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MICROBIAL INACTIVATION BY GAMMA IRRADIATION OF POWDERED SUN-DRIED LEGON-18 PEPPER (*CAPSICUM ANNUUM* L.) AND ITS IMPACT ON PRODUCT QUALITY

BY

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DECLARATION

I hereby declare that this thesis is the result of research work which was undertaken by me at the University of Ghana; that the work has not been submitted elsewhere for the award of any degree, and is not concurrently submitted for any other degree other than the Doctor of Philosophy (PhD) degree of this university (University of Ghana).

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This thesis is dedicated to the Glory of God and to the memory of my late daddy, Julius Nii-Odai who was a source of motivation to me in my academic endeavour.

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ABSTRACT

Pepper powder (being a spice) has been known to be contaminated with several pathogenic microorganisms. These organisms tend to make red pepper powder a source of potential health hazard. The FAO/WHO preliminary report indicated a global concern on the management of these pathogens in foods and the need to reduce or eliminate the health hazards associated with them. Some of these pathogens have been identified with both dried and powdered pepper samples in Ghana. This warranted a study to investigate the use of gamma irradiation on these pathogens in Legon-18 (*Capsicum annuum* L.) pepper powder and also to determine the impact of the gamma radiation treatment on the quality parameters of the samples stored at two different temperatures. Samples of powdered Legon-18 pepper were obtained from a local farmer. Known weights of the samples were sterilised by gamma irradiation at 20 kGy, and a cocktail of *Listeria monocytogenes, Bacillus cereus, Salmonella* Typhimurium, *Staphylococcus aureus* and *Escherichia coli* of pre-determined cell count (colony forming unit/millilitre), were inoculated into them. The samples were irradiated at 1, 2, 4, and 5 kGy with 0 kGy as control, to determine an effective dose of gamma irradiation that could lead to complete inactivation of the pathogens inoculated in the samples. The samples were stored at 4 ^{o}C and 28±2 ^{o}C. Enumeration of the different pathogens was carried out on days 0, 2, 5, 12, 21, 30, 45 and 60 in storage. The effects of gamma irradiation and storage on the quality parameters of unsterile samples were determined. These were irradiated at 1, 2, 4 and 5 kGy. Unirradiated samples served as control (0 kGy). The CIELAB colour components were determined using the Minolta Chroma-meter. Carotenoids and capsaicinoids in the samples were quantified using high performance liquid chromatography. The results suggest that gamma irradiation treatment completely inactivated *L. monocytogenes* and *S.* Typhimurium only at day 60 at 2 and 4 kGy. *E. coli* could not thrive in the samples after 30 days of storage when not exposed to gamma irradiation. *S. aureus* could be completely inactivated at 4 kGy only after 45 days (no detection of *S. aureus* in the samples after). All

the pathogens could be completely inactivated at 2, 4 and 5 kGy. The optimum dose for complete inactivation of the pathogens excluding *B. cereus* was 2 kGy which is subject to a storage period of over 45 days. All pathogens used in the study were completely inactivated at 5 kGy even on day zero. Gamma irradiation treatments and storage significantly ($p<0.05$) affected the quality parameters of the samples. Losses of colour parameters, carotenoids and capsaicinoids were more pronounced in the samples that were stored at 28±2 ^{o}C as compared with the samples that were stored at 4 ^{o}C. Percentage losses for the samples stored at 4 ^{o}C were in the range of 83.32 and 83.81%, 50.00% to 53.72%, 33.53% to 37.80%, 54.52% to 58.60%, 40.25% and 56.00%, 78.35 to 81.71% and percentage increase in the range of 372.36% to 429.14% for lightness, redness, yellowness, browning index, chroma, hue and total colour difference respectively. The total colour difference, hue, chroma, browning index, yellowness, redness and lightness of the samples that were stored at 28±2 ^{o}C were in the range of 410.72% to 417.50%, 80.13% to 84.75%, 39.55% to 57.00 %, 50.69% to 54.02%, 32.98% to 37.37%, 51.86 to 55.06, 72.77 to 76.98% respectively. Moisture content, total titratable acidity and pH of the samples were stable. Capsaicinoid content ranged from 118 in the unirradiated samples to 221.00 (mg/100g) in the irradiated samples. At the end of the storage period there was a loss of 22.46%, 9.95%, 11.78%, 9.86% and 9.53% in the samples that were irradiated at 0, 1, 2, 4and 5 kGy respectively and stored at 4 ^{o}C and for the unirradiated samples, 16.43%, 11.11%, 10.31% and 10.67% for the samples that were irradiated at 1, 2, 4 and 5 kGy respectively and stored at 28±2 ^{o}C. Gamma irradiation caused an increase of 6.33, 17.68, 18.79 % and 20.95% in the samples irradiated at 1, 2, 4 and 5 kGy respectively. Beta cryptoxanthin, beta carotene and capsanthin ranged from 1.04 to 2.11, 5.36 to 10.27 and 1.12 to 1.48 (mg/100 g) in the irradiated samples, respectively. Gamma irradiation and storage caused some reductions in the contents of all the pigments analysed ($p<0.05$).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS

ANOVA	Analysis of variance
AOAC	Association of Official and Applied Chemists
AU	Australia
BD	Becton Dickinson
BHI	Brain heart infusion
BI	Browning index
BPA	Baird Parker Agar
BPW	Buffered peptone water
CDC	Centre for Disease Control and Prevention
CFU	Colony forming unit
CT-SMAC	Cefixime tellurite sorbitol MacConkey
DOH	Department of Health
EU	European Union
FAO	Food and Agriculture Organization
FSAI	Food Safety Authority of Ireland
HPLC	High performance liquid chromatography
IAEA	International Atomic Energy Agency
MOFA	Ministry of Food and Agriculture
MYP	Mannitol egg yolk polymyxin
NMIMR	Noguchi Memorial Institute for Medical Research
PBS	Phosphate Buffer Saline
PLS	Palcam Listeria selective
SHU	Scoville Heat Units

TSB	Tryptic soy broth
TTA	Total titratable acidity
USDA	United States Department of Agriculture
WHO	World Health Organization
XLD	Xylose lysine deoxycholate
YE	Yeast extract

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Red pepper (*Capsicum annuum*), commonly known as chili, has been identified as one of the widely used spices in the world (Lee et al., 2004). It is considered as the second most important vegetable after tomato (Liu et al., 2013; Ali, 2006; Ochoa-Alejo and Ramirez-Malagon, 2001; Yoon, 1989). Chili is produced in several countries (Pinto et al., 2016; Rufino and Penteado, 2006). The ripened matured fruits (red in colour) are harvested and processed into fine powder. The powder is used as a spice, food colourant, a flavouring (Jung et al., 2015) and for the preparation of a special sauce known as 'shito' in Ghana (Doku, 2015).

The commercial quality indices of red pepper powder include the pungency and colour (Jung et al., 2015). The pungency (hotness) of red pepper powder is due to the presence of capsaicinoids. Dihydrocapsaicin and capsaicin are the main capsaicinoids responsible for the hotness of pepper (Jung et al., 2015; Orellana-Escobedo et al., 2013; Lee et al., 2004). Capsanthin is the main carotenoid that gives pepper its red colour (Jung et al., 2015; Giuffrida et al., 2013).

Processed spices, including pepper powder, have been known to be reservoirs of microorganisms (Greig, 2015; Jung et al., 2015; Witkowska et al., 2011; DOH/VICTORIA/AU, 2010; Kahraman and Ozmen, 2009; Shamsuddeen, 2009; Bhunia, 2008; Koch et al., 2005; Kaul and Taneja, 1989; Kovács-Domján; 1988; Christensen et al., 1967) owing to their agricultural origin and processing methods (Jung et al., 2015; Buckenhuskes and Rendlen, 2004; Oularbi and Mansouri, 1996). Piggott and Othman

(1993) and Boer et al. (1985) indicated that pepper can have high microbial contamination of viable counts exceeding 10^{7} colony forming unit per gram with most of these being spore formers. Pathogenic bacteria such as *Salmonella* Montevideo have been associated with pepper in the United States of America (CDC, 2010). Other pathogenic bacteria associated with pepper include *Staphylococcus aureus*, *Escherichia coli*, spore formers such as *Bacillus subtillis, B atrophaeus, B. cereus* and fungi such as *Aspergillus flavus, A. parasiticus, A. nomius, A. pseudotarii* (Koohy-Kamaly-Dehkordy et al., 2013; Oh et al., 2012; Higa, 2011; Aydin et al., 2007; Buckenhuskes and Rendlen, 2004; Gustavsen and Breen, 1984). *Listeria monocytogenes*, a soil borne pathogen, has also been associated with pepper (Kara et al., 2015).

1.2 Rationale

Microbial decontamination methods that have been used in spice such as pepper, include the use of fumigants (ethylene oxide, gaseous ozone) and irradiation techniques such as ultra-violet decontamination, radio frequency heating, cold plasma treatment, gamma irradiation, electron beam and x-rays sterilization (Jung et al., 2015; Cheon et al., 2015; Kim et al., 2013; Witkowska et al., 2011; Rico et al., 2010; Cember and Johnson, 2009; Schweiggert et al., 2007; Gregoire et al., 2003; Oslon, 1998). Some of these methods tend to have adverse effects on the quality (both chemical and sensorial) parameters of the spices. The use of ethylene oxide has been banned by the European Union because it is now classified as a carcinogen (Lilie et al., 2007; Shweggert et al., 2007; Almela et al., 2002; Tainter and Grenis, 2001). The Joint Food and Agriculture Organization (FAO), the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) have approved the use of gamma irradiation for the decontamination of foods and it is used in over 51 countries (IAEA, 2008; WHO, 1981).

Pathogenic microorganisms have been associated with powdered pepper in Ghana (Saba and Gonzalez, 2012). The occurrence of pathogens in powdered pepper may be due to handling and processing conditions (Yankey, 2014). The FAO and WHO expert consultation panel on ranking of low moisture foods lists *Listeria monocytogenes, Bacillus cereus, Salmonella spp, Staphylococcus aureus, and pathogenic E. coli* as some of the microbial hazards associated with low moisture foods which include powdered products (WHO/FAO, 2014). Effective strategies for the reduction or complete elimination of these health hazards in low moisture foods are urgently required. This study therefore is in response to such a research gap to deliver powdered pepper with low microbial loads. The goal was towards reducing the food safety risks associated with powdered pepper using gamma radiation. This is in line with suggestion by other authors (Farkas and Andrassy, 1998; Byun et al., 1996; Cho et al., 1986) that gamma irradiation is more effective for the decontamination of spices than other methods such as ozone treatment, steam-heat treatment and ethylene oxide without any adverse effects.

1.3 Objectives

1.3.1 Main Objective

The main objectives of the study were to investigate the microbial decontamination of pepper (*Capsicum annuum* L.) powder using gamma irradiation and to determine the effects of irradiation on the quality parameters of the pepper powder stored at different temperatures.

1.3.2 Specific objectives

The specific objectives of the study were to:

1. investigate inactivation effects of gamma irradiation on pathogenic microorganisms in powdered pepper
2. determine the effect of irradiation treatment for microbial inactivation on the quality of the powder
3. determine the optimum irradiation conditions (dosage and storage time) for the effective reduction of pathogens in powdered pepper

CHAPTER TWO

2. 0 LITERATURE REVIEW

2.1 Spices

These are plant parts that are used based on their flavor and other properties (Embuscado, 2015; Herman, 2015). They can be classified into various groups such as their taxonomy, taste or flavor, or the part of the plant from which they were obtained (El-Sayed and Youssef, 2019; Embuscado, 2015; Herman, 2015).

Tables 2.1 and 2.2 indicate the various classification of spices.

Table 2.1. Spice classification based on plant part

Plant part	Spice
Aril	Mace
Bulbs	Onion, garlic, leek
Root	Ginger, turmeric
Seed	Dill, mustard, fennel, nut meg, fenugreek
Leaves	Basil, oregano, baby leaf, thyme
Fruits	Chili, allspice, clove, black pepper
Pistil, flower, bud	Saffron, clove
Bark	Cassia, cinnamon

Source: El-Sayed and Youssef, 2019; Embuscado, 2015; Herman, 2015.

Table 2.2. Classification of spices based on flavour

Flavour	Spice
Hot	chilies, cayenne peppers, white and black peppers, mustard
Mild	coriander, paprika
Aromatic	cinnamon, clove, nutmeg, dill, funnel
Vegetables	onion, garlic, shallot

Source: El-Sayed and Youssef, 2019; Embuscado, 2015; Herman, 2015.

Other classification based on taxonomy indicates that spices in general are flowering plants or *Angiospermae* (Embuscado, 2015).

2.2 Peppers: origin, botany and production

Peppers (*Capsicum* spp) belong to the family *Solanacea* (do Rego et al., 2016). Other crops in the *Solanaceae* include tomatoes, potatoes, tobacco (Ryan and Pearce, 2003; Lovell, 1993). *Capsicum* species are known to have originated from the South Americas, and have been domesticated for several millennia in the American continent, notably Latin America. This was introduced to Europe in the 15th century from where its worldwide distribution began (Liu et al., 2013; Perry et al., 2007; Andrews, 1995a) and subsequently introduced to Africa and Asia through the spice trade (Anon, 2014; Kumar et al., 2006). According to Pickersgill (1969), it is one of the most cultivated crops in the Americas before the advent of agriculture. Capsicum is made up of thirty species of which twenty-five are wild and only five have been domesticated (Bosland and Votava, 2000). Costa et al. (2009) indicated that Brazil became the centre of diversity after the cultivation of pepper in the humid and tropical parts of both South and Central America for over seven millennia. The species of pepper domesticated include *Capsicum annuum* comprises of chili (dried for chili powder and paprika) as well as hot peppers, sweet pepper from Mexico (Kraft et al., 2014); *C. chinense* also known as aromatic hot pepper from the Amazonia Region; *C. frutescens* (Bird eye) from the coastal regions of the southern part of tropical South America. *C. frutescence* and *C. chinense* in tropical Africa are treated as a single species as *C. annuum* (Grubben et al., 2004; Purseglove et al., 1981). Among the species of *Capsicum*, *C. annuum* is the most widely cultivated worldwide, mostly used in commercial cultivar breeding programmes, making it the most economically important (Bosland and Votava, 2000).

FAOSTAT (2007) indicated that pepper production is done in about seventy-seven countries worldwide. It is estimated that pepper cultivation is done on over three million hectares of land yearly (Doku, 2015). In terms of production, over 89% of pepper production is done in Asia, 7% in the Americas and 4% in Africa, Europe and the Middle East (Rufino and Penteado 2006).

According to Liu et al. (2013), there are two main types of pepper in terms of their botany. Those of the wild (*Capsicum*) which are perennials whiles the ones commercially cultivated are annuals. Peppers in general are herbaceous plants that turn woody with age, some of which can grow as high as 6 feet (Doku, 2015). The capsicum plant produces flowers that have five petals, sepals, pistils and stamens. There are a range of colour for the stamens, petals and pistils. These can be greenish-white, greenish yellow, white or purple which is variety and species dependent. The identification of the various domesticated species can be attributed to the differences in the colour of the filaments, seed, corolla, and flower patterns per node (Liu et al., 2013; Walsh and Hoot, 2001; DeWitt and Bosland, 1993).

Pepper is a self-pollinated crop which does not show any inbreeding depression. They can be cross-pollinated by insects, with an outcrossing rate ranging from 70-90% been cultivar-dependent (Liu et al., 2013; Andersson et al., 2007). The fruits have different shapes and colour, some constituents including vitamin C, carotenoids, capsaicinoids. *Capsicum spp* can be cultivated in the tropics from sea level to elevations of over 6,000 feet. They require a temperature range of 21 and 30 °C.

2.3 Nutritional Composition

Peppers have high nutritional value which varies from pepper species, variety, fruit age and condition of postharvest treatments. They are a good source of vitamin K and vitamin

B6, riboflavin, niacin, alpha tocopherol, vitamin A and vitamin C, (Liu et al., 2013; Lin and Saltveit, 2012; Nadeem et al., 2011), etc. Table 2.1-2.3 indicates the various composition of dried chili pepper.

Table 2.3. Proximate composition of dried chili pepper powder

Proximate component	g/100 g
Water	10.75
Protein	13.46
Total lipid (fat)	14.28
Ash	11.81
Carbohydrate (by difference)	49.7
	kJ/100g
Energy	1179

Source: USDA National Nutrient Database for Standard Reference 28 slightly revised May 2016.

Table 2.4. General Elemental composition of dried chili pepper powder

Minerals (Element)	mg /100 g
Calcium, Ca	330
Iron, Fe	17.3
Magnesium, Mg	149
Phosphorus, P	300
Potassium, K	1950
Sodium, Na	2867
Zinc, Zn	4.3
Copper, Cu	1
Manganese, Mn	1.7
	µg/100g
Selenium, Se	20.4

Source: USDA National Nutrient Database for Standard Reference 28 slightly revised May 2016.

Table 2.5. General nutrient composition of dried chili pepper powder

Nutrient	Unit	Value per 100 g
Vitamins		
Vitamin C, total ascorbic acid	Mg	0.7
Thiamin	Mg	0.25
Riboflavin	Mg	0.94
Niacin	Mg	11.6
Pantothenic acid	Mg	0.888
Vitamin B-6	Mg	2.094
Folate, total	µg	28
Folate, food	µg	28
Folate, DFE	µg	28
Choline, total	Mg	66.5
Betaine	Mg	2.7
Vitamin A, RAE	µg	1483
Carotene, beta	µg	15000
Carotene, alpha	µg	2090
Cryptoxanthin, beta	µg	3490
Vitamin A, IU	IU	29650
Lycopene	µg	21
Lutein + zeaxanthin	µg	310
Vitamin E (alpha-tocopherol)	Mg	38.14
Tocopherol, beta	Mg	0.24
Tocopherol, gamma	Mg	3.41
Vitamin K (phylloquinone)	µg	105.7
Lipids		Value per 100 g
Fatty acids, total saturated	G	2.462
Fatty acids, total monounsaturated	G	3.211
Fatty acids, total polyunsaturated	G	8.006
Phytosterols	Mg	83
Carbohydrates		
Fibre, total dietary		34.8
Sugars, total		7.19
Sucrose		0.76
Glucose (dextrose)		2.14
Fructose		4.29

Source: USDA National Nutrient Database for Standard Reference 28 slightly revised May 2016 Software v.3.8.6.5.

Table 2.5. General nutrient composition of dried chili pepper powder (continued)

Amino Acids	g/100 g
Tryptophan	0.07
Threonine	0.27
Isoleucine	0.39
Leucine	0.63
Lysine	0.36
Methionine	0.13
Cystine	0.18
Phenylalanine	0.37
Tyrosine	0.19
Valine	0.54
Arginine	0.49
Histidine	0.18
Alanine	0.45
Aspartic acid	1.69
Glutamic acid	1.59
Glycine	0.6
Proline	1.25
Serine	0.23

Source: USDA National Nutrient Database for Standard Reference 28 slightly revised May 2016 Software v.3.8.6.5.

2.4 World production and economic importance

Pinto et al. (2016) indicated that 89% of the total production area for peppers world-wide is in the Asian continent comprising of countries such as India, China, Vietnam, Thailand, Sri Lanka, and Indonesia. The second largest region of production are United States of America and Mexico which accounts for 7% of pepper production globally. The least areas of pepper production (total worldwide production) can be located in Africa, Europe and the Middle East. These account for 4% (Rufino and Penteado 2006). Pepper export and imports yielded over $96,397 billion, being the second largest earner in terms of vegetable export in 2011 (FAOSTAT, 2011).

2.5 Characteristics and quality indices of chili pepper and pepper products

2.5.1 Colour

The colour of pepper (as well as its products such as powder, flakes, prickles and paste) is dependent on the presence of carotenoids available in the tissue of the pepper fruit. These carotenoids have been identified to be red, orange and yellow pigments which are found in plants. According to Biacs et al. (1989), Griesbach and Stommel (2008c), Gnayfeed et al. (2001) and Deli and Molnar (2002), pepper fruits have been identified to contain over 30 different carotenoids. These carotenoids include β carotene and wide range of xanthophylls such as zeaxanthin, β cryptoxanthin, lutein and a host of others. Of all the carotenoids indicated to occur in pepper fruits, the only carotenoids that possess provitamin A activity are β carotene and β cryptoxanthin. The oxidative cleavages of β carotene and cryptoxanthin yield retinal which is needed by humans. Wall et al. (2011) indicated that, the amount of β carotene in pepper both dried and fresh is sufficient to meet the total amount needed by an adult (man) on daily basis. Beta (β) carotene content of chili pepper had been indicated in literature. Topuz and Odzemir (2003) and Topuz et al. (2009) indicated that the β carotene content in some pepper varieties were in the range of 69.5±8.4 to 120.3±11.0 (mg/kg) and Kim et al. (2004) reported a range of 80.74±13.50 to 129.40±3.73 (mg/100g) in Korean chili pepper. The quality of chili pepper in terms of colour is attributed to the presence of carotenoids (which is variety–based), stage of maturity, growing conditions, ripeness. The red colour of pepper fruits is derived from the xanthophylls such as capsanthin and capsorubin. According to Deli and Molnar (2002), Maoka et al. (2001), Ha et al. (2007), Topuz and Ozdemir, (2007), the red colour of pepper fruits is mainly due to the pigment capsanthin; since it contributes the most red colour in a percentage range of 37 to 80 (as the total carotenoids in pepper). Topuz and Odzemir (2003), Kim et al. (2004), Topuz and Odzemir (2007), Jung et al. (2015), reported that the capsanthin content in red pepper was 550.77±20.61 to 951.38 (mg/kg), 15.41±1.28 to 27.11±6.97 (mg/100g), 769.0±71.3 to 1270±89 (mg/kg) and 5.07±0.57 to 6.00±0.07 (µg/100mg), in dried and irradiated pepper, respectively. Topuz and Odzemir (2003) reported a beta cryptoxanthin content of red pepper (paprika) as 113.5±11.0 to 165.5±12.3 (mg/kg) and Kim et al. (2004) also reported that cryptoxanthin in Korean red pepper was l22.06±1.42 to 45.39 (mg/100 g).

2.5.2 Pungency

The hotness of pepper and pepper products is attributed to the availability of capsaicinoids which are a group of related alkaloids formed due to the condensation of vanillylamine with a medium chain branched fatty acid (Luo et al., 2011). There are over 20 capsaicinoids which can be differentiated from each other based on the fatty acid structure. The most abundant capsaicinoids available in pungent or hot peppers are capsaicin and dihydrocapsaicin (Davis et al., 2007; Materska and Perucka, 2005). Others include nornornorcapsaicin, nordihydrocapsaicin, nornorcapsaicin, norcapsaicin, homodihydrocapsaicin, nonivamide and homocapsaicin, (Manirakiza et al. 2003; Pruthi 2003b; Fujinari, 1997). Giuffrida et al. (2013), indicated the proportion of capsaicin and dihydrocapsaicin as 92.5% of the total capsaicinoids found in some varieties of capsicum. Capsaicin can be found in the stem end of the pod (fruit) which is in the range of 0.1% to 1.0% of the total fruit (pod) weight (Al Othman et al., 2011; Tucker, 2001). The pericarp tissues contain the capsaicinoids. The production site for capsaicinoids in red peppers are the glands on the placenta of the pepper, thus making the white ribs and the glands the hottest part of red pepper (Dong, 2000; Bosland, 1992). The amount of capsaicinoids in capsicum fruits varies widely based on the variety, maturity level of the plant, fruit, time of harvest, storage conditions (which are influenced by humidity, temperature, exposure to light, water activity, and contact with oxygen), environmental conditions during cultivation as well as edaphic factor (Al Othman et al., 2011; Rhim and Hong, 2011; Menozzi-Smarrito et al., 2009; Antonious et al., 2006; Tucker, 2001). Capsaicin and dihydrocapsain dominates the flavour of *C. annuum*. The capsaicin content of 28.18- 32.35 (mg/100g) was observed by Lee et al. (2004); Topuz et al. (2009) observed an amount of 499-657 (mg/kg); 0.52-0.56 (mg/g) was observed by Rico et al. (2010); 707 to 38871(µg/g) in 12 pepper varieties investigated by Giuffrida et al. (2013); a content ranging from 1407.98 to 1859.42 (µg/g) by Giuffrida et al. (2014) was reported in red pepper powder and 23.44 to 36.87 (mg/100g) by Jung et al. (2015) and Nagy et al. (2015) reported range of 197 and 440.8(ug/g); and Jung et al. (2015) recorded a capsaicin content of 7.03-7.40 (µg/100g) in both irradiated and unirradiated samples. Dihydrocapsaicin content of some pepper varieties had been reported in literature. Topuz and Odzemir (2004) reported a range of 121±4.53 to 134±4.26 (mg/kg); a range of 308±21 to 14132±1323 (µ/g) by Giuffrida et al. (2013); Giuffrida et al. (2014) reported a range of 811.32±24.66 to 1077.20±54.55 (µg/g); Nagy et al. (2015) reported 88.9 to 780 (µg/g) in some Hungarian varieties, 4.14±0.27 (mg/100g) in some Korean red pepper by Cheon et al. (2015) and a range of 3.23±0.12 to 3.4±0.1 (µg/100g) by Jung et al. (2015).

The hotness of pepper and pepper products (as well as its products such as powder, flakes, prickles and paste) is measured in Scoville Heat Units (SHU) which was first developed in 1912 by Wilbur Scoville (Giuffrida et al., 2013; Al Othman et al., 2011; Scoville, 1912). Five classifications of the pungency of pepper has been identified based on the Scoville heat units (Weiss, 2002). These are non-pungent (0–700 SHU), mildly pungent (700–3,000 SHU), moderately pungent (3,000–25,000 SHU), highly pungent (25,000–70,000 SHU) and very highly pungent (>80,000 SHU). The SHU of some pepper varieties indicated by

Lee et al. (2004) and Orellana-Escobedo et al. (2013) are 717±28 to 750±50 (x1000 in mg/100g) and 961.13± 7.91 to 211247.65±656.47 (x10000 in mg/kg).

