL AEROBIC MESOPHILES of Tomato Fruits Following Gamma Radiation Application and Storage at Low Temperature (10±1°C)

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.471732	4	0.117933	637.97	0.0000
Within groups	0.00184857	10	0.000184857		
Total (Corr.)	0.473581	14			

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	2.55822	4	0.639555	690.93	0.0000
Within groups	0.00925646	10	0.000925646		
Total (Corr.)	2.56748	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	7.68616	4	1.92154	8582.37	0.0000
Within groups	0.00223894	10	0.000223894		
Total (Corr.)	7.6884	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	9.97901	4	2.49475	807.16	0.0000
Within groups	0.0309079	10	0.00309079		
Total (Corr.)	10.0099	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	10.9371	4	2.73427	1342.10	0.0000
Within groups	0.0203731	10	0.00203731		
Total (Corr.)	10.9574	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	5.30212	4	1.32553	871.48	0.0000
Within groups	0.0152101	10	0.00152101		
Total (Corr.)	5.31733	14			

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Appendix 12: ANOVA Table for TOTAL AEROBIC MESOPHILES of Tomato Fruits Following $CaCl_2$ Coating and Storage at Low Temperature (10±1°C)

DAY 0

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	0.471732	4	0.117933	637.97	0.0000
Within groups	0.00184857	10	0.000184857		
Total (Corr.)	0.473581	14			

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.11911	4	0.279777	80.29	0.0000
Within groups	0.0348461	10	0.00348461		
Total (Corr.)	1.15395	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	4.16603	4	1.04151	3009.43	0.0000
Within groups	0.00346082	10	0.000346082		
Total (Corr.)	4.16949	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	13.0627	4	3.26567	2621.19	0.0000
Within groups	0.0124587	10	0.00124587		
Total (Corr.)	13.0751	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	23.3728	4	5.84319	2023.06	0.0000
Within groups	0.0288829	10	0.00288829		
Total (Corr.)	23.4016	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	35.841	4	8.96026	1784.75	0.0000
Within groups	0.0502047	10	0.00502047		
Total (Corr.)	35.8913	14			

Appendix 13: ANOVA Table for MOULDS AND YEASTS GROWTH of Tomato Fruits Following Gamma Radiation Application and Storage at Ambient Temperature (28±1°C)

DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.53779	4	0.384448	1286.68	0.0000
Within groups	0.00298792	10	0.000298792		
Total (Corr.)	1.54078	14			

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DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	18.3421	4	4.58553	1101.51	0.0000
Within groups	0.0416294	10	0.00416294		
Total (Corr.)	18.3837	14			

Appendix 14: ANOVA Table for MOULDS AND YEASTS GROWTH of Tomato Fruits Following $CaCl_2$ Coating and Storage at Ambient Temperature (28±1°C)

DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1.98693	4	0.496732	2847.60	0.0000
Within groups	0.00174439	10	0.000174439		
Total (Corr.)	1.98867	14			

Appendix 15: ANOVA Table for MOULDS AND YEASTS GROWTH of Tomato Fruits Following Gamma Radiation Application and Storage at Low Temperature (10±1°C)

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	5.84049	4	1.46012	5736.01	0.0000
Within groups	0.00254554	10	0.000254554		
Total (Corr.)	5.84304	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	20.4743	4	5.11857	78.61	0.0000
Within groups	0.651156	10	0.0651156		
Total (Corr.)	21.1254	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	3.5111	4	0.877775	1.92	0.1830
Within groups	4.5628	10	0.45628		
Total (Corr.)	8.0739	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	2.93206	4	0.733015	359.57	0.0000
Within groups	0.0203857	10	0.00203857		
Total (Corr.)	2.95244	14			

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Appendix 16: ANOVA Table for MOULDS AND YEASTS GROWTH of Tomato Fruits Following $CaCl_2$ Coating and Storage at Low Temperature (10±1°C)

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	12.9664	4	3.2416	35288.44	0.0000
Within groups	0.000918601	10	0.0000918601		
Total (Corr.)	12.9673	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	26.0584	4	6.51461	104.66	0.0000
Within groups	0.622484	10	0.0622484		
Total (Corr.)	26.6809	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	11.7176	4	2.9294	4344.83	0.0000
Within groups	0.00674226	10	0.000674226		
Total (Corr.)	11.7243	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	17.166	4	4.2915	4261.94	0.0000
Within groups	0.0100693	10	0.00100693		
Total (Corr.)	17.1761	14			

Appendix 17a: ANOVA Table for WEIGHT LOSS of Tomato Fruits Following Gamma Radiation Application and Storage at Ambient Temperature (28±1°C)

DAY 3

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	8.1783	4	2.04458	179300.90	0.0000
Within groups	0.00011403	10	0.000011403		
Total (Corr.)	8.17841	14			

DAY 6

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	55.5207	4	13.8802	28502.05	0.0000
Within groups	0.00486989	10	0.000486989		
Total (Corr.)	55.5256	14			

DAY 9

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	410.506	4	102.627	3696.50	0.0000
Within groups	0.277632	10	0.0277632		
Total (Corr.)	410.784	14			

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Appendix 17b: ANOVA Table for WEIGHT LOSS of Tomato Fruits Following Gamma Radiation Application and Storage at Low Temperature (10±1°C)

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	319.621	4	79.9052	5051755.66	0.0000
Within groups	0.000158173	10	0.0000158173		
Total (Corr.)	319.621	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	285.473	4	71.3683	7632012.38	0.0000
Within groups	0.0000935118	10	0.00000935118		
Total (Corr.)	285.473	14			

DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1034.05	4	258.512	16225637.79	0.0000
Within groups	0.000159323	10	0.0000159323		
Total (Corr.)	1034.05	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1656.99	4	414.248	301024074.11	0.0000
Within groups	0.0000137613	10	0.00000137613		
Total (Corr.)	1656.99	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	3103.92	4	775.98	2996075928.03	0.0000
Within groups	0.00000258999	10	2.58999E-7		
Total (Corr.)	3103.92	14			

Appendix 18a: ANOVA Table for WEIGHT LOSS of Tomato Fruits Following $CaCl_2$ Coating and Storage at Low Temperature (10±1°C)

DAY 5

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	334.378	4	83.5946	175821.38	0.0000
Within groups	0.00475452	10	0.000475452		
Total (Corr.)	334.383	14			

DAY 10

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	336.369	4	84.0922	169606.41	0.0000
Within groups	0.00495808	10	0.000495808		
Total (Corr.)	336.374	14			

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DAY 15

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1133.72	4	283.43	362470.89	0.0000
Within groups	0.00781939	10	0.000781939		
Total (Corr.)	1133.73	14			

DAY 20

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	1777.8	4	444.449	963613.99	0.0000
Within groups	0.00461231	10	0.000461231		
Total (Corr.)	1777.8	14			

DAY 25

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Between groups	3112.88	4	778.221	465055.26	0.0000
Within groups	0.0167339	10	0.00167339		
Total (Corr.)	3112.9	14			

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