2.6 Uses of chili pepper and pepper products

Reilly et al. (2001) and Bosland and Votava (2000), indicated that *Capsicum* and *Capsicum* derived components and ingredients have diverse applications, including as food additives, in traditional medicines, drugs, health-promoting products, pests control in agricultural fields, cosmetics and use as self-defence in pepper sprays. In the food industry, oleoresins which is an extract of carotenoids from pepper is used as a food colorant. The powder of chili pepper is used in various ethnic foods worldwide as components of drinks, soups, stews, sauces, and other fermented foods such as kimchi, gochujang, sauerkraut (Raju et al., 2010); in the cosmetic as well as the pharmaceutical industry for many products.

2.7 Pepper production in Ghana

Pepper is not native to Ghana. It was introduced into Ghana in the 15^{th} Century (La Anyane, 1963). Chili peppers are produced in Ghana for both the local and the international markets. The main varieties cultivated in Ghana are the Bird's eye (which are mostly cultivated in Thailand and India) and the Legon-18 which was bred by Crop Scientists from the University of Ghana (MOFA, 2007). The peppers are cultivated in the Volta, Central, Greater Accra, Eastern, Northern and other Regions of Ghana. About two-thirds of the overall chili pepper production in Ghana is done in the Northern Savannah belt for both the local market and the international market. Over 198,000 households are into chilli production in the Northern Savanah belt of Ghana. Irrigation is used to serve as water supply for dry season production. Chilli peppers from Ghana are exported to the

European Union, most of which come from farms in the southern part of Ghana under rain fed conditions (Asase, 2014; Sualihu, 2012; Schipmann, 2006).

2.8 Microbial ecology of chili pepper powder

Chili pepper powder (which is a product of chili pepper fruits) has been identified to be a reservoir of many pathogenic microorganisms (FSAI, 2005). This is due to its cultivation (chili pepper crop), production, processing and storage conditions, insanitary drying conditions, improper sanitation procedures, failure on the part of processors to validate and verify antimicrobial intervention treatment which will facilitate an effective level of the inactivation of pathogens, cross contamination of food materials etc. (Bakobie et al., 2017; Jung et al., 2015; Gurtler et al., 2014; Rico et al., 2010; Moreira, 2009; Threlfall, 2009; Antai, 1998).

Notable organisms implicated in the contamination of chili pepper include *Bacillus cereus*, *Salmonella* species, *Listeria monocytogenes, Staphylococcus aureus, Aspergillus* species, *E. coli*, *Cladosporium species*, *Penicillium species*, *Clostridium perfringens* (Bakobie et al., 2017; Nokwanda and Ijabadeniyi, 2013; Van et al., 2013; Sualihu, 2012; CDC, 2010; Hampikyan et al., 2009; Vij et al., 2006; Banerjee and Sakar, 2003).

2.9 Processing

Chili pepper fruits are processed into pastes, flakes, powder and pickles (Kim et al., 2017; Jung et al., 2015).

2.9.1 Pepper powder

The process of red pepper powder production varies from one place to the other. The general procedure for the production of red pepper powder is depicted in Figure 2.1.

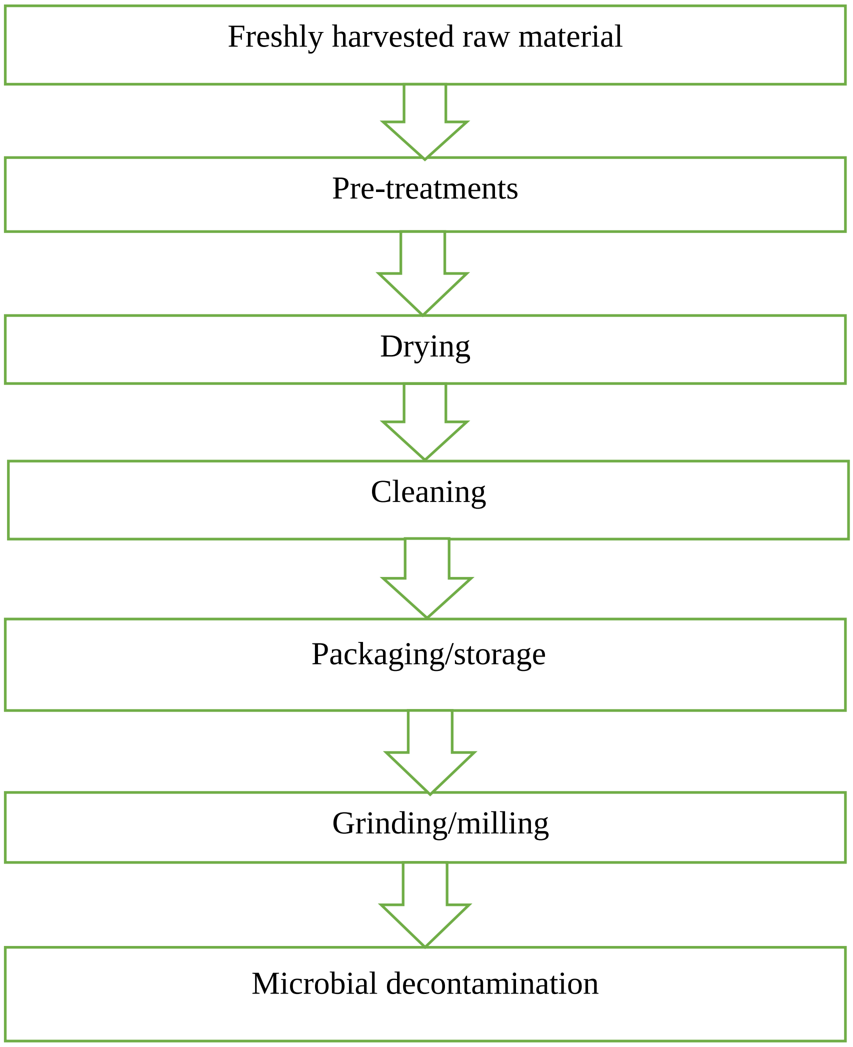

Fig. 2.1. Flow chart for chili (red) pepper powder production (Source: Schweiggert et al., 2007).

2.9.2 Harvesting of pepper fruits

Harvesting of fruits for spice production are either manually or mechanically done (Pruthi et al., 2003b). In Ghana, harvesting of pepper is mostly done manually (Asase, 2014; MOFA, 2007).

2.9.3 Pre-treatment

Pre-treatments of pepper fruits is done before drying (Fig 2.1). Sorting of fruits is done and other undesirable components of the fruits are removed. Processing may involve blanching or boiling of the fruits before drying, however, not all processors boil (Owusu-Kwarteng, 2017; Obeng-Ofori et al, 2007). Blanching before drying aids in obtaining pepper powder with best organoleptic and nutritional qualities (Doymaz and Pala, 2010; Tunde-Akintunde, 2010; Wiriya et al., 2009) In Ghana, harvested, cleaned fruits are blanched or boiled before drying (Owusu-Kwarteng et al., 2017).

2.9.4 Drying of the raw material

There are various drying methods employed in pepper powder production. These include solar drying, sun or open air drying and super-heated steam drying.

2.9.4.1 Sun drying

This is also known as open air drying. It is the commonest drying method employed for chili pepper. Drying period can last for several days which may be due to environmental conditions during the drying period. Generally, the moisture content of the dried produce may be in the range of 4% to 12 % (Jung et al., 2015; Montoya-Ballesteros et al., 2014; Topuz et al., 2011; Schweiggert et al., 2007; Topuz et al., 2004). Sun drying is the main mode of drying pepper in Africa, Central and South America and Asia. In Ghana, pepper is dried either on a tarpaulin or on a raised platform (Sualihu, 2012; Schipmann, 2006). Variations in the moisture content of the final product, inability to control temperature of drying (due to variations in the climatic conditions such as solar radiation, humidity, wind speed and current), variations in colour (a quality parameter of red pepper powder) and poor microbial quality are the disadvantages associated with this method of drying

(Montoya-Ballesteros et al., 2014; Phomkong et al., 2010; Topuz and Odzemir, 2004; KPIC, 2001).

2.9.4.2 Solar drying

This involves the use of solar energy devices (equipment or materials) that are able to harness (concentrate) solar energy with or without natural airflow inside the dryer. Several types exist which are used in vegetable drying. In Ghana, they are also used in the drying of chili pepper (Owusu-Kwarteng et al., 2017; Schipmann, 2006).

2.9.4.3 Super-heated steam (SHS)

This is a drying method that makes use of steam. It is done by exposing the material to be dried to high steam temperature, leading to loss of moisture from the surface of the material. There is no resistance to moisture diffusion in the process and so the rate of drying is controlled by heat transfer only (Devahastin and Suvarnakuta 2008; Mujumdar and Huang, 2007; Kudra and Mujumdar,2002). Kiang and Jon (2015) described the system for superheat steam as operating in a closed cycle and it is made up of a heat chamber, compressor, heat exchanger and a blower to blow the steam on the material. Some advantages of using the SHS is its higher energy efficiency in terms of drying due to higher drying rates. Other advantages include its environmental friendliness (Devahastin and Suvarnakuta, 2008).

2.10 Cleaning

Dried pepper samples are examined and cleaned where appropriate before milling (Schweiggert et al., 2007).

2.11 Milling (Particle size reduction)

Dried pepper samples are well examined and cleaned before milling. Grinding (milling) is done using equipment such as hammer, electric and cryogenic mills (Schipmann, 2006; Minguez-Mosquera et al., 2000).

2.12 Packaging and storage

At the end of processing, powdered pepper is packed and stored in appropriate materials (Schweiggert et al., 2007). During storage, temperature and humidity are critical since these tend to have effect on the quality parameters of chili powder (Rico et al., 2010; Wang et al., 2009; Almela et al., 2008).

2.13 Microbial decontamination of chili pepper powder

There are several processes used in microbial decontamination to enhance food safety and food preservation (Farkas, 2007). These include the following;

2.13.1 Super-heated steam

This is a process of applying high steam temperature to a material leading to the evaporation of water from the material. The treatment aids in the decontamination of vegetative microorganisms and inactivation of spores, resulting from the high-temperature and the absence of oxygen from the chamber during the process. The method has been used in the decontamination of pepper (Rico et al., 2010; Devahastin and Suvarnakuta, 2008; Schweiggert et al., 2007; Tainter and Grenis, 2001).

2.13.2 Radio frequency heating

Radio-frequency heating is the method of using the band of electromagnetic spectrum which covers a frequency range of 1 to 300MHz' (Ryynanen, 1995). This method of heating, also called dielectric heating, allows quick and uniform heating of food materials due to the application of high-voltage electric current to the electrodes. According to Tang et al. (2005), it can be used for the heating of various food stuffs to different temperatures. Radio-frequency heating has been used for the inactivation of *Escherichia coli* O157:H7 and *Salmonella* Typhimurium on black and red pepper (Kim, 2012).

2.13.3 Food Irradiation (gamma rays, electron beams and X-rays)

Food irradiation is a process whereby foods are exposed to ionizing radiations such as gamma rays from radio nuclides like Co^{60} and Ce^{137}; X-rays and electrons generated from machine sources operated at or a below an energy level of 5 million electron volts and at or below an energy level of 10 MeV to meet certain technical objectives respectively (O'Hara, 2013; Arvanitoyannis and Tserkezou, 2010; Cleland, 2010; Ignacio, 2008; Confederation of British Industry, 2007; Codex, 2003; Andress et al., 1998, Olso, 1998; Loaharanu, 1996). Some of the uses of gamma irradiation in the food industry include in sprout inhibition, radiation quarantine treatment, microbial decontamination and delay ripening in fruits and vegetables. X-rays has been used in pepper decontamination (Jung et al., 2015). Gamma, X-rays and Electron beams are three main sources of ionizing radiations used in the food industry (Riganakos, 2010).

Gamma irradiations are produced by radio nuclides such as cobalt-60 (being the commonest) with energy levels of 1.17 and 1.33 MeV; and caesium-135 which has an energy level of 0.662 MeV; X-rays or decelerating rays are produced from accelerators with a maximum quantum energy of electrons not exceeding 5 MeV and Electron beams produced from linear accelerators such as the Van De Graaf generator with a quantum energy not exceeding 10 MeV.

2.13.4 General classification of food irradiation doses

Food irradiation doses have classified into various ranges of doses in order to meet specific targets ranging from low dose to high dose irradiations.

1. Low doses

These are doses of gamma irradiation that are less than 1 kGy. These doses are used mainly for phytosanitary purposes, sprout inhibitions in roots, tubers and bulbs, ripening delay in fruits and vegetables, inactivation of parasites and egg treatment. Other uses include, the treatment of fruits, insect disinfestation and quarantine purposes (IFIS, 2020; Carbo Verde, 2018; Hallman and Loaharanu, 2016; Kalyani and Manjula, 2014; IAEA, 2004; ICGFI, 1991). The application of these low doses to food is also known as radurization.

2. Medium doses

This process is also known as radicidation which involves the use of doses ranging from 1 kGy to 10 kGy. These doses are used for the control of foodborne pathogens as well as the extension of shelf life of food materials such as fresh produce, meat and meat products, poultry and poultry products, spices as well as dried foods (Miller, 2015; Hallman, 2011).

3. High doses

This involves the use of doses in the range of 10 kGy to 100 kGy. These doses are meant for shelf-stable meats, foods meant for astronauts, sterility of foods meant for immunocompromised individuals, microbial decontamination of some spices, muscle food sterilization purposes and some Korean foods (Song et al., 2018; USFDA, 2016; Miller, 2015; Kalyani and Manjula, 2014; IAEA, 2002). This process of irradiation is also known as radappertization (IAEA, 2002).

2.14 Use of Gamma rays in microbial decontamination of foods

Gamma rays of specific energies originate from the spontaneous disintegration of either artificial or natural radionuclides (radioisotopes). They disintegrate spontaneously or decay to a stable state due to their instability. The most commonly used radioisotope for food irradiation by gamma rays is the ^{60}Co. ^{60}Co is produced by the neutron bombardment in a nuclear reactor of ^{59}Co which is then doubly encapsulated in a stainless steel material known as pencils to prevent the leakage into the environment during usage (Riganakos, 2010).

The basics for the use of the gamma rays in microbial decontamination is the ability of the rays to pick electrons from a material leading to free electrons and thus take part in a chemical reaction. This will lead to the disruption or destruction of the DNA, thus inactivating the organism. The advantages with the use of ^{60}Co is its ability to deeply penetrate the food material. It is also considered to pose a low risk to the environment and further has a uniform distribution in terms of its dose in the food material (Riganakos, 2010). Gamma irradiation has been used in the decontamination of several foods (Song et al., 2009; Stewart et al., 2001; CFR, 1986). Some of these include, the decontamination of Korean medicinal herbs (Kim et al., 2000); inactivation of psychrotrophic bacteria in squid rings at 4.8 kGy (Tomac et al., 2013); inactivation of *Escherichia coli* O157:H7 and *Salmonella* Typhimurium in black and red pepper at 5 kGy (Song et al., 2014); improving the hygienic quality of red pepper powder in Korea (Jung et al., 2015); reduction of mesophilic bacteria and fungi in Korean red pepper powder (Lee et al., 2004); and inactivation of *Salmonella* Typhimurium in pea nut butter (Ban and Kang, 2014). Rico et al. (2010) indicated the effect of the use of gamma irradiation and steam on the physiochemical and microbiological properties of dried red pepper.

Gamma rays have been used on spices and other food commodities to determine their impact on the quality parameters of such commodities (Waje et al., 2008; Ray and Bhunia, 2007; Farkas, 2006; Clavero et al., 1994). Some of these include the effect of gamma rays on the quality parameters of Korean pepper with reference to the colour, pungency and volatiles (Lee, 2004). Jung et al. (2015) investigated the effect of gamma irradiation on the physicochemical qualities of red pepper powder; Topuz and Odzemir (2004) investigated the effect of gamma irradiation, storage and drying method on the quality parameters of some spices, Rico et al. (2010) investigated the impact of gamma irradiation and steam on the physicochemical properties of dried red pepper.

2.15 Regulation of food irradiation

The World Trade Organization, the World Health organization and the Food and agriculture Organization and International Atomic Energy Agencies are some of the notable regulatory agencies for food irradiation. The General Standard for the Irradiation of Food by Codex in 1980, indicated that foods irradiated up to doses of 10 kGy are safe. Notwithstanding, foods that are irradiated above 10 kGy are also safe for the consumer (Roberts, 2016; Loaharanu, 2003).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study design

The study was conducted in two phases.

3.1.1 First phase

Firstly, a microbial inactivation test on powdered pepper samples was done. Six kilograms of pepper powder was acquired and divided into 120 sub-samples of 10 g weight each. Each sub sample was pre-contaminated with a cock tail of pathogens (ranging from 6.00±0.08 to 6.49±0.08 cfu/g) containing *Bacillus cereus, Salmonella* Typhimurium, *Escherichia coli*, *Listeria monocytogenes* and *Staphylococcus aureus*. The sub samples were further divided into five subsets and irradiated at 0, 1, 2 4and 5 kGy of gamma radiation for similar durations to de-contaminate them. Viable counts were then done on the irradiated samples using standard microbiological procedures (Jeong et al., 2010; Cheon et al.,2015; Tango et al., 2016; Deng et al., 2015; Luo et al., 2016). The 0 kGy served as control.

3.1.2 Second phase

In the second phase, pepper powder samples that were not pre-inoculated with pathogens were irradiated at same dosage of 0, 1, 2, 4 and 5 kGy and stored at different temperatures. They were then analysed to determine the effect of the irradiation on the quality parameters of powdered pepper. A central composite rotational design for k = 2 (Cochran and Cox, 1957) yielded 13 experimental runs for the study, including 4 centre points. The Central composite design matrix for the two independent variables for both the pathogens and quality parameters are indicated in tables 3.1 and 3.2, respectively.

Table 3.1. Central composite rotational design matrix (template) for two independent variables for inactivation of pathogens at both temperatures

Run order	Doses (kGy)	Days	Survival of organism (log cfu/g)
1	2	60	
2	2	30	
3	0	0	
4	4	0	
5	2	0	
6	2	30	
7	4	30	
8	0	60	
9	0	30	
10	4	60	
11	2	30	
12	2	30	
13	2	30	

Table 3.2. Central composite rotational design matrix (template) for two independent variables on quality parameters at both temperatures

Run order	Doses (kGy)	Storage weeks	Quality parameter
1	2	4	
2	2	4	
3	4	4	
4	0	0	
5	2	4	
6	4	0	
7	0	4	
8	4	8	
9	2	4	
10	0	8	
11	2	4	
12	2	8	
13	2	0	

3.2 Pepper powder samples and microbial culture

3.2.1 Pepper sample

The variety of chilli pepper used was Legon-18, and the pepper powder used for the study was purchased from a local farmer.

3.2.1.1 State of pepper samples

According to the suppliers, they were processed from sun-dried, fully ripened Legon-18 pepper fruits. In order to obtain the powder, the fruits were sorted from unwholesome fruits and the fruit stalks were broken; blanched and sun-dried by open-air drying on raised platforms, cleaned, milled and packaged.

3.2.2 Microbial pathogens

Pure strains of *Listeria monocytogenes* (NCTC 7973/ATCC 35152) and *Bacillus cereus* (NCTC 7464/ATCC 10876) were obtained (purchased) from Becton Dickinson in the United States of America; *Salmonella* Typhimurium, *Esherichia coli* (25922) and *Staphylococcus aureus* (25923) strains were obtained from the Microbiological Collection Centre of the Noguchi Memorial Institute for Medical Research of the University of Ghana.

3.2.3 Sample preparation

Pepper powder samples were sterilized by irradiation and its sterility tested. Samples were contained in sealed pouches and irradiated at the Gamma Irradiation Facility of the Radiation Technology Centre under the Biotechnology and Nuclear Agriculture Research Institute of the Ghana Atomic Energy Commission, Kwabenya. Irradiation was done from a cobalt – sixty (^{60}Co) source (which is a category IV wet storage gamma irradiator) to remove background microflora according to the method employed by Deng et al. (2015). Sterility tests were conducted to confirm the inactivation of the background microflora. Selective media for *Bacillus cereus, Salmonella* Typhimurium, *Escherichia coli, Listeria monocytogenes* and *Staphylococcus aureus* were prepared and poured under sterile conditions and used for the sterility tests according to the procedures of Luo et al. (2016), Tango et al. (2016), Ducic et al. (2016), Deng et al. (2015), Cheon et al. (2015) and Jeong et al. (2010). The procedures of Deng et al. (2015) and Jeong et al. (2010) were used with some modifications. Ten grams of the pepper samples from the pouches were weighed into sterile stomacher (Seward, UK) pouches, and 90 ml of sterile buffered saline water added. The samples were homogenised and serially diluted and spread-plated.

3.3 Microbial inactivation of inoculated pathogens in pepper samples

3.3.1 Inoculum preparation

3.3.1.1 *Salmonella* Typhimurium, *Escherichia coli*

Inoculum preparation and inoculation were done according to the procedures of Cheon et al. (2015), Jeong et al. (2010) and Deng et al. (2015) with some modifications. The stock culture which was in storage at -80 °C in 0.7ml of Tryptic Soy Broth (TSB; Disco) and 0.3ml of 50% glycerol was streaked onto Tryptic Soy Agar (TSA; Difco), incubated at 37 °C for 24 h and then stored at 4 °C. The cells were harvested by centrifugation at 4000 g for 20 minutes at 4 °C and washed three times with phosphate buffered saline (PBS). The final pellets were re-suspended in 10 ml of PBS which corresponded to approximately 10^7-10^8 CFU/ml.

3.3.1.2 *Listeria monocytogenes*

Samples of pepper were inoculated by the method of Luo et al. (2016). The inoculum was prepared by transferring 0.1 ml of the stock cultures into 10 ml of tryptic soy broth (TSB; Becton Dickinson Diagnostic Systems, Sparks, Maryland; BD). This was incubated at 37 °C for 24 h. Cells were centrifuged at 3000 g for 10 min at 4 °C and harvested. The pellets were washed and re-suspended in 10 ml of 0.1% sterile PBS and adjusted to make a final cell concentration of approximately 10^9 CFU/ml.

3.3.1.3 *Bacillus cereus*

The pepper samples were inoculated according to the method of Luo et al. (2016). The *B. cereus* strain used was maintained at -80 °C in tryptic soy broth (TSB, Difco, Sparks, MD, USA) with 0.6% yeast extract (YE, Difco) and 20% glycerol until use. The inoculum was prepared by transferring frozen suspension of *B. cereus* in TSB for overnight incubation at 35 °C with continuous shaking. The cultured strain was streaked onto mannitol egg yolk polymyxin agar (MYP, BD) with egg yolk enrichment 50% and antimicrobic vial P (BD), and incubated at 37 °C for 24 h. After that, single colonies from the incubated plate was transferred to tubes filled with 10 mL TSB and was incubated at 35 °C for 24 h. They were centrifuged at 4000 g for 10 min at 4 °C, and the supernatants decanted. The cell pellets were washed twice with 0.1% sterile PBS and resuspended in 10 mL of the same solution to obtain final cell concentration of approximately 8.0 log CFU/mL.

3.3.1.4 *Staphylococcus aureus*

The samples were inoculated according to the method of Tango et al. (2016). The strain used for the inoculation was in storage at -70 °C in tryptic soy broth (TSB, Difco) containing 25% glycerol and 0.6% yeast extract (YE, Difco) was transferred onto Baird Parker Agar (BPA, BD) plates and incubated at 37 °C for 24 h. A single colony was used for inoculating into10 mL of BHI broth followed by incubation overnight at 37 °C. Following the broth culture, 10 mL of the culture was centrifuged (3000 x g for 10 min at 4 °C). The harvested cells were washed twice in 10 mL of 0.1% buffered peptone water (pH 7.2) (BPW, Difco) to obtain a final cell concentration of approximately 8 log CFU/mL.

3.3.2 Inoculum formulation and inoculation of pepper samples

A cocktail (approximate equal proportions) of the organisms was prepared and used in the study. One millilitre of the suspension was added to 10 g of the powdered pepper samples in sterile pouches. They were thoroughly mixed and dried in a biosafety hood for 1 h.

3.3.3 Irradiation of powdered pepper samples

Inoculated pepper (10 g) was placed in pouches (dimensions of 0.118 m in width and 0.170 m in length) (Figure 3.1 and 3.2) and irradiated at 1, 2, 4 and 5 kGy at a dose rate of 2.01 kGy/h. Unirradiated samples were used as control (0 kGy).

Fig. 3.1. Bulked Samples in pouches for irradiation

Fig. 3.2. Samples on palette in irradiation chamber (area) at the Gamma Irradiation Facility

3.3.4 Microbial enumeration using viable counts

Enumeration for the various organisms was done according to the procedures of Luo et al. (2016), Tango et al. (2016), Ducic et al. (2016), Deng et al. (2015), Cheon et al. (2015) and Jeong et al. (2010) with modifications. Ninety millilitres of PBS was poured into 10 grams of the inoculated pepper in sterile pouches (stomacher bags) and homogenized in a stomacher. The samples were serially diluted onto the various media for the various organisms used in the study and spread plated under sterile conditions onto the various media. XLD agar (BD) was used for *S.* Typhimurium, *L. monocytogenes* on PLS agar (BD), *E. coli* on CT-SMAC (BD), *B. cereus* on MYP agar (BD) and BP (BD) agar for *S. aureus*. All the organisms were incubated at 37 °C for 24 h except *L. monocytogenes* which was incubated for 48 h for days 0, 2, 5, 12, 21, 30, 45 and 60 and colony counted on a colony counter.

3.4 Determination of the effect of gamma irradiation on quality and physicochemical parameters of pepper powder

3.4.1 Irradiation of Samples

Uninoculated pepper powder samples in pouches (dimensions of 0.118 m in width and 0.170 m in length) were irradiated at 1, 2, 4 and 5 kGy at a dose rate of 1.55 kGy/h. The control samples were labelled as 0 kGy (unirradiated inoculated sample).

Fig. 3.3. Packed Legon-18 pepper samples for gamma irradiation

Fig. 3.4. Pepper samples on palette in irradiation chamber (area) at the Gamma Irradiation Facility

3.4.2 Determination of colour

The surface colour of the samples was determined according to the procedure of Lee et al. (2004). Six grams of the sample was put into a petri dish and the colour measured using the Huntler *L* (lightness), *a* (±, redness/ greenness) and *b* (±, yellowness/blueness) with a CR 410 MINOLTA Chroma-meter (Konica Minolta, Japan).

3.4.2.1 Hue, Chroma, colour difference and browning index

The hue, chroma and colour difference were determined using the procedure of Koide and Shi, 2007.

The hue was calculated using the mathematical formula below.

Hue = $\tan^{-1}\left(\frac{b^*}{a^*}\right)$

and the chroma as

Chroma = $(a^{*2} + b^{*2})^{1/2}$

The colour difference (Jung et al., 2015) was calculated using the formula

$$\Delta E^{*} = [(\Delta L^{*2}) + (\Delta a^{*2}) + (\Delta b^{*2})]^{1/2}$$

The Browning Index (BI) using the L, a* and b* according to Mohammadi et al. (2008).

$$\textbf{BI} = \frac{[100(x-0.31)]}{0.17}$$

Where $x = \frac{(a*+1.75L*)}{(5.645L*+a*-3.012b*)}$

3.4.3 Moisture content

The moisture content of the pepper samples (both irradiated and unirradiated) were determined for the period of the study according to the method of AOAC (2000). Two grams of the powder were weighed into petri plates in triplicates. The samples were dried in the oven for 2 hours at 130 °C in an oven (Gallenkamp, United Kingdom). The plates were covered while in the oven, transferred into a desiccator whiles hot to cool to room temperature before they were weighed. The percentage moisture content of the samples was calculated using the formula proposed by Nielson (2017).

$$\% \text{ Moisture Content} = \frac{W2-W3}{W2-W1} \text{ X } 100$$

Where W_1 is the weight of the empty petri plate, W_2 the weight of petri plates and wet sample and W_3 is the weight of the petri dish and dried sample (Nielson, 2017).

3.4.4 pH

The pH of the pepper samples were determined according to the procedure of AOAC (2000). Ten grams of the samples (unirradiated and irradiated samples) were weighed and mixed with 100 ml of distilled water and filtered. The pH of the filtrate was measured using a standard pH meter (WTW Wissenschaftlich-Technishe Werskstatten, Gerrmany) after calibration.

3.4.5 Total titratable acidity

The total titratable acidity (TTA) of the pepper powder (both irradiated and unirradiated) were determined using the AOAC (2000) method. Ten grams of the samples was mixed with 100 ml of distilled water and filtered. Ten millilitres of the filtrate were pippeted into a 25 ml conical flask. The aliquot was diluted with 50 ml distilled water to minimize the interference from the colour of the pepper samples. Three drops of phenolphthalein (1%) was added and titrated against 0.1 M NaOH

TTA was determined in triplicates, expressed as % citric acid (Nielson, 2017) and computed as follows

$$\% \text{ acid} = \frac{Titre\ value\ X\ Normality\ X\ milli\ equivalent\ weight\ of\ the\ acid\ X\ 100}{Volume\ of\ the\ sample}$$

3.4.6 Carotenoids

The main carotenoids analysed in the pepper samples are beta carotene, beta cryptoxanthin, capsanthin and zeaxanthin using reverse phase HPLC according the procedures of Giuffrida et al. (2014) and Topuz et al. (2003).

3.4.6.1 Source of standards and reagents

Standards of the various carotenoids of interest in the study were purchased from Extrasynthese (Lyon, France).

3.4.6.2 Extraction

One gram of the pepper samples were weighed and contents extracted using accelerated solvent extractor equipped with 100-ml stainless steel extraction cells. The cells were loaded with the pepper sample mixed with inert sea sand which had been homogenised. The cells were filled with 90 % ethanol to a pressure of 1500 psi. Heat was applied for the initial period of heat-up time, after which static extraction took place after all the valves were closed. The cells were rinsed with the extraction solvent and purged with N_2 gas for 2 minutes. The extracts were collected from the cells with 20 ml falcon tubes after the system was depressurised.

3.4.6.3 Quantification

The extracts were filtered into a 2 ml glass vial by using a 0.45 µm membrane filter (Millipore), and then used for HPLC injection. The chromatographic separation was performed on a reversed-phase column AQUA 5u C_{18} 125A (150 x4.60, 5um). The binary gradient (acetone:water at the beginning 75:25). Calibration curves of the various carotenoids (standards) were drawn using Microsoft Excel, 2010 (Appendix XCX-XCII).

3.4.7 Capsaicinoids

The capsaicinoids analysed in the samples include capsaicin and dihydrocapsaicin. Pressurized liquid (Fluid Management Systems, USA) extractor was used to extract the capsaicinoids in the pepper samples and quantified using an HPLC. Standards of capsaicin and dihydrocapsaicin were purchased from Extrasynthese (Lyon, France).

3.4.7.1 Extraction

A gram (1.0 g) of the pepper samples were weighed and contents extracted using accelerated solvent extractor equipped with 100-ml stainless steel extraction cells. The cells were loaded with the pepper sample mixed with inert sea sand which had been homogenised. The cells were filled with 90 % ethanol to a pressure of 1500 psi. Heat was applied for the initial period of heat-up time, after which static extraction took place after all the valves were closed. The cells were rinsed with the extraction solvent and purged with N_2 gas for 2 minutes. The extracts were collected from the cells after the system was depressurised (Mustafa and Turner, 2011; Barbero et al., 2006).

3.4.7.2 Quantification

The extracts were filtered into a 2 ml glass vial by using a 0.45 µm membrane filter (Millipore), and then used for HPLC injection. Qualitative and quantitative analysis of the capsaicinoids profile was carried out by the HPLC PDA detector (PerkinElmer Flexar, UK) equipped with a reversed phase column SunFire TM C_{18} (5um, 4.6 x150 mm from Waters) thermostated at 30 ^{o}C. Separation of the compounds was performed by using an isocratic mixture of water: acetonitrile 55:45 v/v. The detection wavelength was set at 280nm (Giuffrida et al., 2013). Calibration curves of the various capsaicinoids (standards) were drawn using Microsoft Excel, 2010 (Appendix XCXIII-XCIV).

3.4.7.3 Scoville heat units

The Scoville heat units and the total capsaicinoids were calculated using the methods of Kim et al. (2004) and Orellana-Escobedo et al. (2013).

Total capsaicinoids= capsaicin + dihydrocapsaicin

SHU= [(% capsaicin x 16.1) + (% dihydrocapsaicin x 16.1)] x 10000.

3.5 Data analysis

Data was analysed with StatGraphics Centurion XV.I and Minitab (version 14) statistical soft wares. Means were separated using Least Significant Difference ($p<0.05$). Response surface regression procedures were used to determine the optimum dose and storage time for effective reduction of pathogens in powdered pepper.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characteristics of pepper samples used

The powdered pepper samples, weighing 6 kg, were packed in food grade polyethylene bags when procured. Microbial analysis done on the samples detected *Staphylococcus aureus*. The presence of *Staphylococcus aureus* in powdered pepper had been indicated in a previous study by Sualihu (2012). Parameters such as pH (5.00±0.01 and 5.12±0.02 of the unirradiated samples and the sterile samples respectively), moisture content (10.03±0.6 and 10.04±0.28 of the unirradiated samples and the sterile samples respectively) and titratable acidity (0.264±0.001 and 0.268±0.018 the unirradiated samples and the sterile samples respectively) were not affected ($p>0.05$) by gamma irradiation after sterilization in comparison with the unirradiated samples which are similar to the observations of Atuobi-Yeboah et al. (2016).

4.1.1 Sample sterilization and inoculation with cocktail of pathogens.

Considering that *Staphylococcus aureus* was detected in the pepper powder obtained from the farmer, the samples were sterilized by irradiation at 20 kGy before it was used for further experimentations. The microbial analysis of samples after the sterilization process showed no detection of pathogens.

4.2. Microbial inactivation of inoculated pathogens in sun-dried Legon-18 pepper powder

The effect of gamma irradiation on the pathogens in the samples have been indicated in Tables 4.1 to 4.7. The microbial count (log $cfug^{-1}$) of the various pathogens ranged from no detection (0) to 6.69 log $cfug^{-1}$throughout the study period. Gamma irradiation caused inactivation of the organisms in the samples that were irradiated at 1, 2, 4 and 5 kGy. Dose-dependent effects were observed. As doses of gamma irradiation increased, the log $cfug^{-1}$ of the organisms were reduced. A general reduction in the microbial count of all the organisms was observed throughout the period of study.

4.2.1 Effect of gamma irradiation, storage time and temperature on the inactivation of *Salmonella enterica* Typhimurium

The log $cfug^{-1}$ of *S.* Typhimurium inoculated in the samples and irradiated ranged from 6.49±0.08 to the point where no detection was observed (Table 4.1) at both storage temperatures (Table 4.1; appendix XCXV; XCXVI). This pathogen was inactivated at the various doses of gamma irradiation irrespective of the storage temperature (appendices CV and CVI), which was dose–dependent ($p<0.05$). The least inactivation of *S.* Typhimurium was observed in the samples irradiated at 1 kGy (showing a higher survival of the pathogen as in Table 4.1). The observed dose-dependent effect on the inactivation of *S.* Typhimurium in all the samples might be attributed to the levels of injuries caused to the cells at the various doses of irradiation as explained by Wu (2008). Byun et al. (2001), however, indicated that the lethality of gamma irradiation on microorganisms was due to the inability of the organisms to adapt to their surroundings (food material), signifying a post-irradiation effect. Deng et al. (2015) and Song et al. (2014) also observed the inactivation of *Salmonella* Typhimurium in red pepper powder) at gamma irradiations of 1, 2, 3 and 5 kGy, which was also dose-dependent.

Table 4.1. Effect of gamma irradiation and storage on the survival of *S.* Typhimurium at 4 °C and 28±2 °C in powdered Legon-18 pepper (C. annuum)

STORAGE		Microbial count (log cfug^{-1})				
DAYS	**TEMP**	**0 kGy**	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	6.49±0.08^{Aa}	5.57±0.11^{Ba}	5.37±0.07^{Ca}	4.40±0.09^{Da}	ND
2		6.38±0.08^{Aa}	5.55±0.11^{Ba}	5.18±0.05^{Cb}	3.89±0.08^{Db}	ND
5		5.72±0.11^{Ab}	5.32±0.11^{Bb}	5.00±0.11^{Cc}	3.65±0.08^{Dc}	ND
12		5.62±0.11^{Abc}	5.10±0.11^{Bc}	4.80±0.09^{Cd}	3.44±0.08^{Dd}	ND
21		5.52±0.11^{Ac}	4.90±0.09^{Bd}	4.60±0.09^{Ce}	3.02±0.09^{De}	ND
30		5.12±0.11^{Ad}	4.60±0.09^{Be}	3.65±0.08^{Cf}	2.72±0.11^{Df}	ND
45		4.99±0.11^{Ad}	3.79±0.08^{Bf}	2.88±0.11^{Cg}	1.46±0.13^{Dg}	ND
60		4.65±0.09^{e}	ND	ND	ND	ND
0	28±2 °C	6.49±0.08^{Aa}	5.21±0.13^{Ba}	4.83±0.11^{Ca}	4.04±0.11^{Da}	ND
2		6.02±0.08^{Ab}	5.19±0.13^{Ba}	4.62±0.11^{Cb}	3.52±0.09^{Db}	ND
5		5.66±0.13^{Ac}	4.96±0.13^{Bb}	4.49±0.11^{Cbc}	3.33±0.09^{Dbc}	ND
12		5.55±0.13^{Ac}	4.69±0.11^{Bc}	4.33±0.11^{Cc}	3.24±0.09^{Dd}	ND
21		5.36±0.13^{Ad}	4.67±0.11^{Bc}	3.99±11^{Cd}	2.88±0.11^{De}	ND
30		4.59±0.11^{Ae}	4.09±0.11^{Bd}	3.14±0.09^{Ce}	2.21±0.13^{Df}	ND
45		3.83±0.09^{Af}	3.32±0.09^{Be}	2.42±0.13^{Cf}	1.25±0.09^{Dg}	ND
60		3.83±0.09^{Af}	ND	ND	ND	ND

Least Significant Difference: Means with the same letters (upper cases, doses within a particular temperature regeme) in the same row are not significantly (P>0.05) different from each other and means with the same letters in the same column (lower case, doses per day within the same temperature regeme) are not significantly different (P>0.05) from each other. Key: ND= not detected. TEMP.= Temperature

There were significant decreases (p<0.05) in the log cfu/g of the pathogen during storage at the different temperatures in all samples irradiated. Similarly, Song et al. (2006) reported a consistent decrease in the count of microorganisms exposed to gamma irradiation in storage.

The *S.* Typhimurium count during storage was higher in the control (unirradiated) samples stored at 4 °C than samples stored at ambient 28±2 °C (4.65±0.09 and 3.38±0.09 log cfu/g, respectively). At both storage temperatures, as days of storage increased inactivation of the pathogen increased in all samples until no detection occurred on the 60th day.

Inactivations during storage as indicated by Ban and Kang (2014) decreases in microbial counts were significant ($p<0.05$) statistically (Table 4.1; appendix XCXV and XCXVI).

4.2.2 Effect of gamma irradiation, storage time and temperature on the inactivation of *Escherichia coli*

Table 4.2 shows the data on the effect of the gamma irradiation on *E. coli* in the pepper samples during storage. Appendices XCXVII and XCXVIII shows the pattern of the counts. Generally, there was a significant reduction in the colony counts ($p<0.05$) with the irradiation treatment. The extent of reduction increased with increasing dosage of the gamma radiation, varying from about 1.5 log $cfug^{-1}$ with the 1kGy treatment to no detection with 5 kGy. Beyond the irradiation treatment (Day 0), however reduction in counts continued but was similar in all samples, including the control and at the two different storage temperatures. Length of storage also had a significant effect ($p<0.05$) on the inactivation of the pathogen. In previous studies, Deng et al. (2015) and Song et al. (2014) observed a dose-dependent inactivation of *E. coli* by gamma irradiation in pepper samples which is similar to this study.

Table 4.2. Effect of gamma irradiation and storage on the survival of *E. coli* at 4 °C and 28±2 °C in powdered Legon-18 pepper (*C. annuum*)

STORAGE		Microbial count (log cfug^{-1})				
DAYS	**TEMP.**	**0 kGy**	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	6.69±0.08^{Aa}	5.17±0.11^{Ba}	4.59±0.11^{Ca}	3.51±0.11^{Da}	ND
2		6.43±0.09^{Ab}	4.84±0.11^{Bb}	4.24±0.11^{Cb}	3.11±0.11^{Db}	ND
5		6.24±0.08^{Ac}	4.44±0.11^{Bc}	3.94±0.11^{Cc}	2.81±0.15^{Dc}	ND
12		5.67±0.11^{Ad}	4.24±0.11^{Bd}	3.66±0.19^{Cd}	2.41±0.15^{Dd}	ND
21		4.85±0.09^{Ae}	4.07±0.11^{Bd}	3.03±0.09^{Ce}	2.11±0.15^{De}	ND
30		3.53±0.09^{Af}	3.43±0.09^{Ae}	2.87±0.13^{Be}	1.78±0.12^{Cf}	ND
45		ND	ND	ND	ND	ND
60		ND	ND	ND	ND	ND
0	28±2 °C	6.40±0.09^{Aa}	4.12±0.09^{Ba}	3.84±0.08^{Ba}	2.57±0.11^{Ca}	ND
2		6.14±0.08^{Ab}	3.85±0.08^{Bba}	3.49±0.08^{Bb}	2.17±0.11^{Cb}	ND
5		5.94±0.76^{Ac}	3.49±0.08^{Bba}	3.19±0.21^{Bc}	2.05±0.2^{Cb}	ND
12		5.37±0.11^{Ad}	3.29±0.72^{Bba}	3.06±0.08^{Bc}	1.40±0.09^{Cc}	ND
21		4.55±0.08^{Ae}	3.14±0.68^{Bb}	2.32±0.11^{Cd}	1.10±0.09^{Dd}	ND
30		3.14±0.08^{Af}	2.67±0.58^{ABc}	2.15±0.11^{Be}	1.06±0.03^{Cd}	ND
45		ND	ND	ND	ND	ND
60		ND	ND	ND	ND	ND

Least Significant Difference: Means with the same letters (upper cases, doses within a particular temperature regeme) in the same row are not significantly (P>0.05) different from each other and means with the same letters in the same column (lower case, doses per day within the same temperature regeme) are not significantly different (P>0.05) from each other. Key: ND= not detected.

The inactivation and dose-dependent effect can be attributed to the impact of the damage caused to the cells by the gamma rays. Ban and Kang (2014), indicated that the inactivation of an organism is dose-dependent (inactivation of an organisms exposed to gamma irradiation increases with an increasing dose), which was also observed in this study. Higher survival rates (least inactivation) were observed in the samples stored at 4 °C than the samples that were stored at 28±2 °C for the study period. Thayer and Boyd (1993), indicated that the resistance of bacteria to gamma irradiation during post-irradiation storage is increased at lower temperatures than at higher temperatures. This is in agreement with the effect of gamma irradiation on the activation of pathogens in this study.

4.2.3 Effect of gamma irradiation, storage time and temperature on the inactivation of *Bacillus cereus*

The enumeration of *Bacillus cereus* after the irradiation treatment gave about 6 log cfu/g for the samples with no irradiation and about 5.0 log cfu/g to no detection for samples irradiated (Table 4.3; appendix XCXIX and C).

Table 4.3. Effect of gamma irradiation and storage on the inactivation of *B. cereus* at 4 °C and 28±2 °C in powdered Legon-18 pepper (*C. annuum*)

STORAGE		Microbial count (log cfug^{-1})				
DAYS	TEMP.	0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	4 °C	6.15±0.08^{Ac}	5.62±0.11^{Bc}	5.15±0.11^{Ca}	4.97±0.11^{Ca}	ND
2		6.17±0.08^{Ac}	5.62±0.11^{Bb}	5.15±0.11^{Ca}	4.55±0.09^{Db}	ND
5		6.09±0.08^{Ac}	5.96±0.08^{Ab}	4.78±0.09^{Bb}	4.23±0.09^{Cc}	ND
12		6.32±0.08^{Ab}	5.85±0.11^{Bb}	4.55±0.09^{Cc}	3.79±0.08^{Dd}	ND
21		6.48±0.08^{Aa}	6.15±0.08^{Ba}	4.80±0.09^{Cb}	4.30±0.09^{Dc}	ND
30		6.17±0.08^{Ac}	5.67±0.11^{Bc}	4.45±0.09^{Cc}	3.74±0.08^{Dd}	ND
45		5.87±0.11^{Ad}	5.17±0.11^{Bd}	3.97±0.09^{Cd}	3.54±0.08^{De}	ND
60		5.07±0.11^{Ae}	3.95±0.09^{Be}	3.02±0.17^{Ce}	2.65±0.04^{Df}	ND
0	28±2 °C	6.00±0.08^{Ac}	5.41±0.13^{Bc}	4.93±0.09^{Ca}	4.74±0.11^{Ca}	ND
2		6.02±0.08^{Ac}	5.64±0.13^{Bb}	4.87±0.14^{Ca}	4.34±0.11^{Db}	ND
5		5.94±0.08^{Ac}	5.78±0.13^{Ab}	4.55±0.11^{Bb}	4.02±0.11^{Bc}	ND
12		6.17±0.08^{Ab}	5.75±0.13^{Bb}	4.24±0.11^{Cc}	3.48±0.09^{Dd}	ND
21		6.33±0.08^{Aa}	5.87±0.13^{Ba}	4.49±0.11^{Cb}	3.43±0.09^{Dc}	ND
30		6.02±0.08^{Ac}	5.36±0.13^{Bc}	4.14±0.11^{Cc}	3.23±0.09^{Dd}	ND
45		5.72±0.13^{Ad}	4.90±0.09^{Bd}	3.30±0.09^{Cd}	2.98±0.09^{De}	ND
60		4.89±0.11^{Ae}	3.64±0.11^{Be}	2.47±0.13^{Be}	2.33±0.13^{Bf}	ND

Least Significant Difference: Means with the same letters (upper cases, doses within a particular temperature regeme) in the same row are not significantly (P>0.05) different from each other and means with the same letters in the same column (lower case, doses per day within the same temperature regeme) are not significantly different (P>0.05) from each other. Key: ND= not detected.

Generally, there were significant (p<0.05) reductions in the colony counts during storage, however the effects were more severe in samples treated with higher doses. The trends were similar in the samples at the two different storage temperatures, and the longer the storage period, especially beyond 45 days, the more reduction in the counts. Dose-dependent effect of gamma irradiation on the samples were observed as inactivation increased with increasing dose of gamma irradiation (Jung et al., 2015; Carcel et al., 2015; Song et al., 2014; Ban and Kang, 2014; Rico et al., 2010; Stewart, 2001; Simic, 1983). At the end of the storage period, 81.50% and 82.44% of the organisms were counted in control samples and 0% in the samples that were irradiated 5 kGy at 28±2 ºC and 4 ºC respectively.

4.2.4 Effect of gamma irradiation, storage time and temperature on the inactivation of *Listeria monocytogenes*

Presented in Table 4.4 and appendices CI and CII are the data on the survival of *L. monocytogenes* after the gamma irradiation treatment and during storage at the different temperatures. Inactivation of *L. monocytogenes* by gamma irradiation was observed with all the irradiation doses applied. There was a dose-dependent effect ($p<0.05$) in all cases, with complete inactivation in the 2 and 4 kGy samples by the 60th day (Table 4.4, appendices CXIX and CXX), compared to the high survival in the control (unirradiated samples). The progress of inactivation in the 1 kGy sample stored at 4°C was not consistent with time, as shown in Table 4.4, as the observed differences in the survival data were not statistically significant ($p > 0.05$). Percentage of survival at the 60th day were 77.48 and 76.34at 4°C and 28±2 ºC, respectively for the control (unirradiated) samples; 35.46% and 31.71% at 4°C and 28±2 ºC for the 1 kGy samples and no detection in the 2, 4 kGy, and 5 kGy samples at both temperatures.

Table 4.4. Effect of gamma irradiation and storage on the survival of *L. monocytogenes* at 4 °C and 28±2 °C in powdered Legon-18 pepper (*C. annuum*)

STORAGE		Microbial count (log cfug^{-1})				
DAYS	TEMP.	0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	4 °C	6.26±0.08^{Aa}	5.87±0.11^{Ba}	4.97±0.11^{Ca}	4.83±0.12^{Da}	ND
2		6.15±0.08^{Aa}	5.42±0.11^{Bb}	4.46±0.09^{Cb}	3.81±0.11^{Db}	ND
5		6.04±0.08^{Aa}	5.28±0.11^{Bb}	4.26±0.09^{Cc}	3.12±0.11^{Dc}	ND
12		5.78±0.11^{Ab}	5.02±0.11^{Bc}	4.10±0.09^{Cc}	2.86±0.11^{Dd}	ND
21		5.42±0.11^{Ac}	4.90±0.09^{Bc}	3.84±0.09^{Cd}	2.66±0.13^{Dde}	ND
30		5.18±0.11^{Ad}	4.30±0.09^{Bd}	3.15±0.08^{Ce}	2.46±0.13^{De}	ND
45		5.07±0.11^{Ad}	3.19±0.08^{Be}	2.47±0.11^{Cf}	1.96±0.13^{Df}	ND
60		4.85±0.09^{Ae}	2.22±0.11^{Bf}	ND	ND	ND
0	28±2 °C	5.96±0.08^{Aa}	5.37±0.11^{Ba}	4.20±0.09^{Ca}	4.55±0.09^{Da}	ND
2		5.88±0.08^{Aa}	5.11±0.11^{Bb}	4.16±0.09^{Cb}	3.53±0.11^{Db}	ND
5		5.77±0.08^{Aa}	4.97±0.11^{Bb}	3.96±0.09^{Cc}	2.87±0.11^{Dc}	ND
12		5.48±0.11^{Ab}	4.70±0.11^{Bc}	3.79±0.09^{Cc}	2.56±0.11^{Dd}	ND
21		5.12±0.11^{Ac}	4.60±0.09^{Bc}	3.54±0.08^{Cd}	2.37±0.13^{De}	ND
30		4.86±0.11^{Ad}	4.00±0.09^{Bd}	2.88±0.08^{Ce}	2.17±0.13^{Df}	ND
45		4.75±0.11^{Ad}	2.92±0.08^{Be}	2.16±0.11^{Cf}	1.65±0.13^{Dg}	ND
60		4.55±0.09^{Ae}	1.89±0.11^{Bf}	ND	ND	ND

Least Significant Difference::Means with the same letters (upper cases, doses within a particular temperature regeme) in the same row are not significantly (P>0.05) different from each other and means with the same letters in the same column (lower case, doses per day within the same temperature regeme) are not significantly different (P>0.05) from each other. Key: ND= not detected

The trends of inactivation of *L. monocytogenes* in this study were similar to trends reported in literature (Jeong and Kang, 2017; Mukhopadhyay et al., 2013; Rico et al., 2010). The mechanisms of inactivation are expected to be similar to that earlier described for the other pathogens.

4.2.5 Effect of gamma irradiation, storage time and temperature on the inactivation of *Staphylococcus aureus*

Data on the survival of *S. aureus* after exposure to gamma irradiation treatment during storage at different temperatures are depicted in Table 4.5.

Table 4.5. Effect of gamma irradiation and storage on the survival of *S. aureus* at 4 °C and 28±2 °C in powdered Legon-18 pepper (*C. annuum*)

STORAGE		Microbial count (log cfug^{-1})				
DAYS	**TEMP.**	**0 kGy**	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	6.43±0.08^{Aa}	5.56±0.13^{Ba}	4.79±0.11^{Ca}	2.86±0.13^{Da}	ND
2		6.01±0.09^{Ab}	5.36±0.13^{Bb}	4.64±0.11^{Cb}	2.71±0.13^{Da}	ND
5		5.81±0.13^{Ab}	4.96±0.13^{Bb}	4.50±0.11^{Cc}	1.96±0.13^{Db}	ND
12		5.41±0.13^{Ac}	4.74±0.13^{Bc}	4.14±0.11^{Cd}	1.91±0.13^{Db}	ND
21		5.21±0.13^{Acd}	4.59±0.11^{Bc}	3.83±0.09^{Ce}	1.52±0.13^{Dc}	ND
30		5.06±0.13^{Ad}	4.42±0.11^{Bd}	3.13±0.09^{Cf}	1.26±0.13^{Dd}	ND
45		4.69±0.11^{Ae}	3.78±0.09^{Be}	3.08±0.09^{Cg}	ND	ND
60		4.37±0.11^{f}	ND	ND	ND	ND
0	28±2 °C	5.94±0.08^{Aa}	5.27±0.11^{Ba}	4.55±0.09^{Ca}	2.57±0.11^{Da}	ND
2		5.56±0.08^{Ab}	4.75±0.09^{Bb}	4.30±0.09^{Cb}	2.17±0.11^{Db}	ND
5		5.32±0.11^{Ac}	4.60±0.09^{Bb}	4.10±0.09^{Cc}	1.82±0.11^{Dc}	ND
12		4.80±0.11^{Ad}	4.40±0.09^{Bc}	3.79±0.11^{Dd}	1.42±0.11^{Dd}	ND
21		4.65±0.09^{Ad}	4.30±0.09^{Bc}	3.49±0.08^{Ce}	1.22±0.11^{De}	ND
30		4.45±0.09^{Ae}	4.13±0.11^{Bd}	2.63±0.11^{Cf}	1.17±0.11^{Df}	ND
45		4.10±0.09^{Af}	3.09±0.08^{Be}	ND	ND	ND
60		ND	ND	ND	ND	ND

Least Significant Difference:: Means with the same letters (upper cases, doses within a particular temperature regeme) in the same row are not significantly different (p>0.05) from each other and means with the same letters in the same column (lower case, doses per day within the same temperature regeme) are not significantly different (P>0.05) from each other. Key: ND= not detected.

Inactivation (p<0.05) of *S. aureus* was observed at 1, 2 and 4 kGy (Table 4.5, appendices CIII, CIV, CXVI and CXVII) which was dose-dependent and a complete inactivation in samples irradiated at 1, 2 and 4 kGy. Inactivation trends observed in *S. aureus* is typical in literature (Jung et al., 2015; Ban and Kang, 2014; Song et al., 2014; Arzina et al., 2012; Rico et al., 2010). This has been attributed to the increase in the lethality of the corresponding dose that the organisms were exposed to due to more production of radiolytic compounds that affected the cellular content of the organism leading to a corresponding effect.

4.2.6 Effect of gamma irradiation on all the organisms at 4 ºC and 28±2 ºC.

Presented in Tables 4.6 and 4.7 are the comparative of the effect of gamma irradiation and storage period on the survival of *E. coli, S. aureus, S.* Typhimurium, *B. cereus* and *L. monocytogenes* (appendix CXXI). Generally, microbial counts reduced with increasing storage time and increasing doses of gamma irradiation used. The observed reductions were statistically significant ($p<0.05$). Generally, the inactivation was more pronounced in *E. coli* after day 30 and less in *B. cereus*. Song et al. (2014) observed *E. coli* to be more sensitive when *E. coli* and *S* Typhimurium were irradiated together in both black and red pepper powder samples. Deng et al. (2015) also made a similar observation when *E. coli*, *S* Typhimurium and *Aspergillus niger* were inoculated in pepper and irradiated. Jeong and Kang (2017) and Clavero et al. (1994) reported that the most resistant gram-negative organism to gamma irradiation is *Salmonella*, as observed in this study (Table 4.6). *L. monocytogenes* which is Gram-positive, was more resistant to gamma irradiation than *E. coli* and *S.* Typhimurium, which is similar to the observations of Jeong and Kang (2017). Zahran et al. (2008) indicated that *B. cereus* was more resistant to gamma irradiation than *L. monocytogenes* and this was also observed during this study. In this study, the most resistant of the organisms was *B. cereus* it was the only organism detected throughout the 60 days of storage at all the doses irrespective of the storage temperatures. A dose-dependent effect was however observed.

Table 4.6. Effect of gamma radiation on the survival of microorganisms in powdered Legon-18 pepper (*C. annuum*) at 4 °C.

STORAGE DAYS	ORGANISMS	Microbial count (log cfug^{-1})				
		0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	*E. coli*	6.69±0.08^{A}	5.17±0.11^{C}	4.59±0.11^{D}	3.51±0.11^{C}	ND
	S. aureus	6.43±0.08^{B}	5.56±0.13^{B}	4.79±0.11^{C}	2.86±0.13^{D}	ND
	L. monocytogenes	6.26±0.08^{C}	5.87±0.11^{A}	4.97±0.11^{BC}	4.83±0.12^{A}	ND
	S. Typhimurium	6.49±0.08^{B}	5.57±0.11^{B}	5.37±0.07^{A}	4.40±0.09^{B}	ND
	B. cereus	6.15±0.08^{C}	5.62±0.11^{B}	5.15±0.11^{B}	4.97±0.11^{A}	ND
2	*E. coli*	6.43±0.09^{A}	4.84±0.11^{C}	4.24±0.11^{D}	3.11±0.11^{C}	ND
	S. aureus	6.01±0.09^{C}	5.36±0.13^{B}	4.64±0.11^{B}	2.71±0.13^{D}	ND
	L. monocytogenes	6.15±0.08^{BC}	5.42±0.11^{B}	4.46±0.09^{C}	3.81±0.11^{B}	ND
	S. Typhimurium	6.38±0.08^{A}	5.55±0.11^{B}	5.18±0.05^{A}	3.89±0.08^{B}	ND
	B. cereus	6.17±0.08^{B}	5.62±0.11^{A}	5.15±0.11^{A}	4.55±0.09^{A}	ND
5	*E. coli*	6.24±0.08^{A}	4.44±0.11^{D}	3.94±0.11E	2.81±0.15^{D}	ND
	S. aureus	5.81±0.13^{C}	4.96±0.13^{C}	4.50±0.11^{C}	1.96±0.13E	ND
	L. monocytogenes	6.04±0.08^{B}	5.28±0.11^{B}	4.26±0.09^{D}	3.12±0.11^{C}	ND
	S. Typhimurium	5.72±0.11^{C}	5.32±0.11^{B}	5.00±0.11^{A}	3.65±0.08^{B}	ND
	B. cereus	6.09±0.08^{AB}	5.96±0.08^{A}	4.78±0.09^{B}	4.23±0.09^{A}	ND
12	*E. coli*	5.67±0.11^{B}	4.24±0.11^{D}	3.66±0.19^{D}	2.41±0.15^{D}	ND
	S. aureus	5.41±0.13^{C}	4.74±0.13^{C}	4.14±0.11^{C}	1.91±0.13E	ND
	L. monocytogenes	5.78±0.11^{B}	5.02±0.11^{B}	4.10±0.09^{C}	2.86±0.11^{C}	ND
	S. Typhimurium	5.62±0.11^{B}	5.10±0.11^{B}	4.80±0.09^{A}	3.44±0.08^{B}	ND
	B. cereus	6.32±0.08^{A}	5.85±0.11^{A}	4.55±0.09^{B}	3.79±0.08^{A}	ND
21	*E. coli*	4.85±0.09^{D}	4.07±0.11E	3.03±0.09^{D}	2.11±0.15^{D}	ND
	S. aureus	5.21±0.13^{C}	4.59±0.11^{D}	3.83±0.09^{C}	1.52±0.13^{E}	ND
	L. monocytogenes	5.42±0.11^{B}	4.90±0.09^{B}	3.84±0.09^{C}	2.66±0.13^{C}	ND
	S. Typhimurium	5.52±0.11^{B}	4.90±0.09^{B}	4.60±0.09^{B}	3.02±0.09^{B}	ND
	B. cereus	6.48±0.08^{A}	6.15±0.08^{A}	4.80±0.09^{A}	4.30±0.09^{A}	ND
30	*E. coli*	3.53±0.09^{C}	3.43±0.09^{D}	2.87±0.13^{D}	1.78±0.12^{D}	ND
	S. aureus	5.06±0.13^{B}	4.42±0.11^{C}	3.13±0.09^{C}	1.26±0.13E	ND
	L. monocytogenes	5.18±0.11^{B}	4.30±0.09^{C}	3.15±0.08^{C}	2.46±0.13^{C}	ND
	S. Typhimurium	5.12±0.11^{B}	4.60±0.09^{B}	3.65±0.08^{B}	2.72±0.11^{B}	ND
	B. cereus	6.17±0.08^{A}	5.67±0.11^{A}	4.45±0.09^{A}	3.74±0.08^{A}	ND
45	*E. coli*	ND	ND	ND	ND	ND
	S. aureus	4.69±0.11^{C}	3.78±0.09^{B}	3.08±0.09^{B}	ND	ND
	L. monocytogenes	5.07±0.11^{B}	3.19±0.08^{C}	2.47±0.11^{D}	1.96±0.13^{B}	ND
	S. Typhimurium	4.99±0.11^{B}	3.79±0.08^{B}	2.88±0.11^{C}	1.46±0.13^{C}	ND
	B. cereus	5.87±0.11^{A}	5.17±0.11^{A}	3.97±0.09^{A}	3.54±0.08^{A}	ND
60	*E. coli*	ND	ND	ND	ND	ND
	S. aureus	4.37±0.11^{C}	ND	ND	ND	ND
	L. monocytogenes	4.85±0.09^{B}	ND	ND	ND	ND
	S. Typhimurium	ND	ND	ND	ND	ND
	B. cereus	5.07±0.11^{A}	3.95±0.09	3.02±0.17	2.65±0.04	ND

Least significance difference. Means with the same letters (upper cases, doses within a particular a day) in the same column are not significantly (P>0.05) different from each other for all the orgnisms.

Table 4.7. Effect of gamma radiation on the survival of microorganisms in powdered Legon-18 pepper (*C. annuum*) at 28±2 °C

STORAGE DAYS	ORGANISMS	Microbial count (log $cfug^{-1}$)				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	*E. coli*	6.40±0.09^{A}	4.12±0.09^{B}	3.84±0.08^{D}	2.57±0.11^{D}	ND
	S. aureus	5.94±0.08^{B}	5.27±0.11^{A}	4.55±0.09^{B}	2.57±0.11^{D}	ND
	L. monocytogenes	5.96±0.08^{B}	5.37±0.11^{A}	4.20±0.09^{C}	4.55±0.09^{B}	ND
	S. Typhimurium	6.49±0.08^{A}	5.21±0.13^{A}	4.83±0.11^{A}	4.04±0.11^{C}	ND
	B. cereus	6.00±0.08^{B}	5.41±0.13^{A}	4.93±0.09^{A}	4.74±0.11^{A}	ND
2	*E. coli*	6.14±0.08^{A}	3.85±0.08^{C}	3.49±0.08^{D}	2.17±0.11^{C}	ND
	S. aureus	5.56±0.08^{C}	4.75±0.09^{B}	4.30±0.09^{C}	2.17±0.11^{C}	ND
	L. monocytogenes	5.88±0.08^{B}	5.11±0.11^{AB}	4.16±0.09^{C}	3.53±0.11^{B}	ND
	S. Typhimurium	6.02±0.08^{AB}	5.19±0.13^{AB}	4.62±0.11^{B}	3.52±0.09^{B}	ND
	B. cereus	6.02±0.08^{AB}	5.64±0.13^{A}	4.87±0.14^{A}	4.34±0.11^{A}	ND
5	*E. coli*	5.94±0.76^{A}	3.49±0.08^{C}	3.19±0.21^{C}	2.05±0.20^{D}	ND
	S. aureus	5.32±0.11^{C}	4.60±0.09^{B}	4.10±0.09^{B}	1.82±0.11^{D}	ND
	L. monocytogenes	5.77±0.08^{AB}	4.97±0.11^{B}	3.96±0.09^{B}	2.87±0.11^{C}	ND
	S. Typhimurium	5.66±0.13^{B}	4.96±0.13^{B}	4.49±0.11^{A}	3.33±0.09^{B}	ND
	B. cereus	5.94±0.08^{A}	5.78±0.13^{A}	4.55±0.11^{A}	4.02±0.11^{A}	ND
12	*E. coli*	5.37±0.11^{B}	3.29±0.72^{C}	3.06±0.08^{C}	1.40±0.09^{D}	ND
	S. aureus	4.80±0.11^{C}	4.40±0.09^{B}	3.79±0.11^{B}	1.42±0.11^{D}	ND
	L. monocytogenes	5.48±0.11^{B}	4.70±0.11^{B}	3.79±0.09^{B}	2.56±0.11^{C}	ND
	S. Typhimurium	5.55±0.13^{B}	4.69±0.11^{B}	4.33±0.11^{A}	3.24±0.09^{B}	ND
	B. cereus	6.17±0.08^{A}	5.75±0.13^{A}	4.24±0.11^{A}	3.48±0.09^{A}	ND
21	*E. coli*	4.55±0.08^{D}	3.14±0.68^{C}	2.32±0.11^{D}	1.10±0.09^{D}	ND
	S. aureus	4.65±0.09^{D}	4.30±0.09^{B}	3.49±0.08^{C}	1.22±0.11^{D}	ND
	L. monocytogenes	5.12±0.11^{C}	4.60±0.09^{B}	3.54±0.08^{C}	2.37±0.13^{C}	ND
	S. Typhimurium	5.36±0.13^{B}	4.67±0.11^{B}	3.99±11^{B}	2.88±0.11^{B}	ND
	B. cereus	6.33±0.08^{A}	5.87±0.13^{A}	4.49±0.11^{A}	3.43±0.09^{A}	ND
30	*E. coli*	3.14±0.08^{D}	2.67±0.58^{C}	2.15±0.11E	1.06±0.03^{C}	ND
	S. aureus	4.45±0.09^{C}	4.13±0.11^{B}	2.63±0.11^{D}	1.17±0.11^{C}	ND
	L. monocytogenes	4.86±0.11^{B}	4.00±0.09^{B}	2.88±0.08^{C}	2.17±0.13^{B}	ND
	S. Typhimurium	4.59±0.11^{C}	4.09±0.11^{B}	3.14±0.09^{B}	2.21±0.13^{B}	ND
	B. cereus	6.02±0.08^{A}	5.36±0.13^{A}	4.14±0.11^{A}	3.23±0.09^{A}	ND
45	*E. coli*	ND	ND	ND	ND	ND
	S. aureus	4.10±0.09^{C}	3.09±0.08^{C}	ND	ND	ND
	L. monocytogenes	4.75±0.11^{B}	2.92±0.08^{C}	2.16±0.11^{C}	1.65±0.13^{B}	ND
	S. Typhimurium	3.83±0.09^{D}	3.32±0.09^{B}	2.42±0.13^{B}	1.25±0.09^{C}	ND
	B. cereus	5.72±0.13^{A}	4.90±0.09^{A}	3.30±0.09^{A}	2.98±0.09^{A}	ND
60	*E. coli*	ND	ND	ND	ND	ND
	S. aureus	ND	ND	ND	ND	ND
	L. monocytogenes	4.55±0.09^{B}	1.89±0.11^{B}	ND	ND	ND
	S. Typhimurium	3.18±0.09^{C}	ND	ND	ND	ND
	B. cereus	4.89±0.11^{A}	3.64±0.11^{A}	2.47±0.13^{A}	2.33±0.13^{A}	ND

Least significance difference: Means with the same letters (upper cases, doses within a particular a day) in the same column are not significantly (P>0.05) different from each other for all the orgnisms.

After 60 days of storage, the microbial counts of 4.37±0.11 (67.96%), 4.85±0.09 (77.48%) and 5.07±0.11 (82.44%) for *S. aureus*, *L. monocytogenes* and *B. cereus* respectively at 4 °C were recorded. Percentage microbial count in the samples stored at 28±2 °C were 76.34%, 49.00% and 77.25% of *L. monocytogenes*, S. Typhimurium and *B. cereus* respectively were detected.

4.3 The effect of gamma irradiation on the quality parameters of pepper powder

4.3.1 Effect on colour

4.3.1.1 Effect on L* values

Table 4.8 depicts the lightness (L* values), that is the brightness or whiteness of the samples irradiated at different doses and stored at different temperatures for different periods. Gamma irradiation had a statistically significant ($p<0.05$) impact on the L* values of the pepper samples. There were marginal increases in the values of the samples immediately after the treatment, especially as the irradiation doses increased. During storage however, there were some discoloration (loss of brightness) in the samples. This effect is observed through to the fourth week of storage, after which there were some marginal stability. The decrease in L* values during storage was more pronounced in the samples stored at 28±2 °C. At the end of the storage period there was less than 20% loss in the L*values of all the samples irrespective of the doses applied as well as the storage condition. The L* values of both irradiated and unirradiated pepper samples have been indicated in literature. Lee et al. (2004) indicated that the L* values of some Korean pepper samples were in the range about 30.77 in both irradiated and unirradiated samples; Topuz et al. (2009) reported a range of 40.50 to 49.18 in Anaheim variety and 40.47 to 48.11 in Jalapeno; while Rico et al. (2010) recorded about 51 and about 52 in unirradiated and irradiated samples, respectively; Jung et al. (2015) reported about 46 in some Korean varieties and Song et al. (2014) also indicated values of about 27 in unirradiated samples and about 34 in irradiated samples which were lower than the L* values of Legon-18 pepper powder. The reduction in the lightness of the colour of the pepper samples can be attributed to the deterioration caused by oxidation of the carotenoids in the pepper samples (Schweiggert et al., 2005).

Table 4.8. L* values of Legon-18 pepper powder after gamma irradiation, and during storage at different storage conditions.

S W	S C	L-values 0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	4 °C	50.93±0.01^{Ha}	50.96±0.01^{Hab}	51.09±0.14^{Gb}	51.42±0.06^{Hc}	51.85±0.00^{Hd}
1		49.81±0.01^{Ga}	49.88±0.01^{Ga}	50.21±0.06^{Fb}	50.42±0.15^{Gc}	50.96±0.09^{Gd}
2		48.60±0.01^{Fa}	48.93±0.04^{Fb}	49.16±0.01^{Ec}	49.47±0.02^{Fd}	50.20±0.05^{Fe}
3		44.46±0.01^{Ea}	45.65±0.01^{Eb}	46.33±0.01^{Dc}	47.35±0.03^{Ed}	48.73±0.06^{Ee}
4		42.84±0.00^{Ba}	43.02±0.00^{Db}	43.55±0.09^{Cc}	43.91±0.03^{Dd}	44.59±0.07^{De}
5		42.86±0.00^{Da}	42.88±0.00^{Ba}	42.96±0.01^{Bc}	42.88±0.01^{Aa}	42.96±0.01^{Cc}
6		42.85±0.00^{Ca}	42.94±0.02^{Cb}	42.99±0.03^{Bc}	43.27±0.02^{Bd}	43.93±0.07^{Bd}
7		42.60±0.00^{Ba}	43.01±0.01^{Db}	43.58±0.12^{Cc}	43.73±0.01^{Cd}	43.89±0.0.4^{Be}
8		42.51±0.00^{Aa}	42.69±0.01^{Ab}	42.82±0.03^{Ac}	42.97±0.01^{Ad}	43.20±0.07^{Ae}
0	28±2 °C	50.49±0.04^{Ia}	50.63±0.02^{Ib}	50.76±0.02^{Ic}	51.05±0.09^{Id}	51.66±0.02^{Ie}
1		49.48±0.03^{Ha}	49.80±0.02^{Hb}	49.88±0.18^{Hb}	50.12±0.13^{Hc}	50.62±0.10^{Hd}
2		47.10±0.10^{Ga}	47.37±0.13^{Gb}	47.70±0.10^{Gc}	48.24±0.04^{Gd}	49.83±0.04^{Ge}
3		43.53±0.06^{Fa}	44.58±0.30^{Fb}	45.29±0.06^{Fc}	46.22±0.06^{Fd}	47.26±0.12^{Fe}
4		41.29±0.06^{Ea}	42.27±0.11^{Eb}	43.18±0.06^{Ec}	43.55±0.28^{Ed}	44.22±0.06^{Ee}
5		40.22±0.12^{Da}	40.78±0.10^{Db}	41.25±0.11^{Dc}	41.91±0.06^{Dd}	42.25±0.10^{De}
6		38.98±0.08^{Ca}	40.28±0.11^{Cb}	40.98±0.02^{Cc}	41.51±0.14^{Cd}	43.00±0.05^{Ce}
7		38.28±0.06^{Ba}	39.00±0.08^{Bb}	40.20±0.05^{Bc}	40.75±0.11^{Bd}	41.18±0.08^{Be}
8		36.74±0.06^{Aa}	37.18±0.12^{Ab}	38.12±0.11^{Ac}	39.30±0.13^{Ad}	40.65±0.10^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORGE WEEKS; SC-STORAGE CONDITION

The observed pattern in the differences recorded in L*values of the pepper samples stored at both temperatures are similar to the observations of Liu et al. (2010). They indicated that temperature during storage led to the reduction of L* values in tomato powder. Rhim and Hong (2011) indicated that storage temperature leads to the reduction in L* values in dried pepper products during storage. This observation may be attributed to the rate of non-enzymatic browning and package-free space of the packaging material (Rhim and Hong, 2011).

4.3.1.2 Effect on a* values

The a* values which depict the redness of the pepper powder are indicated in Table 4.9. The value was about 21.5 for the control sample at day 0 but increased to about 24.5 after the irradiation treatment at day 0. The increase with irradiation was dose-dependent. During the storage periods, the a* values significantly decreased. The patterns of decrease were similar at the different storage temperatures. The a* value of pepper powder has been variously reported in literature. Lee et al. (2004) reported the redness of unirradiated Korean red pepper powder to be 26.21, Topuz et al. (2009) measured the redness of some Turkish pepper varieties to be 29.56, Rico et al. (2010) reported a value of 20.78 in samples analysed, Arslan and Ozcan (2011) reported a* values of some pepper products to be over 30 and Jung et al. (2015) reported 17.5 for red peeper powder analysed.

Table 4.9. The a* values of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	a* values				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	21.48±0.02^{Ia}	21.87±0.01^{Hb}	22.60±0.02^{Ic}	23.55±0.05^{Id}	24.50±0.13^{Ie}
1		19.07±0.02^{Ha}	19.93±0.07^{Gb}	20.61±0.06^{Hc}	21.32±0.06^{Hd}	22.62±0.05^{He}
2		18.00±0.06^{Ga}	18.54±0.17^{Fb}	19.34±0.03^{Gc}	20.42±0.21^{Gd}	21.17±0.05^{Ge}
3		17.38±0.06^{Fa}	18.24±0.10^{Eb}	18.75±0.08^{Fc}	19.48±0.00^{Fd}	20.67±0.02^{Fe}
4		15.30±0.05^{Ea}	16.11±0.16^{Db}	16.87±0.02^{Ec}	17.46±0.09^{Ed}	18.88±0.02^{Ee}
5		14.77±0.03^{Da}	16.24±0.03^{Db}	16.66±0.03^{Dc}	17.63±0.01^{Dd}	18.27±0.06^{De}
6		14.21±0.01^{Ca}	14.84±0.01^{Cb}	15.21±0.05^{Cc}	15.59±0.01^{Cd}	17.91±0.01^{Ce}
7		10.08±0.00^{Ba}	10.58±0.00^{Bb}	11.24±0.31^{Bc}	11.32±0.06^{Bc}	12.80±0.13^{Bd}
8		9.94±0.07^{Aa}	10.34±0.03^{Ab}	10.98±0.01^{Ac}	11.09±0.11^{Ac}	12.25±0.18^{Ad}
0	28±2 °C	21.45±0.01^{Ia}	21.86±0.02^{Hb}	22.56±0.02^{Ic}	23.52±0.08^{Id}	24.41±0.01^{Ie}
1		18.64±0.02^{Ha}	19.22±0.06^{Gb}	19.83±0.07^{Hc}	20.25±0.1^{Hd}	21.48±0.04^{He}
2		17.19±0.01^{Ga}	18.22±0.06^{Fb}	19.46±0.02^{Gc}	19.87±0.02^{Gd}	20.35±0.01^{Ge}
3		17.04±0.01^{Fa}	18.18±0.02^{Fb}	18.68±0.04^{Fc}	19.30±0.05^{Fd}	20.00±0.05^{Fe}
4		15.03±0.01^{Ea}	15.84±0.05^{Eb}	16.36±0.02^{Ec}	16.88±0.01^{Ed}	17.45±0.06^{Ee}
5		11.03±0.02^{Da}	11.45±0.01^{Db}	12.69±0.30^{Dc}	13.69±0.11^{Dd}	16.31±0.12^{De}
6		10.85±0.01^{Ca}	10.93±0.01^{Ca}	11.48±0.14^{Cb}	12.29±0.12^{Cc}	15.64±0.17^{Cd}
7		9.83±0.0.5^{Ba}	10.14±0.03^{Bb}	10.77±0.09^{Bc}	11.13±0.12^{Bd}	12.00±0.01^{Be}
8		9.64±0.01^{Aa}	9.99±0.02^{Ab}	10.32±0.06^{Ac}	10.77±0.09^{Ad}	11.75±0.01^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.

The differences in the values reported can be attributed to the varietal differences, edaphic factors, methods of drying employed, as well as the storage conditions of the samples (Cheon et al., 2015; Kim et al., 2012; Rico et al., 2010). Almela et al., (2002), indicated that higher temperatures tend to promote the degradation of colour in paprika. In this study, higher redness (a*) of the samples were observed in the samples that were stored at refrigeration temperature (4 °C) than the samples that were stored at 28±2 °C. This observation is similar to the findings of Almela et al. (2002). At the end of the 8 weeks storage period, there was over 50% loss in the a* values for both storage conditions.

4.3.1.3 Effect on b* values

The results of the colour parameter b* (yellowness) are shown in Table 4.10. The b* value for the control sample (unirradiated) was about 22 at day 0 but increased to about 24 in sample irradiated with 5 kGy gamma rays. The increase was dose-dependent which was statistically significant ($p<0.05$). The b* values decreased with storage. The b* values reported by Lee et al. (2004) was less than 17 in both irradiated and unirradiated Korean pepper samples, Rico et al. (2010) recorded less than 27 in both irradiated and unirradiated samples; less than 16 in other varieties (Song et al., 2014) and Jung et al. (2015) reported values less than 11 in both irradiated and unirradiated samples. Legon-18 values were higher than some of the b* values reported in literature, except during storage. The observed differences may be due to the differences in terms of variety, edaphic factors, stage of maturity during harvest, post-harvest treatments as well as drying methods (Won et al., 2015; Rhim and Hong, 2011; Topuz et al., 2009, Kim et al., 2004). The general reduction observed in the b* values of the samples irrespective of the storage condition and the doses of gamma irradiation that the samples were exposed to, might be due to the breakdown of the pigments that are responsible for the yellowness of the pepper samples which is similar in previous report (Kim et al., 2005).

Rico et al. (2010), observed that red pepper samples that were stored at room temperature (20±2 ^{o}C) had higher losses of colour as compared with the samples that were stored at 4 ^{o}C. In this study, the samples that were stored at 4 ^{o}C had higher b* values as compared with the samples that were stored at 28±2 ^{o}C. This may be attributed to the higher rate of colour degradation of colour in the samples at the higher temperature (Rico et al., 2010).

Table 4.10. B*values of Legon-18 pepper powder after gamma irradiation, during storage at different temperatures

SW	SC	b* values				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	22.10±0.01^{Ia}	22.82±^{b}0.06^{Hb}	23.48±0.03^{Ic}	23.98±0.01^{Id}	24.59±0.01^{Ie}
1		17.28±0.01^{Ha}	18.05±0.03^{Gb}	18.82±0.06^{Hc}	19.17±0.06^{Hd}	20.03±0.08^{He}
2		15.77±0.01^{Ga}	16.43±0.08^{Fb}	17.22±0.06^{Gc}	18.08±0.06^{Gd}	19.08±0.06^{Ge}
3		15.38±0.04^{Fa}	16.18±0.06^{Eb}	16.95±0.05^{Fc}	17.42±0.04^{Fd}	18.18±0.11^{Fe}
4		13.05±0.02^{Ea}	13.89±0.02^{Db}	14.43±0.07^{Ec}	15.25±0.07^{Ed}	17.70±0.01^{Ee}
5		12.64±0.04^{Da}	13.17±0.03^{Cb}	13.89±0.02^{Dc}	14.28±0.01^{Dd}	15.37±0.03^{De}
6		12.56±0.00^{Ca}	12.95±0.05^{Bb}	13.21±0.06^{Cc}	13.95±0.01^{Cd}	14.89±0.01^{Ce}
7		7.64±0.01^{Ba}	7.94±0.02^{Ab}	8.22±0.03^{Bc}	8.89±0.13^{Bd}	9.68±0.04^{Be}
8		7.41±0.02^{Aa}	7.87±0.03^{Ab}	8.01±0.01^{Ac}	8.41±0.03^{Ad}	9.19±0.03^{Ae}
0	28 ±2 °C	21.10±0.01^{Ia}	22.92±0.12^{Ib}	23.19±0.13^{Hc}	23.98±0.01^{Id}	24.23±0.01^{He}
1		16.55±0.02^{Ha}	17.23±0.07^{Hb}	17.96±0.02^{Gc}	18.46±0.02^{Hd}	19.60±0.04^{Ge}
2		13.82±0.01^{Ga}	14.24±0.03^{Gb}	14.91±0.03^{Fc}	15.52±0.06^{Gd}	16.38±0.06^{Fe}
3		11.98±0.04^{Fa}	12.58±0.08^{Fb}	13.27±0.02^{Ec}	13.97±0.02^{Fd}	15.24±0.11^{Ee}
4		8.71±0.01^{Ea}	9.19±0.03^{Eb}	9.92±0.06^{Dc}	10.52±0.06^{Ed}	11.38±0.01^{De}
5		8.35±0.1^{Da}	8.92±0.06^{Db}	9.27±0.33^{Cc}	9.88±0.02^{Dd}	10.40±0.03^{Ce}
6		7.78±0.01^{Ca}	8.40±0.00^{Cb}	9.00±0.10^{Bc}	9.63±0.05^{Cd}	10.52±0.01^{Ce}
7		7.53±0.01^{Ba}	8.13±0.03^{Bb}	8.83±0.05^{Bc}	9.20±0.13^{Bd}	10.11±0.03^{Be}
8		7.46±0.01^{Aa}	7.56±0.01^{Ab}	7.85±0.06^{Ac}	8.48±0.05^{Ad}	9.16±0.03^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

The loss of the yellowness (b* values) of the samples during storage was remarkable in all the samples. At the end of the study, there was loss of over 60% of the b* values for all the doses applied and at the different storage temperatures.

4.3.1.4 Effect on chroma

Table 4.11 indicates the chroma values (which depicts the colourfulness quantitatively) of the samples. The chroma of the samples were in the range of 12.19±0.01 and 34.71±0.10. There was a dose-dependent effect on the chroma of the pepper from week 0 to week 8 irrespective of the doses applied as well as the temperature of storage. The chroma values at both temperatures reduced as the weeks progressed. Higher values of chroma were observed in the samples that were irradiated as compared with the samples that were not irradiated irrespective of the storage condition.

Table 4.11. Chroma of Legon-18 pepper powder after gamma irradiation, during storage at different temperatures

SW	SC	Chroma				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0		30.81±0.01^{Ia}	31.61±0.05^{Ib}	32.58±0.03^{Ic}	33.61±0.03^{d}	34.71±0.10^{Ie}
1		25.73±0.03^{Ha}	26.89±0.05^{Hb}	27.91±0.04^{Hc}	28.67±0.01^{d}	30.22±0.02^{He}
2		23.93±0.04^{Ga}	24.78±0.09^{Gb}	25.89±0.03^{Gc}	27.27±0.19^{d}	28.50±0.05^{Ge}
3		23.21±0.05^{Fa}	24.38±0.05^{Eb}	25.28±0.08^{Fc}	26.14±0.03^{d}	27.53±0.07^{Fe}
4	4 °C	20.11±0.06^{Ea}	21.27±0.12^{Eb}	22.20±0.03^{Ec}	23.18±0.07^{d}	25.87±0.02^{Ee}
5		19.44±0.02^{Da}	20.91±0.02^{Db}	21.69±0.02^{Dc}	22.68±0.004^{d}	23.88±0.04^{De}
6		18.97±0.004^{Ca}	19.70±0.07^{Cb}	20.15±0.03^{Cc}	20.92±0.01^{d}	23.29±0.00^{Ce}
7		12.65±0.003^{Ba}	13.23±0.01^{Bb}	13.92±0.24^{Bc}	14.39±0.12^{d}	16.05±0.08^{Be}
8		12.40±0.04^{Aa}	12.99±0.04^{Ab}	13.59±0.01^{Ac}	13.92±0.09^{d}	15.31±0.16^{Ae}
0		30.08±0.01^{Ia}	31.68±0.01^{Ib}	32.35±0.08^{Ic}	33.59±0.05^{Id}	34.39±0.02^{Ie}
1		24.93±0.01^{Ha}	25.81±0.09^{Hb}	26.75±0.04^{Hc}	27.40±0.08^{Hd}	29.08±0.18^{He}
2		22.05±0.02^{Ga}	23.12±0.06^{Gb}	24.51±0.03^{Gc}	25.21±0.05^{Gd}	26.13±0.06^{Ge}
3		20.83±0.03^{Fa}	22.11±0.05^{Fb}	22.92±0.03^{Fc}	23.82±0.04^{Fd}	25.14±0.08^{Fe}
4	28 ±2 °C	17.37±0.01^{Ea}	18.31±0.03^{Eb}	19.13±0.03^{Ec}	19.89±0.04^{Ed}	20.84±0.04^{Ee}
5		13.83±0.04^{Da}	14.52±0.04^{Db}	15.72±0.03^{Dc}	16.88±0.06^{Dd}	19.34±0.15^{De}
6		13.35±0.01^{Ca}	13.79±0.01^{Cb}	14.59±0.05^{Cc}	15.61±0.08^{Cd}	18.84±0.13^{Ce}
7		12.38±0.04^{Ba}	13.00±0.04^{Bb}	13.93±0.10^{Bc}	14.44±0.14^{Bd}	15.69±0.04^{Be}
8		12.19±0.01^{Aa}	12.53±0.01^{Ab}	12.96±0.03^{Ac}	13.71±0.09^{Ad}	14.90±0.1^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

The colourfulness of the pepper samples was less than what was observed in the samples that were studied by Topuz et al. (2009). They observed that the colourfulness of Jalapeno red pepper powder was in the range of 33.57 to 35.53 over a period of 90 days of storage at -18 °C. The chroma of Legon-18 was higher than the chroma of the Anaheim samples. Since the values of a* and b* reduced with time due to the oxidation of the carotenoids in the samples irrespective of the storage condition (Schweiggert et al., 2005), the observed phenomenon in terms of the colourfulness can be attributed to the behaviour of the a* and b* values which reduced gradually in the samples as a result of the breakdown of the pigments (carotenoids) in the samples (Schweiggert et al., 2005). Chroma values in the samples were generally higher in the ones that were stored at 4 ^{o}C as compared with the samples that were stored at 28±2 ^{o}C is consistent with literature (Sirisoontaralak and Noomhorm, 2006).

4.3.1.5 Effect on browning index

The values for browning index (which ascertains the rate of decolouration) are shown Table 4.12. The browning index of the samples reduced with time. Gamma irradiation had effect on browning index of the pepper samples at both storage temperatures ($p<0.05$). Due to the effect of gamma irradiation (bleaching effect on the colour), the browning index of the irradiated pepper samples were higher than the samples that were not irradiated- giving an indication of the higher likelihood of becoming browner as compared with the samples that were not irradiated. Differences observed in the browning index of the samples were storage-temperature dependent. The higher values of browning index obtained in the samples at the beginning of the study was higher than what was observed in mushroom samples irradiated and stored for twelve months period (Kortei et al., 2015).

Table 4.12. Browning index of Legon-18 pepper powder after gamma irradiation, during storage at different temperatures

SW	SC	Browning index				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0		86.03±0.04^{Ia}	88.91±0.24^{Ib}	91.85±0.2^{Hc}	94.10±0.07^{Hd}	96.46±0.18^{Ie}
1		69.43±0.18^{Ha}	72.85±0.11^{Hb}	75.60±0.23^{Gc}	77.30±0.39^{Gd}	80.76±0.20^{He}
2		65.20±0.14^{Ga}	67.50±0.14^{Gb}	70.65±0.17^{Fc}	74.31±0.44^{Fd}	77.21±0.27^{Ge}
3		69.84±0.13^{Fa}	71.71±0.13^{Fb}	73.82±0.26^{Ec}	74.60±0.14^{Fd}	76.25±0.34^{Fe}
4	4 °C	61.41±0.21^{Ea}	65.25±0.23^{Eb}	67.39±0.08^{Dc}	70.49±0.28 ^{Ed}	80.01±0.13^{Ee}
5		59.17±0.03^{Da}	63.26±0.08^{Db}	66.21±0.03^{Cc}	69.22±0.01^{Dd}	73.94±0.11^{De}
6		58.05±0.01^{Ca}	60.20±0.23^{Cb}	61.60±0.19^{Bc}	64.22±0.05^{Cd}	69.90±0.14^{Ce}
7		36.41±0.02^{Ba}	37.74±0.0^{B}4	39.04±0.35^{Ac}	40.97±0.41^{Bd}	45.43±0.13^{Be}
8		35.62±0.05^{Aa}	37.43±0.14^{Ab}	38.75±0.02^{Ac}	39.96±0.2^{Ad}	43.87±0.30^{Ae}
0		83.54±0.09^{Ia}	89.94±0.41^{Hb}	91.53±0.16^{Hc}	94.87±0.14^{Id}	95.51±0.11^{He}
1		67.14±0.02^{Ha}	69.49±0.29^{Gb}	72.43±0.29^{Gc}	74.16±0.19^{Hd}	78.53±0.26^{Ge}
2		60.33±0.10^{Ga}	62.69±0.12^{Fb}	65.98±0.08^{Fc}	67.59±0.15^{Gd}	68.42±0.42^{Fe}
3		59.55±0.10^{Fa}	61.60±0.58^{Eb}	63.46±0.12^{Ec}	65.12±0.09^{Fd}	68.46±0.70^{Fe}
4	28±2 °C	49.06±0.05^{Ea}	50.61±0.10^{Db}	52.50±0.12^{Dc}	54.69±0.54^{Ed}	57.30±0.09^{Ee}
5		42.58±0.41^{Da}	44.47±0.31^{Cb}	47.06±1.42^{Cc}	49.81±0.22^{Dd}	55.18±0.40^{De}
6		41.82±0.08^{Ca}	42.50±0.10^{Bb}	44.52±0.09^{Bc}	47.22±0.15^{Cd}	53.48±0.30 ^{Ce}
7		39.97±0.17^{Ba}	41.71±0.23^{Ab}	43.71±0.26^{Bc}	44.85±0.62^{Bd}	48.73±0.10^{Be}
8		41.19±0.07^{Aa}	41.65±0.15^{Aab}	42.10±0.28^{Ab}	43.62±0.44^{Ac}	45.87±0.08^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.

Reduction in the browning index with time may be attributed to the reduction in the pigments of the pepper samples used in the study (Schweiggert et al., 2005). At the end of the study, less than 50% of the browning index was observed in all the samples irrespective of the doses applied as well as the storage condition (temperature). The effect of temperature on the colour degradation (L*, a*, b*) played a role in the differences thus observed in the samples stored at 4°C as compared with the samples stored at 28±2 °C which is similar to literature (Rico et al., 2010; Liu et al., 2010; Sirisoontaralak and Noomhorm, 2006; Almela et al., 2002).

4.3.1.6 Effect on colour difference

The colour difference (which is an indication of the magnitude of the change in colour between the samples stored and the day 0 samples (control or irradiated) (Martins and Silva, 2002; Patras et al., 2011)) are indicated in Table 4.13. The differences ranged from 5.14±0.07 and 23.62±0.03. A general rise in the colour difference of the samples of the storage weeks for all the storage conditions was observed. There was a general dose-dependent effect on the colour difference of all the samples for the period of the study. There were no significant differences ($p>0.05$) in the samples during weeks seven and eight for all the samples stored at 4 ^{o}C. There was significant ($p<0.05$) differences in all the samples that were stored at 28±2 ^{o}C during the period of the study.

Colour difference in the samples was due to the change in the a*, b* and L*-values of the samples (as there was the breakdown of the pigments in the pepper samples) as well as the effect of storage (Topuz et al., 2011; Topuz, et al., 2009; Schweiggert et al., 2005). The total colour difference of some irradiated pepper samples ranged from 0.24 to 1.12 (Nieto-Sandoval et al., 1999), 0.19 to 0.33 in samples stored at 4 ^{o}C and 1.05 to 1.37 (Rico et al., 2010) and 0.6 to 0.9 in red Korean pepper samples (Jung et al., 2015) which were lower than the total colour difference of Legon-18 the pepper samples used in this study. The colour difference in the samples in this study was greater than 3 and this indicates 'very distinctive' colour difference of the samples from the onset of the study to the end of the study irrespective of the storage temperature (Adekunte et al., 2010). The samples that were stored at 28±2 ^{o}C had a higher total colour difference (Table 4.13) as compared with the ones that were stored at 4 ^{o}C.

Table 4.13. Colour difference of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Total Colour Change				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
1	4 °C	5.50±0.06^{Ad}	5.26±0.03^{Ac}	5.14±0.07^{Ab}	5.50±0.06^{Ad}	5.01±0.07^{Aa}
2		7.59±0.03^{Bc}	7.48±0.10^{Bc}	7.32±0.06^{Bb}	7.59±0.03^{Bc}	6.64±0.03^{Ba}
3		10.18±0.04^{Cd}	9.24±0.03^{Cc}	8.94±0.12^{Cb}	10.18±0.04^{Cd}	8.10±0.11^{Ca}
4		13.62±0.06^{Dd}	13.27±0.06^{Dc}	13.09±0.07^{Db}	13.62±0.06^{Dd}	11.49±0.12^{Da}
5		14.13±0.02^{Ec}	13.78±0.03^{Ea}	13.90±0.08^{Eb}	14.13±0.02^{Ec}	14.25±0.08^{Ea}
6		20.21±0.02^{Fa}	20.30±0.05^{Fa}	20.45±0.11^{Fb}	20.21±0.02^{Fb}	20.56±0.06^{Fc}
7		20.48±0.03^{Ga}	20.61±0.08^{Ga}	21.03±0.07^{Gb}	20.48±0.03^{Gc}	21.50±0.23^{Gc}
8		20.48±0.03^{Ga}	20.61±0.08^{Gb}	21.03±0.07^{Gc}	20.48±0.03^{Ga}	21.50±0.23^{Gb}
1	28±2 °C	5.43±0.01^{Aa}	6.33±0.16^{Ac}	5.97±0.13^{Ab}	5.43±0.01^{Ac}	5.57±0.15^{Aa}
2		9.09±0.06^{Ba}	9.97±0.05^{Bd}	9.36±0.05^{Bb}	9.09±0.06^{Bc}	9.02±0.15^{Ba}
3		12.28±0.04^{Cc}	12.54±0.22^{Cd}	11.98±0.07^{Cb}	12.28±0.04^{Cb}	10.93±0.13^{Ca}
4		16.71±0.05^{Dc}	17.17±0.04^{Db}	16.49±0.17^{Da}	16.71±0.05^{Db}	16.39±0.45^{Da}
5		19.40±0.06^{Eb}	20.03±0.09^{Ec}	19.53±0.34^{Eb}	19.40±0.06^{Eb}	18.59±0.16^{Ea}
6		20.54±0.05^{Fb}	20.92±0.04^{Fc}	20.49±0.08^{Fb}	20.54±0.05^{Fb}	18.44±0.04^{Ea}
7		21.63±0.04^{Gb}	22.17±0.10^{Gd}	21.37±0.18^{Ga}	21.63±0.04^{Gc}	21.52±0.07^{Gab}
8		22.67±0.06^{Hb}	23.62±0.03^{Ge}	23.34±0.04^{Hd}	22.67±0.06^{Hc}	22.55±0.05^{Ga}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION.

Rico et al. (2010), Liu et al. (2010) and Almela et al. (2002) had indicated the effect of temperature (higher temperatures tend to promote 'increased' colour change) on the colour of particular food products. The temperature-dependent total colour differences observed in the samples is according to literature, thus the rate of colour degradation on the samples that were stored at 4 °C was lower due to a slower degradation rate than the samples that were stored at 28±2 °C (Liu et al., 2010; Rico et al., 2010; Almela et al., 2002). There were percentage increases of 372.36, 374.73, 382.36, 372.36 and 390.91 for the samples at 0, 1, 2, 4 and 5 kGy respectively in the samples that were stored at 4 °C. In the samples that were stored 28±2 °C had differences up to 417.50%, 434.99%, 429.83%, 428.18% and 415.29% for the samples irradiated at 0, 1, 2, 4 kGy and 5 kGy respectively.

4.3.1.7 Effect on hue

The results of the hue angle which depicts the qualitative attribute (in terms of angle) of the colour of a commodity (Pathare et al., 2012) are shown in Table 4.14. The hue angle of the samples ranged from 30.08±0.14 to 46.35±0.13. There was a general reduction in the hue of the samples at both temperatures of storage. Generally, there was a dose-dependent effect on the hue of the pepper samples that were stored for the period at both storage temperatures which was statistically significant ($p<0.05$). Storage temperature had an effect on the hue of the samples ($p<0.05$).

A previous study conducted by Topuz et al. (2009), showed that the hue of pepper powders from two varieties stored at -18 ^{o}C was in the range of 31.35 to 41.18, however in the samples used in this study, the hue ranged from 30.08±0.14 to 46.35±0.13 which is an indication of varietal and different storage conditions. The observed pattern in the hue of the pepper samples which is in the range of redness, may be attributed to the effect of gamma irradiation on the a* and b* of the pepper samples. This can be attributed to the effect of the breakdown of the pigments of the pepper samples (Schweiggert et al., 2005) irrespective of the storage conditions.

Table 4.14. Hue of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Hue				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	45.82 ± 0.01^{Fd}	46.22 ± 0.06^{Hd}	46.09 ± 0.01^{Gc}	45.52 ± 0.07^{Fb}	45.11 ± 0.15^{Fa}
1		42.19 ± 0.12^{Ebc}	42.17 ± 0.13^{Gbc}	42.39 ± 0.17^{Fc}	41.96 ± 0.17^{Eb}	41.53 ± 0.12^{Ea}
2		41.22 ± 0.10^{Da}	41.55 ± 0.37^{Fab}	41.68 ± 0.13^{Dbc}	41.53 ± 0.20^{Eab}	42.03 ± 0.08^{Dc}
3		41.51 ± 0.09^{Da}	41.59 ± 0.24^{Fab}	42.11 ± 0.10^{EFc}	41.81 ± 0.06^{Eb}	41.33 ± 0.18^{Ca}
4		40.45 ± 0.02^{Ca}	40.76 ± 0.30^{Da}	40.54 ± 0.17^{Ca}	41.13 ± 0.23^{Db}	43.15 ± 0.04^{Cb}
5		40.55 ± 0.10^{Cd}	39.04 ± 0.08^{Ca}	39.82 ± 0.06^{Bb}	39.01 ± 0.02^{Ca}	40.06 ± 0.11^{Bc}
6		41.47 ± 0.01^{Dc}	41.10 ± 0.02^{Eb}	40.98 ± 0.20^{Cb}	41.81 ± 0.01^{Dd}	39.73 ± 0.04^{Ba}
7		37.15 ± 0.02^{Bb}	36.90 ± 0.05^{Aab}	36.20 ± 0.84^{Aa}	38.16 ± 0.25^{Bc}	37.10 ± 0.38^{Ab}
8		36.72 ± 0.28^{Ab}	37.28 ± 0.03^{Bd}	36.11 ± 0.05^{Aa}	37.19 ± 0.30^{Acd}	36.86 ± 0.30^{Acb}
0	28 ±2 °C	44.53 ± 0.003^{Ia}	46.35 ± 0.13^{Hd}	45.80 ± 0.03^{Hc}	45.56 ± 0.10^{Fc}	44.78 ± 0.17^{Ib}
1		41.60 ± 0.06^{Ha}	41.87 ± 0.03^{Gb}	42.17 ± 0.13^{Gc}	42.36 ± 0.11^{Ec}	42.38 ± 0.24^{Hc}
2		38.80 ± 0.004^{Gc}	38.01 ± 0.04^{Eb}	37.46 ± 0.04^{Da}	38.00 ± 0.09^{Cb}	38.84 ± 0.43^{Gc}
3		35.12 ± 0.07^{Bb}	34.67 ± 0.15^{Ba}	35.38 ± 0.06^{Bb}	35.89 ± 0.09^{Bc}	37.32 ± 0.40^{Fd}
4		30.08 ± 0.14^{Aa}	30.11 ± 0.15^{Aa}	31.22 ± 0.18^{Ab}	31.93 ± 0.15^{Ac}	33.11 ± 0.13^{Ed}
5		37.13 ± 0.37^{Ec}	37.92 ± 0.20^{Ed}	36.13 ± 0.33^{Cb}	35.81 ± 0.12^{Bb}	32.51 ± 0.29^{Da}
6		35.63 ± 0.04^{Cb}	37.53 ± 0.03^{Dc}	38.11 ± 0.65^{Ec}	38.08 ± 0.37^{Cc}	33.92 ± 0.37^{Ca}
7		37.45 ± 0.09^{Da}	38.73 ± 0.03^{Fb}	39.35 ± 0.08^{Fc}	39.60 ± 0.42^{Dc}	40.12 ± 0.14^{Bd}
8		37.74 ± 0.05^{Fb}	37.14 ± 0.06^{Ca}	37.25 ± 0.35^{Da}	38.23 ± 0.11^{Cc}	37.95 ± 0.05^{Abc}

Least Significant Difference: Means with the same letters (upper case, with the same column for a particular temperature regeme) are not significantly ($P>0.05$) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different ($P>0.05$) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

The lower values that were observed in the samples stored at 4 °C can be attributed to the higher values in the L*, a*, b* values of the samples which had lower degradation due to the lower effect of rate of degradation in relation to lower temperature as compared with the samples that were stored at 28±2 °C (Rico et al., 2010; Liu et al., 2010; Sirisoontaralak and Noomhorm, 2006; Almela et al., 2002). At the end of the storage period, losses of 19.55%, 18.83%, 21.19%, 18.64%, 19.86% were recorded in the hue of the samples that were irradiated at 5 kGy, 4 kGy, 2 kGy, 1 kGy and 0 kGy respectively and were stored at 4 °C. A loss of 15.25%, 16.60%, 16.35%, 14.15% and 14.78% for the samples that were irradiated at 0, 1, 2 4 kGy and 5 kGy respectively and stored at 28±2 °C. Comparing the storage temperatures, the samples that were stored at 4 °C had lower hue values as compared the ones stored at 28±2 °C.

4.3.2 Effect on physiochemical properties

4.3.2.1 Effect on pH and Titratable acidity (TTA)

Tables 4.15 and 4.16 show the pH and TTA of the samples. pH and TTA of the samples were not affected by gamma irradiation. Rico et al. (2010) observed that gamma irradiation and storage did not have effect (p>0.05) on the pH and TTA of dried red pepper samples at 4 °C and 20±2 °C. Similar occurrence was also observed by Liu et al. (2010) for tomato samples stored below 37 °C in powdered tomato samples. The observed pattern in both pH and TTA may be due to the stability of the organic acids in the samples.

Table 4.15. The pH of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	pH				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0		5.00 ± 0.00^{Aa}	5.05 ± 0.15^{Aa}	5.06 ± 0.01^{Aa}	5.06 ± 0.05^{Aa}	5.09 ± 0.01^{Aa}
1		5.11 ± 0.05^{Ba}	5.15 ± 0.03^{ABCa}	5.12 ± 0.01^{Ba}	5.15 ± 0.01^{Ba}	5.14 ± 0.00^{Ba}
2		5.13 ± 0.03^{Bb}	5.08 ± 0.01^{Aba}	5.12 ± 0.02^{Bab}	5.09 ± 0.01^{ABab}	5.11 ± 0.02^{Aa}
3		5.13 ± 0.01^{Ba}	5.13 ± 0.01^{Aba}	5.14 ± 0.01^{Ba}	5.15 ± 0.01^{Ba}	5.14 ± 0.02^{Ba}
4	4 °C	5.14 ± 0.02^{Ba}	5.15 ± 0.01^{ABCa}	5.21 ± 0.04^{Ca}	5.16 ± 0.06^{BCa}	5.19 ± 0.01^{Ca}
5		5.24 ± 0.02^{Ca}	5.29 ± 0.01^{Ea}	5.25 ± 0.01^{CDa}	5.24 ± 0.05^{CDb}	5.24 ± 0.01^{Db}
6		5.21 ± 0.01^{Ca}	5.19 ± 0.04^{BCDEa}	5.22 ± 0.01^{Ca}	5.33 ± 0.03^{EFa}	5.33 ± 0.01^{Ea}
7		5.29 ± 0.02^{Da}	5.27 ± 0.03^{DEa}	5.28 ± 0.01^{Da}	5.26 ± 0.03^{DEa}	5.28 ± 0.01^{Fa}
8		5.40 ± 0.11^{Eab}	5.43 ± 0.01^{Fb}	5.41 ± 0.02^{Eab}	5.36 ± 0.04^{Fab}	5.40 ± 0.01^{Gab}
0		5.09 ± 0.05^{Aa}	5.06 ± 0.00^{Aa}	5.10 ± 0.02^{Aa}	5.07 ± 0.04^{Aa}	5.16 ± 0.04^{Aa}
1		5.14 ± 0.01^{Aa}	5.17 ± 0.01^{Ba}	5.15 ± 0.01^{Aba}	5.16 ± 0.03^{ABa}	5.18 ± 0.01^{Aa}
2		5.14 ± 0.01^{Aa}	5.15 ± 0.0^{Ba}	5.16 ± 0.02^{Bb}	5.15 ± 0.01^{Bb}	5.16 ± 0.03^{Aa}
3		5.16 ± 0.03^{Aa}	5.15 ± 0.02^{Ba}	5.23 ± 0.01^{Bb}	5.24 ± 0.14^{Bb}	5.24 ± 0.01^{Bb}
4	28±2 °C	5.25 ± 0.01^{Ba}	5.29 ± 0.01^{Cb}	5.25 ± 0.03^{Bab}	5.26 ± 0.13^{CDab}	5.24 ± 0.00^{Ba}
5		5.24 ± 0.00^{Bab}	5.27 ± 0.01^{Cab}	5.25 ± 0.01^{Bb}	5.27 ± 0.13^{Db}	5.27 ± 0.02^{Ba}
6		5.26 ± 0.00^{Ba}	5.28 ± 0.01^{Ca}	5.27 ± 0^{Ba}	5.28 ± 0.26^{Da}	5.25 ± 0.01^{Ba}
7		5.38 ± 0.08^{Cab}	5.46 ± 0.01^{Db}	5.44 ± 0.06^{Cab}	5.44 ± 0.26^{Eab}	5.48 ± 0.01^{Ca}
8		5.40 ± 0.01^{Ca}	5.46 ± 0.04^{Da}	5.42 ± 0.03^{Ca}	5.41 ± 0.13^{Ea}	5.37 ± 0.03^{Da}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

Table 4.16. Total titratable acidity of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Titratable acidity (%)				
		0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0		0.224 ± 0.009^{Aa}	0.199 ± 0.009^{Aa}	0.218 ± 0.018^{Aa}	0.224 ± 0.027^{Aa}	0.218 ± 0.00^{Aa}
1		0.263 ± 0.009^{Bab}	0.263 ± 0.009^{Bab}	0.243 ± 0.000^{Aa}	0.275 ± 0.009^{Bb}	0.275 ± 0.00^{Bb}
2		0.263 ± 0.009^{Ba}	0.275 ± 0.009^{BCa}	0.275 ± 0.009^{Ba}	0.269 ± 0.000^{Ba}	0.275 ± 0.00^{Ba}
3		0.275 ± 0.009^{BCa}	0.288 ± 0.009^{Ca}	0.275 ± 0.009^{Ba}	0.282 ± 0.018^{Ba}	0.288 ± 0.00^{Ba}
4	4 °C	0.275 ± 0.009^{BCa}	0.269 ± 0.000^{Ba}	0.275 ± 0.009^{Ba}	0.269 ± 0.000^{Ba}	0.275 ± 0.00^{Ba}
5		0.275 ± 0.009^{BCa}	0.275 ± 0.009^{BCa}	0.275 ± 0.009^{Ba}	0.275 ± 0.009^{Ba}	0.275 ± 0.00^{Ba}
6		0.295 ± 0.001^{CDa}	0.275 ± 0.009^{BCa}	0.288 ± 0.009^{Ba}	0.288 ± 0.027^{Ba}	0.282 ± 0.00^{Ba}
7		0.295 ± 0.018^{CDa}	0.269 ± 0.000^{Ba}	0.282 ± 0.018^{Ba}	0.301 ± 0.009^{Ba}	0.288 ± 0.00^{Ba}
8		0.301 ± 0.009^{Da}	0.275 ± 0.009^{Ba}	0.282 ± 0.018^{Ba}	0.282 ± 0.000^{Ba}	0.288 ± 0.00^{Ba}
0		0.224 ± 0.009^{Aa}	0.224 ± 0.027^{Aa}	0.224 ± 0.009^{Aa}	0.211 ± 0.009^{Aa}	0.218 ± 0.00^{Aa}
1		0.231 ± 0.000^{ABa}	0.231 ± 0.018^{ABa}	0.211 ± 0.027^{Aa}	0.231 ± 0.000^{Aa}	0.231 ± 0.00^{Aa}
2		0.231 ± 0.000^{ABab}	0.243 ± 0.000^{ABCb}	0.224 ± 0.009^{Aa}	0.237 ± 0.009^{ABab}	0.263 ± 0.01^{CDc}
3		0.250 ± 0.009^{BCb}	0.263 ± 0.009^{BCEab}	0.263 ± 0.009^{Bc}	0.263 ± 0.009^{BCab}	$0.256\pm0.0\ ^{o}C^{Da}$
4	28±2 °C	0.263 ± 0.009^{CDa}	0.250 ± 0.009^{ABCDa}	0.269 ± 0.000^{Ba}	0.263 ± 0.009^{BCa}	0.243 ± 0.00^{BCa}
5		0.269 ± 0.000^{CDa}	0.263 ± 0.027^{BCDEa}	0.275 ± 0.009^{Ba}	0.275 ± 0.009^{CDa}	0.275 ± 0.01^{Da}
6		0.275 ± 0.009^{Da}	0.275 ± 0.009^{CDEa}	0.269 ± 0.000^{Ba}	0.263 ± 0.027^{BCa}	0.275 ± 0.01^{DEa}
7		0.282 ± 0.018^{DEa}	0.288 ± 0.009^{Ea}	0.275 ± 0.009^{Ba}	0.288 ± 0.009^{CDa}	0.288 ± 0.01^{EFa}
8		0.301 ± 0.009^{Ea}	0.282 ± 0.018^{DEa}	0.275 ± 0.009^{Ba}	0.295 ± 0.000^{Da}	0.301 ± 0.01^{Fa}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION.

4.3.2.2 Effect on moisture content

The moisture content of the samples are shown in Table 4.17. There was no apparent effect of gamma irradiation on the moisture content of the samples. The moisture content seemed to vary slightly during long storage, however the changes were generally not significant.

Table 4.17. Moisture content of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Moisture Content (%)				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	10.20±0.57^{Da}	10.40±0.00^{Ca}	11.00±0.28^{Ea}	10.60±0.28^{BCa}	10.9±0.14^{Da}
1		10.10±0.07^{BDa}	10.30±0.14^{BCa}	10.90±0.14^{BCEa}	10.40±0.28^{Ba}	10.40±028^{BCa}
2		9.60±0.28^{BCDa}	9.80±0.00^{BCa}	10.10±0.71^{BCa}	10.50±0.42^{Ba}	10.70±0.14^{CDa}
3		9.10±0.14^{ABCa}	9.00±0.28^{Ba}	9.80±0.57^{ABCEa}	9.80±0.00^{Aba}	9.40±0.00^{Aa}
4		9.30±0.14^{ABCa}	9.50±0.14^{ABCab}	9.90±0.42^{ABCEab}	10.40±0.57^{Bb}	10.20±0.00^{Bb}
5		9.70±0.14^{CDab}	8.80±0.14^{Aba}	10.60±0.85^{BCAab}	12.00±0.13^{Cb}	10.30±0.14^{BCab}
6		9.30±0.14^{Aba}	9.40±0.00^{ABCa}	10.30±0.70^{BCa}	10.20±0.57^{ABa}	10.70±0.14^{CDa}
7		8.90±0.14^{Aba}	9.00±0.00^{ABab}	9.70±0.42^{ABab}	10.60±0.13^{BCb}	9.30±0.42^{Aab}
8		8.80±0.00^{Aa}	8.60±0.28^{Aa}	8.90±0.14^{Aa}	8.90±0.14^{Aa}	9.20±0.00^{Ab}
0	28±2 °C	9.70±0.14^{BCa}	10.20±0.00^{BCa}	10.30±0.71^{Ba}	10.40±0.57^{Da}	10.70±0.14^{Eb}
1		9.60±0.28^{Ca}	9.90±0.14^{ABCa}	9.90±0.99^{Ba}	10.20±0.00^{CDa}	10.70±0.14^{Eb}
2		10.40±0.28^{Ea}	10.10±0.42^{BCa}	9.90±0.14^{Ba}	10.00±0.57^{CDa}	10.60±0.00^{DEa}
3		9.20±0.28^{Aa}	9.50±0.14^{Aba}	8.80±0.85^{Aba}	9.20±0.00^{Ba}	9.30±0.14^{Aa}
4		9.70±0.28^{BCa}	10.20±0^{BCa}	9.20±0.57^{Aba}	9.60±0.57^{BCa}	9.90±0.14^{BCa}
5		9.80±0.28^{BCDa}	10.70±0.14^{Cb}	9.70±0.14^{Ba}	10.70±0.14^{Db}	10.30±0.42^{CDEa}
6		10.30±0.42^{DEa}	9.40±0.85^{Aba}	10.10±0.71^{Ba}	9.50±0.14^{BCa}	10.10±0.42^{CDa}
7		9.00±0.28^{Aa}	9.00±0.85^{Aa}	9.00±0.13^{Aba}	9.10±0.14^{Aa}	9.40±0.28^{Aa}
8		9.20±0.00^{ABc}	9.40±0.00^{ABd}	8.10±0.14^{Aa}	8.40±0.00^{Ab}	9.50±0.14^{Ad}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other. KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

The marginal reduction in moisture content of the samples might be due to the probable permeability of the packaging material to moisture, thereby leading to a loss in the moisture content over the period as well as changes pertaining to the relative humidity in the storage environment (Hussain et al., 2011; Hossain and Gottschalk, 2009; Latapi and Barret, 2006). The observed marginal reduction in the moisture content (Tables 4.17) of the samples was similar to the observations made by Rico et al. (2010) when dried red pepper samples were stored at 4 °C and 20±2 °C. The moisture content of the samples reduced with storage. Das et al. (1994) indicated an increase in the moisture content of tea and they attributed to the activities of microorganisms in the unirradiated samples. In another study, Thomas et al. (2008) also made a similar observation as they found that the moisture content in tea increased in the unirradiated samples and was fairly stable in the irradiated samples. In another study, moisture content of some irradiated tomato powder (freeze dried and solar dried samples) increased with storage in a two-month study (Atuobi-Yeboah et al., 2016).

4.3.3 Effect of gamma irradiation and storage on the capsaicinoids and SHU

4.3.3.1 Effect on capsaicin

The capsaicin content of the samples is indicated in Table 4.18. The values were in the range of 118 in the unirradiated samples to 221.00 (mg/100g) in the irradiated samples. Gamma irradiation 'caused' significant increases ($p<0.05$) in the capsaicin content of the samples and was dose-dependent. The values however significantly ($p<0.05$) reduced during storage with time at both storage temperatures, although it was more pronounced in the samples stored at 28±2 °C.

The capsaicin content of Legon-18 was higher than some of the samples indicated in previous studies (Jung et al., 2015; Nagy et al., 2015; Giuffrida et al., 2014; Giuffrida et al., 2013; Rico et al., 2010; Topuz et al., 2009; Lee et al., 2004). Topuz and Odzemir (2004), Wang et al. (2009) and Giuffrida et al. (2014) indicated that gamma irradiation and storage had effect on the capsaicin content of some pepper varieties leading to the reduction of capsaicin in those pepper samples.

Table 4.18. Capsaicin content of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Capsaicin (mg/100g)				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0		178.74±1.30^{Ia}	192.70±1.90^{Hb}	217.38±6.07^{Fc}	216.06±1.43^{Hc}	221.00±2.29^{Hc}
1		177.18±0.28^{Ha}	188.20±7.43^{Gb}	216.88±0.07^{Fc}	216.96±0.12^{Hc}	217.35±0.37^{Hc}
2		173.25±0.00^{Ga}	182.55±0.85^{Fb}	211.09±0.05^{Ec}	214.39±0.14^{Gd}	216.88±0.11^{Ge}
3		165.73±0.77^{Fa}	176.18±1.05^{Eb}	207.59±0.02^{Ec}	211.19±0.56^{Fd}	213.72±0.17^{Fe}
4	4 °C	161.51±0.15^{Ea}	169.32±0.89^{Db}	201.67±3.64^{Dc}	206.52±0.75^{Ed}	210.53±0.00^{Ee}
5		154.40±1.22^{Da}	165.05±0.52^{CDb}	194.03±0.41^{Cc}	199.61±1.41^{Dd}	207.31±0.39^{De}
6		146.93±0.00^{Ca}	161.40±0.25^{Cb}	182.88±3.85^{Bc}	195.78±1.11^{Cd}	204.44±0.73^{Ce}
7		144.74±0.00^{Ba}	156.52±0.02^{Bb}	178.59±0.00^{Bc}	186.72±1.01^{Bd}	198.95±0.09^{Be}
8		140.34±0.00^{Aa}	150.39±0.04^{Ab}	171.87±0.00^{Ac}	184.10±0.16^{Ad}	190.57±0.11^{Ae}
0		180.33±3.35^{Ha}	190.65±4.97^{Ha}	218.40±15.38^{Gb}	213.23±0.33^{Ib}	219.66±1.48^{Hb}
1		170.81±0.37^{Ha}	184.56±0.41^{Gb}	204.78±0.75^{Fc}	210.52±0.00^{BHd}	218.42±0.34^{He}
2		167.91±0.76^{Ga}	180.38±0.41^{Fb}	194.09±2.97^{Ec}	207.67±0.02^{Gd}	214.85±0.01^{Ge}
3		154.98±1.15^{Fa}	169.74±4.57^{Eb}	182.47±8.76^{Dc}	197.66±0.45^{Fd}	206.04±0.77^{Fe}
4	28± 2 °C	148.71±1.47^{Ea}	156.72±0.46^{Db}	165.37±0.16^{Cc}	190.81±2.61^{Ed}	198.30±0.11^{Ee}
5		144.46±0.39^{Da}	150.59±0.00^{Cb}	156.87±0.89^{BCc}	179.92±0.11^{Dd}	188.55±0.56^{De}
6		135.41±4.13^{Ca}	144.71±0.01^{Bb}	147.81±0.07^{Abb}	170.75±0.33^{Cc}	183.17±0.55^{Cd}
7		123.54±1.21^{Ba}	144.24±0.42^{Bb}	145.36±0.51^{Ab}	164.77±0.50^{Bc}	177.06±0.42^{Bd}
8		118.04±0.49^{Aa}	137.35±0.12^{Ab}	144.50±0.39^{Ac}	159.24±0.33^{Ad}	169.78±1.04^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other. KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

However, Byun et al. (1996) and Lee et al. (2004) also indicated that capsaicin is stable after gamma irradiation with doses less than 15 kGy. The dose-dependent effect on the capsaicin content of the pepper samples from 0 kGy to 4 kGy was similar to the observations of Giuffrida et al. (2014), Wang et al. (2009) and Topuz and Odzemir (2004). The reduction in the content of capsaicin in the pepper samples may be attributed to the presence of some residual enzymatic induced oxidation as well as the effect of the milling process (Wang et al., 2009). The higher content of capsaicin in the irradiated samples may also be attributed to the changes in the conformation of the molecules as well as the accompanying compounds that affected the extraction of the capsaicin in the pepper samples (Topuz et al., 2004; Subbulakshmi et al., 1991). Rico et al. (2010) reported that the temperature of storage of irradiated red pepper did not affect the capsaicin content in red pepper samples. Wang et al. (2009) and Giuffrida et al. (2014) indicated the effect of storage temperature on the capsaicinoids in red chilli pepper powder as temperature-dependent. The effect of temperature on the kinetics of degradation might have played a role in the higher content of capsaicin in the samples stored at 4 ^{o}C as compared to samples stored at 28±2 ^{o}C, which is similar to what has been reported in literature (Giuffrida et al., 2014; Wang et al., 2009).

4.3.3.2 Effect on dihydrocapsaicin

The dihydrocapsaicin content of the pepper powdered samples are presented in Table 4.19. Dihydrocapsaicin content was significantly affected by gamma irradiation ($p<0.05$). A dose-dependent effect was observed. A reduction in the dihydrocapsaicin content was observed for all samples during storage at the different temperatures. The dihydrocapsaicin content of Legon-18 was in the range of dihydrocapsaicin content of some pepper varieties in literature (Nagy et al., 2015; Cheon et al., 2015; Jung et al., 2015; Giuffrida et al., 2014; Giuffrida et al., 2013; Topuz and Odzemir, 2004). The observed dose-dependent effect of gamma irradiation on the increment of dihydrocapsaicin in the pepper samples was similar to the observation of Giuffrida et al. (2014), Wang et al. (2009) and Topuz and Odzemir (2004). The general increase in the dihydrocapsaicin content of the samples due to dose-dependence might have resulted in a change in the conformation and the other accompanying compounds that were in the samples and had affected the dihydrocapsaicin content on the extraction (Subbulakshmi et al., 1991) irrespective of the storage temperatures at which the samples were stored. Lee et al. (2000), Lee et al. (2004) and Byun et al. (1996), indicated the stability of dihydrocapsaicin after exposure to gamma irradiation, however, this is in contrast to the current study. Griesbach (2003) indicated that constituents of different varieties of the same crop may behave differently after exposure to gamma irradiation which was observed in this study in terms of the effect of gamma irradiation on the content of dihydrocapsaicin in the samples used in this study. The general reduction in the dihydrocapsaicin content of the pepper samples with time which has been stated elsewhere in literature (Giuffrida et al., 2014; Wang et al., 2009; Topuz and Odzemir 2004,). This may be attributed to the oxidative effect of some enzymes noted for the degradation of dihydrocapsaicin as well as effect of processing (Wang et al., 2009). Samples stored at 4 ^{o}C had higher dihydrocapsaicin content than the samples that were stored at 28±2 ^{o}C. At the end of the storage period there was a loss of 22.46%, 9.95%, 11.78%, 9.86% and 9.53% in the samples that were irradiated at 0, 1, 2, 4 and 5 kGy respectively and stored at 4 ^{o}C and for the unirradiated samples, 16.43%, 11.11%, 10.31% and 10.67% for the samples that were irradiated at 1, 2, 4 and 5 kGy respectively and stored at 28±2 ^{o}C.

Table 4.19. Dihydrocapsaicin content of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Dihydrocapsaicin (mg/100g)				
		0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	4 °C	77.12±1.84^{Ga}	79.37±0.02^{Ib}	83.73±0.47^{Hc}	87.91±0.59^{Hd}	88.48±1.11^{Hd}
1		75.48±0.02^{Fa}	79.01±0.03^{Hb}	83.45±0.17^{Hc}	87.71±0.08^{Hd}	88.76±0.04^{He}
2		74.29±0.05^{Ea}	78.48±0.43^{Gb}	82.79±0.11^{Gc}	85.90±0.38^{Gd}	87.21±0.00^{Ge}
3		73.35±0.12^{Ea}	77.49±0.13^{Fb}	80.94±0.13^{Fc}	85.11±0.23^{Fd}	86.38±0.37^{Fe}
4		66.15±0.00^{Da}	76.87±0.07^{Eb}	80.08±0.26^{Ec}	83.80±0.45^{Ed}	85.32±0.15^{Ee}
5		64.46±0.63^{Ca}	76.35±0.04^{Db}	79.51±0.04^{Dc}	82.66±0.00^{Dd}	83.56±0.51^{De}
6		63.82±0.58^{Ca}	75.71±0.15^{Cb}	78.66±0.34^{Cc}	81.93±0.04^{Cd}	82.62±0.39^{Cd}
7		61.97±0.00^{Ba}	74.96±0.03^{Bb}	77.13±0.37^{Bc}	80.53±0.05^{Bd}	80.84±0.10^{Bd}
8		59.80±0.15^{Aa}	71.47±0.20^{Ab}	73.87±0.15^{Ac}	79.24±0.32^{Ad}	80.05±0.18^{Ae}
0	28± 2 °C	76.42±1.36^{Ga}	79.35±0.15^{Ib}	83.68±0.47^{Hc}	87.85±0.59^{Hd}	89.25±0.02^{He}
1		72.94±0.13^{Fa}	78.70±0.03^{Hb}	83.12±0.17^{Hc}	86.24±0.08^{Hd}	87.02±0.08^{Ge}
2		72.10±0.23^{Ea}	77.38±0.43^{Gb}	80.95±0.11^{Gc}	85.17±0.38^{Gd}	86.46±0.33^{Fe}
3		60.38±0.34^{Ea}	75.52±0.13^{Fb}	79.27±0.13^{Fc}	84.15±0.23^{Fd}	85.51±0.23^{Ee}
4		59.78±0.06^{Da}	74.83±0.07^{Eb}	78.67±0.26^{Ec}	82.74±0.45^{Ed}	85.24±0.01^{Ee}
5		52.04±0.79^{Ca}	74.07±0.04^{Db}	77.91±0.04^{Dc}	81.99±0.00^{Dd}	84.00±0.55^{De}
6		47.94±0.76^{Ca}	72.74±0.15^{Cb}	77.01±0.34^{Cc}	81.14±0.04^{Cd}	82.61±0.07^{Ce}
7		40.90±0.4^{Ba}	68.89±0.03^{Bb}	75.43±0.37^{Bc}	79.32±0.05^{Bd}	81.69±0.41^{Be}
8		37.18±0.4^{Aa}	66.31±0.20^{Ab}	73.88±0.14^{Ac}	78.79±0.32^{Ad}	79.73±0.54^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other. KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION.

4.3.3.3 Effect on total capsaicinoids

The total capsaicinoids in the samples are indicated Table 4.20. Generally, the samples that were irradiated had higher content of total capsaicinoids as compared to the unirradiated samples. Gamma irradiation caused an increase of 6.33, 17.68, 18.79 % and 20.95% in the samples irradiated at 1, 2, 4 and 5 kGy respectively. The total capsaicinoids reduced with storage just as there was a reduction in the capsaicin and dihydrocapsaicin content of the pepper samples for all the temperature conditions as well as the doses that the samples were exposed to. The total capsaicinoids content of the samples that were stored at 28±2 °C were reduced by percentages of 39.54 for the unirradiated, 24.57 for samples at 1 kGy, 27.7 at 2 kGy, 20.94 for samples at 4 kGy and 0.94% at 5 kGy.

Table 4.20. Total capsaicinoids of Legon-18 pepper powder after gamma irradiation and during storage at different temperatures

SW	SC	Total capsaicinoids (mg/100 g)				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0	4 °C	255.87±2.57^{Ia}	272.07±1.95^{Hb}	301.11±5.93^{Hc}	303.96±0.89^{Hcd}	309.47±3.32^{Id}
1		252.65±0.39^{Ha}	267.21±7.43^{Gb}	300.33±0.11^{Hc}	304.67±0.18^{Hc}	306.12±0.36^{Hc}
2		247.54±0.30^{Ga}	261.04±1.17^{Fb}	293.88±0.13^{Gc}	300.28±0.46^{Gd}	304.09±0.11^{Ge}
3		239.08±1.06^{Fa}	253.68±1.00^{Eb}	288.53±^{E}0.15^{Fc}	296.29±0.51^{Fd}	300.10±0.47^{Fe}
4		227.66±0.21^{Ea}	246.20±0.90^{Db}	281.74±3.90^{Ec}	290.32±1.19^{Ed}	295.85±0.15^{Ee}
5		218.86±1.14^{Da}	241.40±0.54^{Cb}	273.54±0.43^{Dc}	282.27±1.40^{Dd}	290.86±0.20^{De}
6		210.75±0.76^{Ca}	237.10±0.37^{Cb}	261.54±3.71^{Cc}	277.71±1.09^{Cd}	287.06±0.34^{Ce}
7		206.70±0.05^{Ba}	231.49±0.04^{Bb}	255.72±0.37^{Bc}	267.25±1.09^{Bd}	279.79±0.17^{Be}
8		200.14±0.42^{Aa}	221.86±0.17^{Ab}	245.74±0.15^{Ac}	263.35±0.19^{Ad}	270.61±0.14^{Ae}
0	28± 2 °C	256.75±3.23^{Ia}	270.00±4.90^{Ia}	302.07±15.53^{Gb}	301.08±0.38^{Ib}	308.91±1.49^{Ib}
1		243.74±0.37^{Ha}	263.27±0.41^{Hb}	287.90±0.49^{Fc}	296.77±0.09^{Hd}	305.44±0.35^{He}
2		240.01±0.42^{Ga}	257.76±0.42^{Gb}	275.04±3.17^{Ec}	292.84±0.33^{Gd}	301.31±0.35^{Ge}
3		215.36±1.25^{Fa}	245.26±4.57^{Fb}	261.74±8.49^{Dc}	281.81±0.43^{Fd}	291.55±0.53^{Fe}
4		208.50±1.38^{Ea}	231.56±0.45^{Eb}	244.04±0.28^{Cc}	273.54±2.64^{Ed}	283.53±0.10^{Ee}
5		196.50±0.45^{Da}	224.66±0.08^{Db}	234.78±0.96^{BCc}	261.91±0.23^{Dd}	272.55±0.61^{De}
6		183.35±4.06^{Ca}	217.46±1.15^{Cb}	224.82±0.25^{ABc}	251.90±0.38^{Cd}	265.78±0.62^{Ce}
7		164.44±1.33^{Ba}	213.13±1.11^{Bb}	220.79±0.35^{Ac}	244.09±0.44^{Bd}	309.47±3.32^{Id}
8		155.22±0.50^{Aa}	203.66±0.11^{Ab}	218.39±0.26^{Ac}	238.02±0.19^{Ad}	306.12±0.36^{Hc}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other. KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

The higher total capsaicinoids recorded in the irradiated samples is similar to previous studies (Giuffrida et al., 2014; Wang et al., 2009; Topuz and Odzemir 2004). but contrasts the findings of Lee et al. (2000), Lee et al. (2004) and Byun et al. (1996). The general reduction of total capsaicinoids of the samples may be due to the oxidative effect of some enzymes noted for the degradation of capsaicin and dihydrocapsaicin as well as effect of processing (Wang et al., 2009) and varietal differences (Griesbach, 2003). Since the total capsaicinoids is a computation of the addition of the capsaicin and dihydrocapsaicin (Jung et al., 2015; Orellana-Escobedo et al., 2013; Lee et al., 2004), the effect of temperature on the capsaicin and dihydrocapsaicin obviously will have an effect on the total capsaicin content of the pepper samples. The higher total capsaicin content that were detected in the samples that were stored at 4 ^oC than the samples that were stored at 28±2 ^oC may be due to the slower rate of degradation of the both capsaicin and dihydrocapsaicin in the samples that were stored at 4 ^oC, which is similar to literature (Giuffrida et al., 2014; Wang et al., 2009).

4.3.3.4 Effect on Scoville Heat Units (hotness index)

The Scoville Heat Units (SHU) of the pepper samples used in the study are depicted in Table 4.21. The SHU of Legon-18 pepper samples were in the range of 4119.46 (x1000 in mg/100g) in the unirradiated samples and 4893(x1000 in mg/100g). Gamma irradiation affected the SHU of the samples. The hotness of the samples increased with dose from the unirradiated to the irradiated samples which was statistically significant ($p<0.05$). There was a general reduction in the SHU for all the samples from the beginning to the end of the storage period irrespective of the storage temperatures, however, it was more pronounced in the samples that were stored at 28±2 ^oC. The SHU of Legon-18 pepper samples is less than that reported by Lee et al. (2004) and Orellana-Escobedo et al. (2013).

Table 4.21. Scoville heat unit of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	SCOVILLE HEAT UNIT (x10000 mg/100 g)				
		0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	4 °C	4119.46±41.33^{Ia}	4380.27±31.39^{Gb}	4847.90±96.17^{Hc}	4893.82±14.41^{Idc}	4982.51±53.49^{Id}
1		4067.74±62.26^{Ha}	4302.05±119.55^{Fb}	4835.38±1.82^{Hc}	4905.17±2.96^{Hc}	4928.46±57.45^{Hc}
2		3985.45±36.96^{Ga}	4202.69±18.90^{Eb}	4731.43±0.21^{Gc}	4834.56±7.47^{Gd}	4865.9118.19^{Ge}
3		3849.15±17.01^{Fa}	4084.19±16.03^{Db}	4645.32±2.41^{Fc}	4770.33±8.15^{Fd}	4831.62±76.45^{Fe}
4		3665.39±33.07^{Ea}	3963.75±14.53^{Cb}	4536.07±62.74^{Ec}	4674.10±19.17^{Ed}	4763.26±23.72^{Ee}
5		3523.64±18.43^{Da}	3886.48±8.68^{Bb}	4403.97±6.90^{Dc}	4544.47±22.62^{Dd}	4682.88±32.45^{De}
6		3393.05±12.30^{Ca}	3817.36±5.94^{Bb}	4210.79±59.66^{Cc}	4471.08±17.61^{Cd}	4621.74±54.33^{Ce}
7		3327.91±0.78^{Ba}	3726.92±0.63^{Ab}	4117.08±5.98^{Bc}	4302.80±17.54^{Bd}	4504.64±27.11^{Be}
8		3222.23±67.96^{Aa}	3571.93±2.81^{Ab}	3956.39±2.24^{Ac}	4239.86±3.04^{Ad}	4356.87±22.17^{Ae}
0	28±2 °C	4133.65±51.94^{Ia}	4347.07±78.87^{Ia}	4863.39±249.98^{Gb}	4847.44±6.07^{Ib}	4973.43±24.03^{Ib}
1		3924.25±5.95^{Ha}	4238.58±6.53^{Hb}	4635.19±7.85^{Fc}	4777.94±1.49^{Hd}	4917.57±55.95^{He}
2		3864.16±6.88^{Ga}	4149.98±6.83^{Gb}	4428.13±50.99^{Ec}	4714.67±5.36^{Gd}	4851.09±55.64^{Ge}
3		3467.35±20.18^{Fa}	3948.62±73.55^{Fb}	4214.01±136.64^{Dc}	4537.16±6.91^{Fd}	4693.95±85.88^{Fe}
4		3356.81±22.20^{Ea}	3728.10±7.62^{Eb}	3929.08±4.57^{Cc}	4404.05±4.26^{Ed}	4564.90±16.83^{Ee}
5		3163.62±7.25^{Da}	3617.00±1.27^{Db}	3779.97±15.52^{BCc}	4216.75±3.69^{Dd}	4388.04±97.97^{De}
6		2951.97±65.44^{Ca}	3501.04±18.55^{Cb}	3619.61±3.99^{ABc}	4055.53±6.06^{Cd}	4279.13±10.53^{Ce}
7		2647.55±21.36^{Ba}	3431.42±17.89^{Bb}	3554.76±5.68^{Ac}	3929.79±7.14^{Bd}	4165.96±10.53^{Be}
8		2499.05±7.97^{Aa}	3278.95±1.78^{Ab}	3516.03±4.14^{Ac}	3832.14±3.12^{Ad}	4017.12±11.00^{Ae}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

The observed reduction in SHU in the samples may be due to the effect of some residual enzymatic action which led to the oxidation of the capsaicinoids, the effect of milling as well as change in the conformation of the molecules and the accompanying compounds that affected the extraction of the capsaicinoids (Giuffrida et al., 2014; Wang et al., 2009; Topuz and Odzemir, 2004; Subbulakshmi et al., 1991). At the end of the storage period, the hotness of the pepper samples irrespective of the storage condition and doses applied were less than the samples that were analysed at the beginning of the study. Capsaicin and dihydrocapsaicin were more stable in the samples stored at 4 ^{o}C than the samples stored at 28±2 ^{o}C (Wang et al., 2009; Giuffrida et al., 2014) hence the SHU of the samples were higher in the samples that were stored at 4 ^{o}C than the samples that were stored at 28±2 ^{o}C. Samples that were stored at 28±2 ^{o}C were reduced by over 10.00 %. Gamma irradiation caused an increment of over 6.3% in the SHU of the samples used in the study.

4.3.4 Impact of gamma irradiation and storage weeks on the carotenoids content

The carotenoids analysed and quantified in this study were beta carotene, beta cryptoxanthin, capsanthin and zeaxanthin which are known to be the main carotenoids in red chili peppers (Giuffrida et al., 2013; Kim et al., 2004). Except for zeaxanthin, beta carotene, beta cryptoxanthin and capsanthin were detected during the HPLC analysis.

4.3.4.1 Effect on beta cryptoxanthin

The beta cryptoxanthin content of the samples are shown in Table 4.22. The values were in the range of 1.04 to 1.87 in the irradiated samples to 1.29 to 2.11 (mg/100 g) in the unirradiated samples. Gamma irradiation had effect on the values which was dose-dependent ($p<0.05$). There was a general reduction in the values during storage irrespective of the storage temperatures the samples were stored at, but more pronounced in the samples that were stored at 28±2 °C.

Table 4.22. Beta cryptoxanthin content of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Beta cryptoxanthin (mg/100 g)				
		0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	4 °C	2.11±0.02^{He}	1.87±0.02^{Id}	1.71±0.00^{Hc}	1.67±0.04^{Ib}	1.55±0.01^{Da}
1		2.05±0.00^{Ge}	1.84±0.00^{Hd}	1.71±0.00^{Hc}	1.63±0.01^{Hb}	1.59±0.00^{Da}
2		2.03±0.02^{Ge}	1.75±0.00^{Gd}	1.68±0.00^{Gc}	1.59±0.01^{Gb}	1.56±0.03^{Da}
3		1.95±0.00^{Fe}	1.70±0.01^{Fd}	1.62±0.02^{Fc}	1.53±0.01^{Fb}	1.48±0.01^{Ca}
4		1.87±0.00^{Ee}	1.64±0.00^{Ed}	1.57±0.01^{Ec}	1.51±0.01^{Eb}	1.43±0.02^{BCa}
5		1.80±0.01^{De}	1.55±0.01^{Dd}	1.48±0.00^{Dc}	1.44±0.00^{Db}	1.40±0.00^{Ba}
6		1.71±0.00^{Ce}	1.49±0.01^{Cd}	1.41±0.00^{Cc}	1.37±0.00^{Cb}	1.30±0.00^{Aa}
7		1.66±0.00^{Be}	1.42±0.01^{Bd}	1.36±0.01^{Bc}	1.27±0.00^{Bb}	1.24±0.00^{Aa}
8		1.50±0.03^{Ae}	1.36±0.00^{Ad}	1.29±0.01^{Ac}	1.23±0.00^{Ab}	1.24±0.11^{Aa}
0	28±2 °C	2.10±0.01^{Ie}	1.87±0.02^{Id}	1.74±0.00^{Ic}	1.67±0.03^{Ib}	1.55±0.00^{Ia}
1		2.06±0.01^{He}	1.79±0.00^{Hd}	1.68±0.01^{Hc}	1.59±0.01^{Hb}	1.52±0.00^{Ha}
2		2.00±0.00^{Ge}	1.73±0.02^{Gd}	1.63±0.00^{Gc}	1.53±0.02^{Gb}	1.44±0.00^{Ga}
3		1.91±0.00^{Fe}	1.66±0.00^{Fd}	1.56±0.01^{Fc}	1.45±0.01^{Fb}	1.41±0.02^{Fa}
4		1.76±0.02^{Ee}	1.59±0.01^{Ed}	1.46±0.01^{Ec}	1.38±0.02^{Eb}	1.34±0.01^{Ea}
5		1.65±0.02^{De}	1.44±0.00^{Dd}	1.39±0.01^{Dc}	1.30±0.00^{Db}	1.24±0.00^{Da}
6		1.54±0.01^{Ce}	1.41±0.01^{Cd}	1.33±0.01^{Cc}	1.22±0.00^{Cb}	1.16±0.01^{Ca}
7		1.43±0.01^{Be}	1.34±0.02^{Bd}	1.26±0.01^{Bc}	1.18±0.00^{Bb}	1.09±0.01^{Ba}
8		1.29±0.01^{Ae}	1.26±0.00^{Ad}	1.15±0.01^{Ac}	1.08±0.01^{Ab}	1.04±0.02^{Aa}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

The beta-cryptoxanthin content of the pepper samples of Legon-18 pepper samples was less than the content of a Korean variety found by Kim et al. (2004) and higher than the other variety observed by Topuz and Odzemir (2003). This may be due to varietal differences (Wang et al., 2009). Topuz and Odzemir (2003) and Kim et al. (2004) indicated that radiolytic products formed and absorbed energy during gamma irradiation led to reduced content of carotenoids. The observed reduction in the values due to increasing doses of gamma irradiation is similar to previous studies (Kim et al., 2004; Topuz and Odzemir, 2003). The observed reduction during storage might be attributed to secondary effects of gamma irradiation, storage temperature, oxidation of components, form of pepper samples and the structure of beta cryptoxanthin (Guadarrama-Lezama et al., 2014; Giuffrida et al., 2014; Kim et al., 2006; Perez-Galvez and Minguez-Mosquera, 2001; Tang and Chen, 1999; Goda et al., 1995).

4.3.4.2 Effect on beta carotene

Beta carotene content of the pepper samples are indicated in Table 4.23. The beta carotene content of the samples ranged from 5.36 to 10.25 in the irradiated 7.17 to 10.27 (mg/100g) in the unirradiated samples. The content was affected by gamma irradiation which was dose-dependent ($p<0.05$). There was a marginal reduction in the beta carotene content from unirradiated through to the irradiated samples immediately after gamma irradiation ($p<0.05$) and also due to storage at the different temperatures.

The observed phenomenon in the values are similar as to the observations recorded in beta cryptoxanthin.

Table 4.23. Beta carotene content of Legon-18 pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Beta carotene (mg/100 g)				
		0 kGy	1 kGy	2 kGy	4 kGy	5 kGy
0	4 °C	10.27±0.00^{Id}	10.25±0.02^{Id}	9.86±0.02^{Hc}	9.54±0.00^{Ib}	9.38±0.00^{Ia}
1		10.04±0.00^{Hd}	9.92±0.00^{Hc}	9.43±0.00^{Gb}	9.24±0.00^{Ha}	9.24±0.00^{Ha}
2		9.92±0.00^{Ge}	9.66±0.04^{Gd}	9.42±0.06^{Gc}	9.01±0.00^{Gb}	8.78±0.00^{Ga}
3		9.43±0.00^{Fe}	9.57±0.02^{Fd}	8.95±0.06^{Fc}	8.75±0.03^{Fb}	8.48±0.00^{Fa}
4		9.20±0.00^{Ee}	9.42±0.02^{Ed}	8.82±0.01^{Ec}	8.55±0.00^{Eb}	8.23±0.02^{Ea}
5		8.91±0.02^{De}	9.26±0.02^{Dd}	8.57±0.02^{Dc}	8.44±0.00^{Db}	8.21±0.00^{Da}
6		8.69±0.07^{Ce}	9.04±0.04^{Cd}	8.36±0.00^{Cc}	8.20±0.02^{Cb}	7.91±0.00^{Ca}
7		8.48±0.00^{Be}	8.89±0.00^{Bd}	7.64±0.00^{Bc}	7.53±0.00^{Bb}	7.26±0.00^{Ba}
8		8.17±0.00^{Ae}	8.51±0.07^{Ad}	7.21±0.02^{Ac}	6.35±0.00^{Ab}	6.01±0.00^{Aa}
0	28±2 °C	10.29±0.02^{Ie}	10.25±0.01^{Id}	9.89±0.01^{Ic}	9.53±0.01^{Ib}	9.38±0.00^{Ia}
1		9.96±0.01^{He}	9.77±0.00^{Hd}	9.55±0.02^{Hc}	9.27±0.00^{Hb}	9.20±0.01^{Ha}
2		9.77±0.00^{Ge}	9.43±0.04^{Gd}	8.96±0.02^{Gc}	8.89±0.00^{Gb}	8.67±0.00^{Ga}
3		9.28±0.00^{Fe}	8.88±0.02^{Fd}	8.69±0.01^{Fc}	8.51±0.00^{Fb}	8.21±0.00^{Fa}
4		8.86±0.00^{Ee}	8.33±0.01^{Ed}	8.21±0.00^{Ec}	7.87±0.00^{Eb}	7.72±0.00^{Ea}
5		8.38±0.02^{De}	7.87±0.00^{Dd}	7.54±0.02^{Dc}	7.29±0.04^{Db}	7.06±0.18^{Da}
6		7.91±000^{Cd}	7.29±0.02^{Cc}	7.19±0.01^{Cc}	6.66±0.05^{Cb}	6.27±0.00^{Ca}
7		7.54±0.03^{Bc}	7.17±0.02^{Bb}	6.70±0.19^{Bc}	6.16±0.00^{Bb}	5.57±0.02^{Ba}
8		7.17±0.00^{Ae}	6.68±0.02^{Ad}	6.15±0.02^{Ac}	5.80±0.02^{Ab}	5.36±0.00^{Aa}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other.
KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION

4.3.4.3 Effect on capsanthin

Table 4.24 shows the capsanthin content of the samples. Capsanthin content of the irradiated were in the range of 1.14 to 1.44 and 1.12 to 1.48 (mg/100 g) in the unirradiated samples. Lower values were recorded in the samples that were irradiated which was statistically significant ($p<0.05$). There was a dose-dependent effect (resulting in a reduction in the capsanthin content as doses increased) on the content of capsanthin in the samples during storage with some few stabilities in the capsanthin content of the samples. The observed phenomenon is similar to the other pigments discussed earlier. The few stabilities observed in the values is similar to what has been reported in literature (Jung et al., 2015; Rico et al., 2010; Lee et al., 2004).

Table 4.24. Capsanthin content of Legon-18 pepper powder pepper powder after gamma irradiation, and during storage at different temperatures

SW	SC	Capsanthin (mg/100 g)				
		0 kGy	**1 kGy**	**2 kGy**	**4 kGy**	**5 kGy**
0		1.48±0.00^{Fe}	1.44±0.00^{Fd}	1.41±0.00^{Ec}	1.38±0.01^{Gb}	1.36±0.02^{Ga}
1		1.46±0.01^{Ee}	1.437±0.00^{Ed}	1.40±0.00^{Dec}	1.37±0.00^{Gb}	1.35±0.01^{Ga}
2		1.42±0.00^{Dc}	1.43±0.00^{Dd}	1.39±0.02^{Dc}	1.37±0.00^{Gb}	1.33±0.00^{GFa}
3		1.41±0.00^{Dd}	1.42±0.00^{Ccd}	1.39±0.02^{Dc}	1.34±0.00^{Fb}	1.30±0.00^{EFa}
4	4 °C	1.41±0.00^{De}	1.42±0.00^{Cd}	1.33±0.00^{Cc}	1.32±0.01^{Eb}	1.27±0.00^{DEa}
5		1.41±0.00^{Dc}	1.40±0.00^{Bd}	1.30±0.00^{Bc}	1.30±0.00^{Db}	1.26±0.00^{DCa}
6		1.38±0.02^{Cd}	1.40±0.00^{Bd}	1.29±0.01^{Bc}	1.27±0.00^{Cb}	1.23±0.00^{Ca}
7		1.35±0.02^{Bc}	1.37±0.00^{Ab}	1.26±0.01^{Aa}	1.25±0.01^{Bb}	1.20±0.00^{Ba}
8		1.32±0.02^{Ae}	1.37±0.00^{Ad}	1.25±0.00^{Ac}	1.20±0.00^{Ab}	1.14±0.04^{Aa}
0		1.47±0.00^{Ie}	1.45±0.01^{Id}	1.41±0.00^{Ic}	1.39±0.01^{Ib}	1.35±0.02^{Ha}
1		1.46±0.00^{He}	1.44±0.00^{Hd}	1.40±0.00^{Hc}	1.38±0.00^{Hb}	1.32±0.01^{Ga}
2		1.43±0.00^{Ge}	1.40±0.00^{Gd}	1.37±0.00^{Gc}	1.35±0.00^{Gb}	1.29±0.00^{Fa}
3		1.41±0.00^{Fe}	1.37±0.00^{Fd}	1.36±0.00^{Fc}	1.32±0.01^{Fb}	1.30±0.00^{Fa}
4	28± 2 °C	1.40±0.00^{Ed}	1.33±0.00^{Ec}	1.29±0.00^{Eb}	1.29±0.01^{Eb}	1.26±0.01^{Ea}
5		1.36±0.01^{Dd}	1.29±0.01^{Dc}	1.25±0.01^{Db}	1.25±0.00^{Db}	1.23±0.00^{Da}
6		1.32±0.00^{Cd}	1.25±0.01^{Cc}	1.22±0.00^{Cb}	1.21±0.00^{Cb}	1.18±0.00^{Ca}
7		1.28±0.00^{Be}	1.22±0.01^{Bd}	1.18±0.00^{Bc}	1.17±0.00^{Bb}	1.15±0.01^{Ba}
8		1.22±0.01^{Ae}	1.18±0.00^{Ad}	1.16±0.00^{Ac}	1.14±0.00^{Ab}	1.12±0.01^{Aa}

Least Significant Difference: Means with the same letters (upper case, within the same column for a particular temperature regeme) are not significantly (P>0.05) different from each other and means with the same letters in the same row (lower case, doses week within the same temperature regeme) are not significantly different (P>0.05) from each other. KEY: SW-STORAGE WEEKS; SC-STORAGE CONDITION.

Giuffrida et al. (2014), Guadarrama-Lezama et al. (2014), Kim et al. (2006) and Tang and Chen (1999) indicated that higher temperatures led to lower carotenoid content of agricultural produce. Beta carotene, beta cryptoxanthin and capsanthin content in the samples that were stored at 4 °C were higher than the ones that were stored at 28±2 °C. The observed reduction in the carotenoids investigated in the study might be due to the rate of degradation of the carotenoids at such temperatures (Guadarrama-Lezama et al., 2014; Giuffrida et al., 2014; Kim et al., 2006; Tang and Chen, 1999).

4.4 Optimization of microbial inactivation by gamma irradiation and storage days on *S.* Typhimurium, *E. coli, B. cereus, L. monocytogenes* and *S. aureus* using response surface methodology (Central Composite Design)

4.4.1 *Salmonella* Typhimurium

The estimated regression coefficients from the central composite design (appendix I) for the inactivation (survival) of *S.* Typhimurium and days of storage in the samples that were stored at 4°C were all not statistically significant (p>0.05) except the constant of regression. A general reduction in the log cfu/g of *S.* Typhimurium was observed for all doses (Fig.4.1 and appendix XXI). The regression analysis fitted the model at 92.50%.

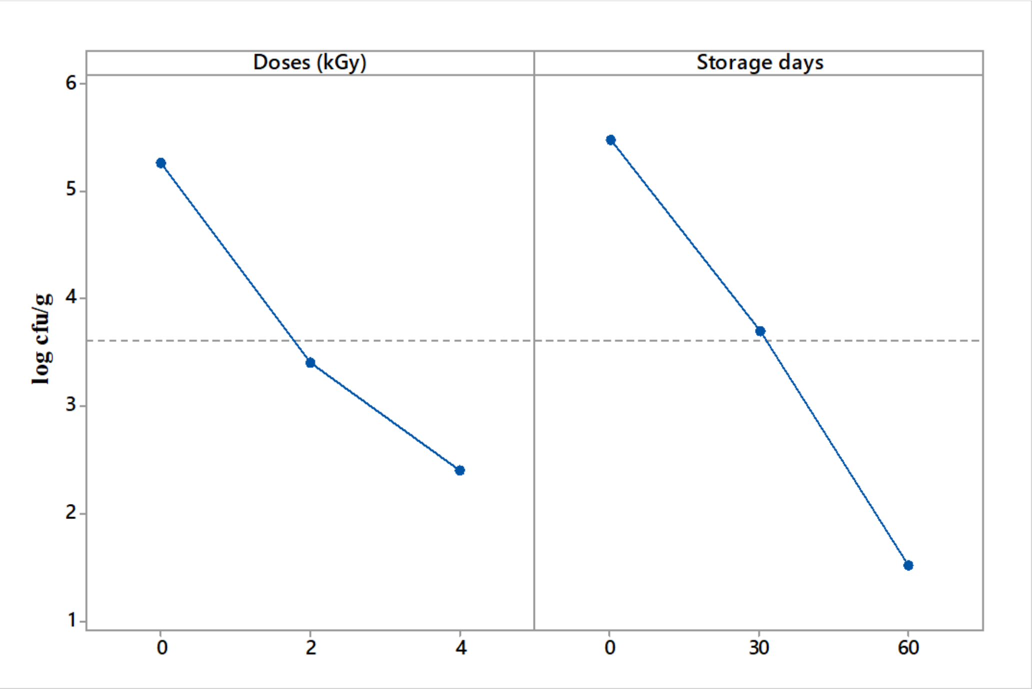

Fig. 4.1. Effect of gamma irradiation and storage on the survival of S. Typhimurium at 4°C

The observed inactivation might be due to the effect levels of injuries caused to the cells, the inability of the cells to repair their DNA as well as the post-irradiation effect on the cells (Lucht et al., 1998; Byun et al., 2001; Song et al., 2006; Song et al., 2007; Wu, 2008).

Figure 4.2 and appendices III and XXII indicate the inactivation of the pathogen in the samples that were stored at 28±2 °C. The regression coefficients were all statistically significant ($p<0.05$). The model fitted the inactivation (R^2) at 98.80%. A general reduction in the log cfu/g of the organisms was observed. Complete inactivation of the organisms was only during day 60 at all the doses including the control. The gradual inactivation in the irradiated samples over time may be attributed to the post irradiation effect as well as the lethality of the doses applied (Cárcel et al., 2015; Song et al., 2007, Song et al., 2006; Byun et al., 2001; Lucht et al., 1998).

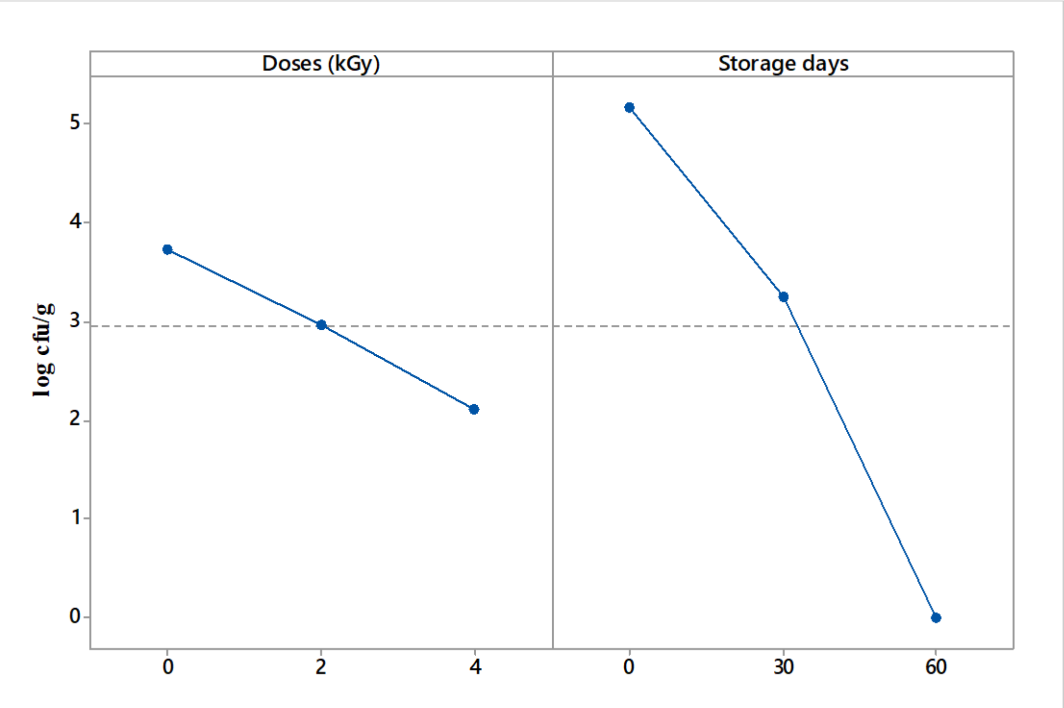

Fig. 4.2. Effect of gamma irradiation and storage on the survival of *S.* Typhimurium at 28±2 °C

4.4.2 *Escherichia coli*

The estimated regression coefficients are indicated in appendix V for the samples stored at 4 °C. There was a general reduction in the count of organisms with time (Fig. 4.3 and appendix V). The model fitted the inactivation (R^2) at 99.40%. A gradual inactivation of the pathogen irrespective of the doses, however the highest inactivation (lowest survival rate) was observed in the samples at the various doses (Fig. 4.3 and appendix III). The observed inactivation might be due to other factors like the composition of the material and probably nutrient for growth (Ban and Kang, 2014; Song et al., 2014).

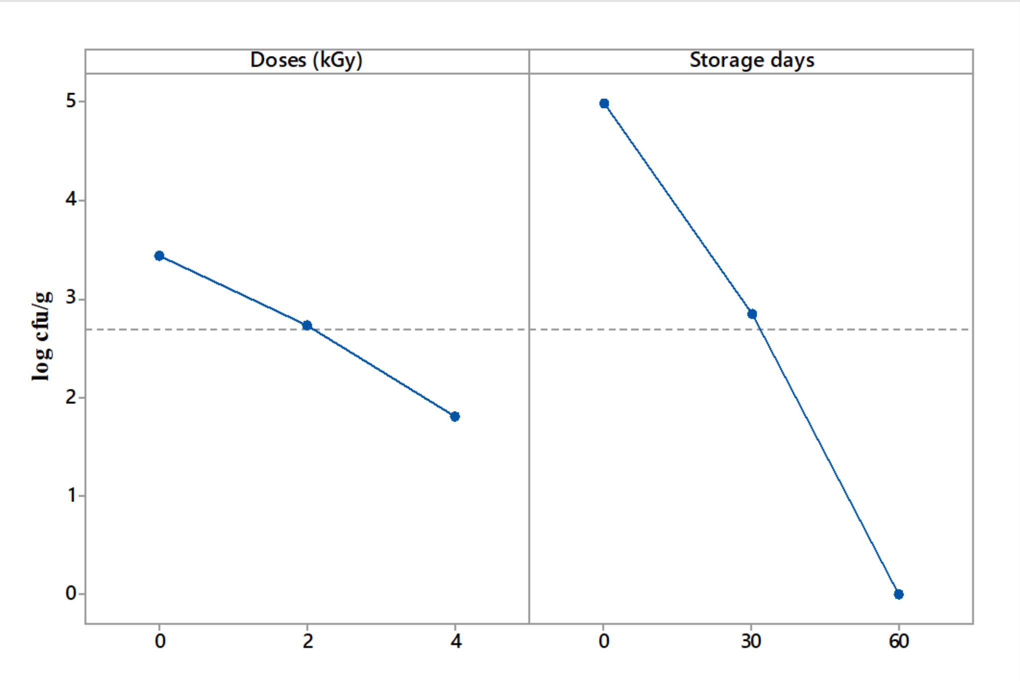

Fig. 4.2. Effect of gamma irradiation and storage on the survival of *E. coli* at 4°C

The gradual inactivation especially among the irradiated samples may be attributed to the lethality of the doses as well as the effect of post irradiation effect (Lucht et al., 1998; Byun et al., 2001; Song et al., 2006, Song et al., 2007, Cárcel et al., 2015).

Statistically significant ($p<0.05$) coefficients of regression in terms of doses of gamma irradiation, days of storage, constant of regression was observed for the samples that were stored at 28±2 °C (appendix VII and VIII). The R^2 for the model fit was 99.20%.

A general reduction in the survival (increase in the inactivation) of *E. coli* was observed (Fig. 4.4 and appendix XXIV).

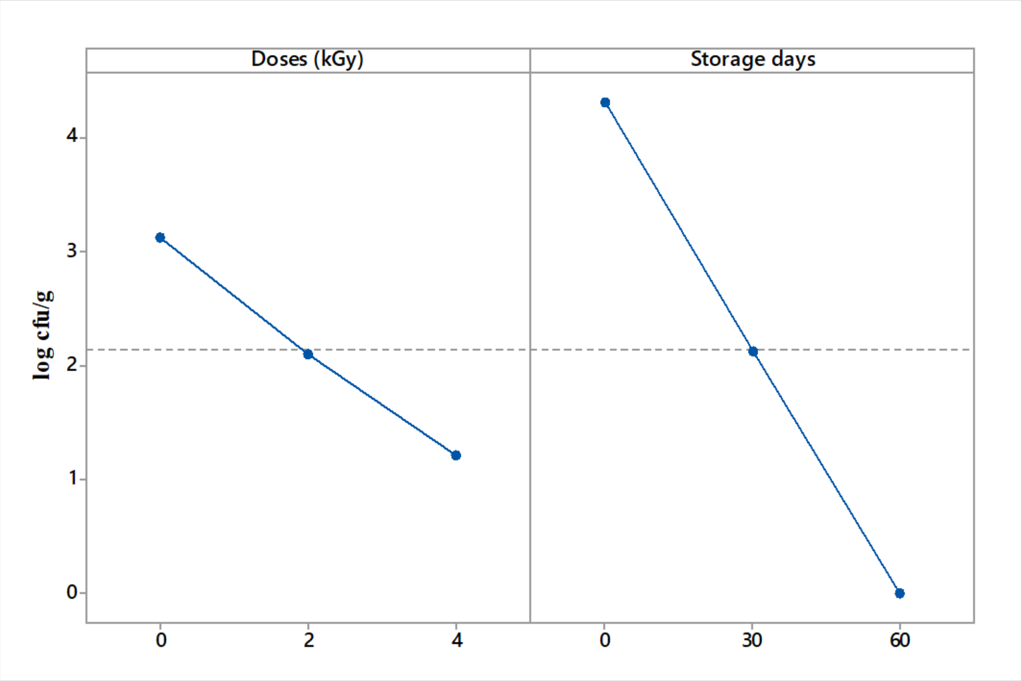

Fig. 4.3. Effect of gamma irradiation and storage on the survival of *E. coli* at 28±2 °C

Higher inactivation (lower survivability) from day 0 was observed for all the irradiated samples (Fig 3.6 and 3.7). The impact of lethality of the gamma irradiated samples was gradual (Byun et al., 2001; Lucht et al., 1998) thereby leading to a complete inactivation at day 60 (Fig.3.6). These doses applied indicates that complete decontamination of the samples can be achieved with storage.

4.4.3 *Bacillus cereus*

The regression coefficients for the only spore former *B. cereus* are indicated in appendices appendix IX, X) at storage 4 °C. A general reduction in the survival of the organisms was conspicuous (Fig. 4.5 and appendix XXV). Samples that were stored at 28±2°C had regression coefficients indicated in appendix XI, XII. The experiment fitted the model at an R^2 of 97.30%. The highest inactivation during the study was observed in the samples irradiated at 4 kGy (Fig 3.6 and appendix XXVI), which could not achieve complete inactivation of this pathogen except beyond 60 days of storage.

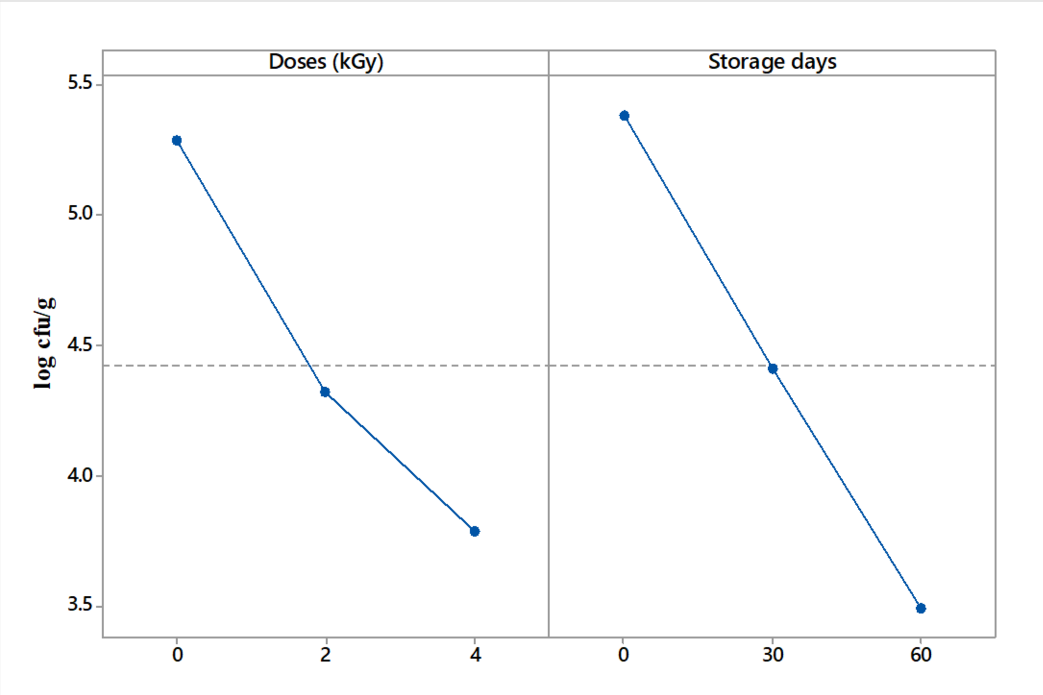

Fig. 4.4. Effect of gamma irradiation and storage on the survival of *B. cereus* at 4°C

The gradual inactivation of the pathogen with storage had been reported in literature (Ban and Kang, 2014).

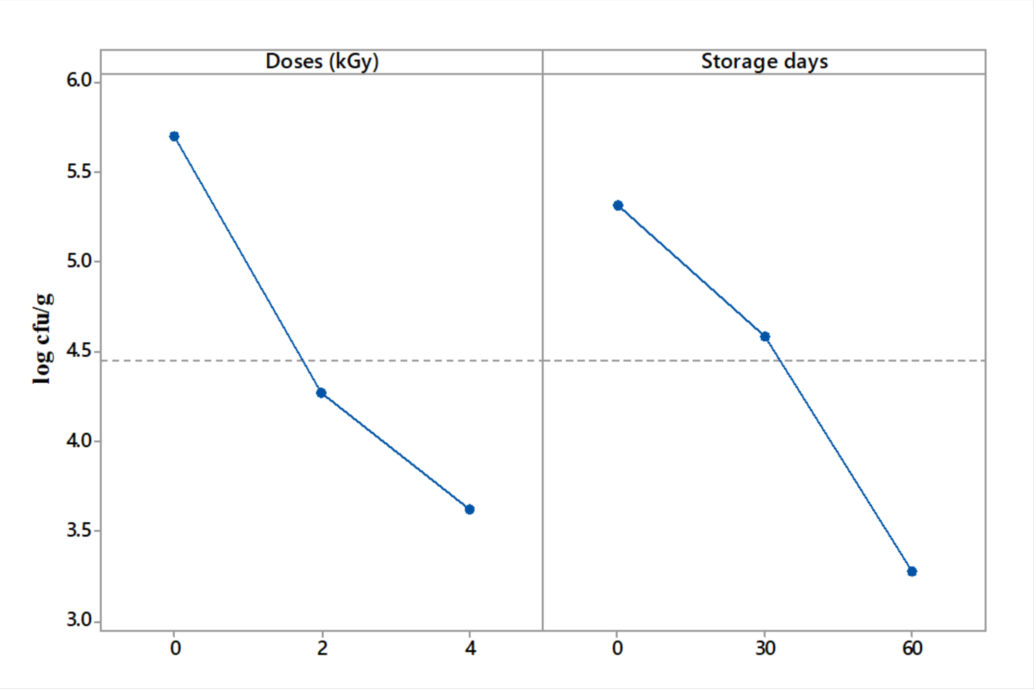

Fig. **4.5.** Effect of gamma irradiation and storage on the survival of *B. cereus* at 28±2 °C

4.4.4. *Listeria monocytogenes*

Regression coefficients for the samples that were stored at 4 °C had can be found appendix XIII and XIV. The R^2 value was 96.10% for the model fit. A general reduction in the count of the organisms was observed (Fig. 4.7 and appendix XXVII).

The complete inactivation of the sample was achieved at both doses 2 and 4 kGy only after a long storage period of 60 days (Fig. 4.7 and appendix XXVII) which is an indication of the effect of lower lethality from the lower doses that were used in the study. The post irradiation effect and the injury caused to the organisms could not inactivate them completely even at day 0 (Byun et al., 2001; Lucht et al., 1998).

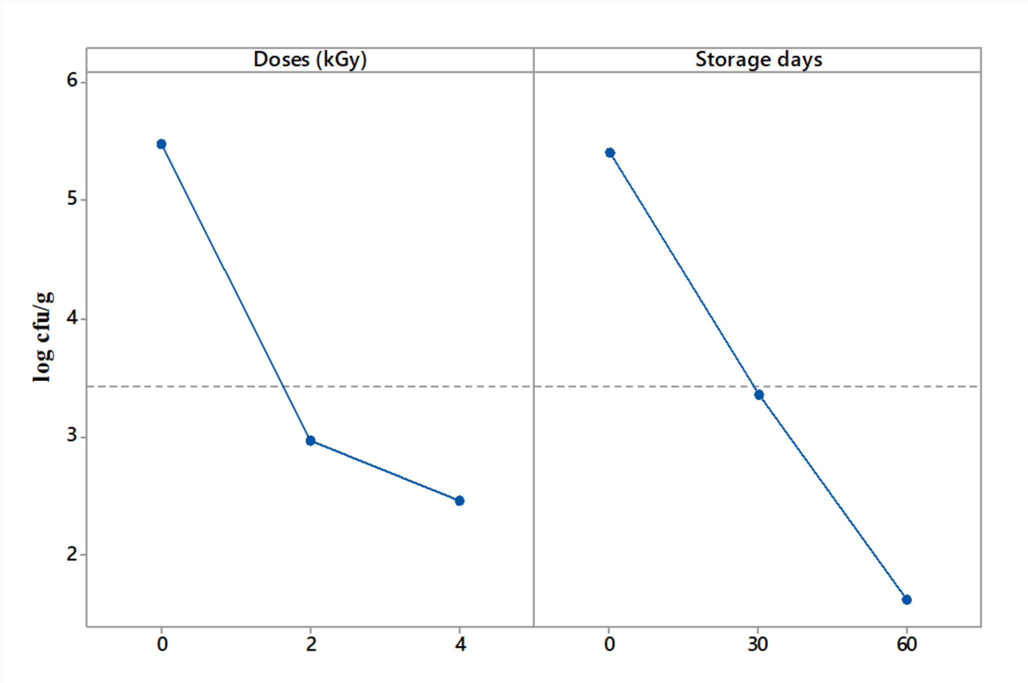

Fig. 4.6. Effect of gamma irradiation and storage on the survival of *L. monocytogenes* at 4ºC.

The complete inactivation of the sample was achieved at both doses 2 and 4 kGy only after a long storage period of 60 days (Fig. 4.7 and appendix XXVII) which is an indication of the effect of lower lethality from the lower doses that were used in the study. The post irradiation effect and the injury caused to the organisms could not inactivate them completely even at day 0 (Byun et al., 2001; Lucht et al., 1998).

Inactivation of the organisms was dose dependent which is typical of literature (Torgby-Tetteh et al., 2014; Ban and Kang, 2014; Rico et al., 2010). Higher doses from 5 kGy would have inactivated all the organisms even at day zero (a preliminary observation during the study) which is typical of literature (Song et al., 2014).

The coefficient of the regression parameters for the samples irradiated at 28±2 °C are displayed in appendix XV and XVI. The R^2 value for the model was 96.80% (appendix XV). A general reduction in the count of the organisms was observed (Fig. 4.8 and appendix XXVIII).

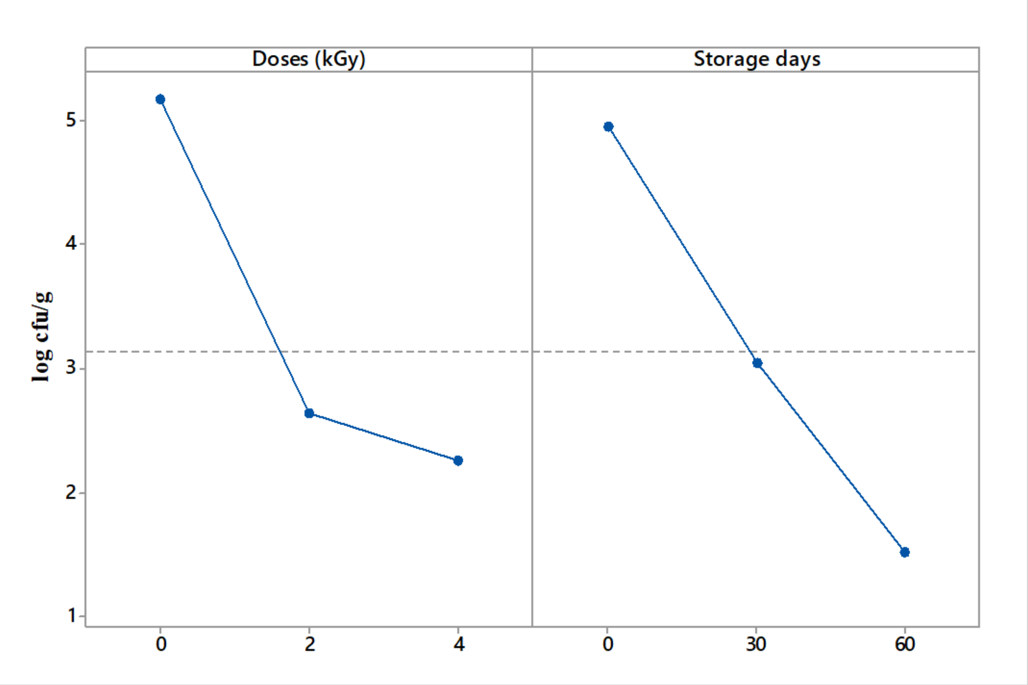

Fig. 4.7. Effect of gamma irradiation and storage on the survival of *L. monocytogenes* at 28±2 °C.

Post irradiation effect on the *L. monocytogenes* was obvious as depicted in Fig. 4.8 due to the gradual inactivation of the pathogen (Cárcel et al., 2015; Song et al, 2007; Song et al, 2006, Byun et al., 2001; Lucht et al., 1998). The injuries that were caused to the organisms could not inactivate them immediately or render the samples microbiologically safe for use until day 60. Higher doses (Table 4.4) could have led to the inactivation even during day zero (Oularbi and Mansouri, 1996).

4.4.5 *Staphylococcus aureus*

The effect of the gamma irradiation on *S. aureus* were fitted to model at an r^2 of 97.60% (appendix XVII). The coefficients of regression are shown in appendix XVII and XVIII. Fig. 4.9 and appendix XXIX depict the effect of days and doses on the survival of the organisms. The most effective dose for the inactivation of *S. aureus* in this current study was 4 kGy, however its effect was with time which is typical in literature (Cárcel et al., 2015; Song et al., 2007; Song et al., 2006, Byun et al., 2001; Lucht et al., 1998).

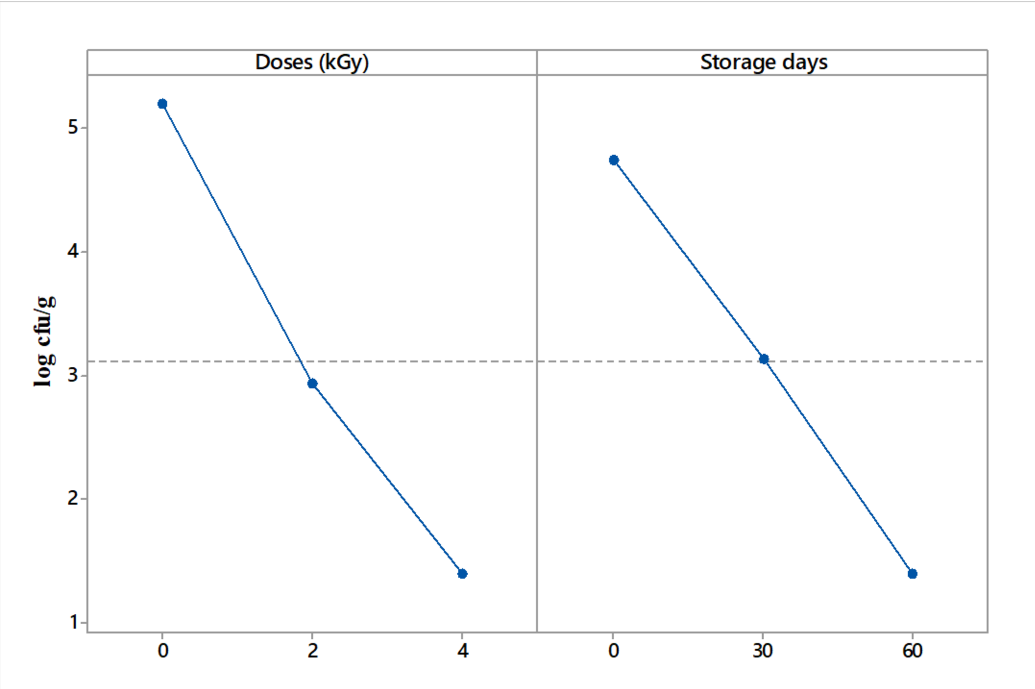

Fig. 4.8. Effect of gamma irradiation and storage on the survival of *S. aureus at* 4°C.

The coefficient of the regression for the samples that were stored at 28±2 °C were -1.33263, -0.03545 and -0.00254 for the doses, days and interaction between the days and the doses respectively (XIX and XX). The r^2 for the model was 94.10%. Interactive effects and effects of the main factors are displayed in Fig. 4.10 and appendix XXX. Inactivation of the pathogen at this storage temperature was gradual due to the doses applied as these doses had a lower lethality on the cells as well as a lower post irradiation effect (Song et al., 2007; Song et al., 2006; Byun et al., 2001; Lucht et al., 1998). The injuries that were caused to the organisms could not inactivate them completely within the first day of (day zero) of the study (Lucht et al., 1998).

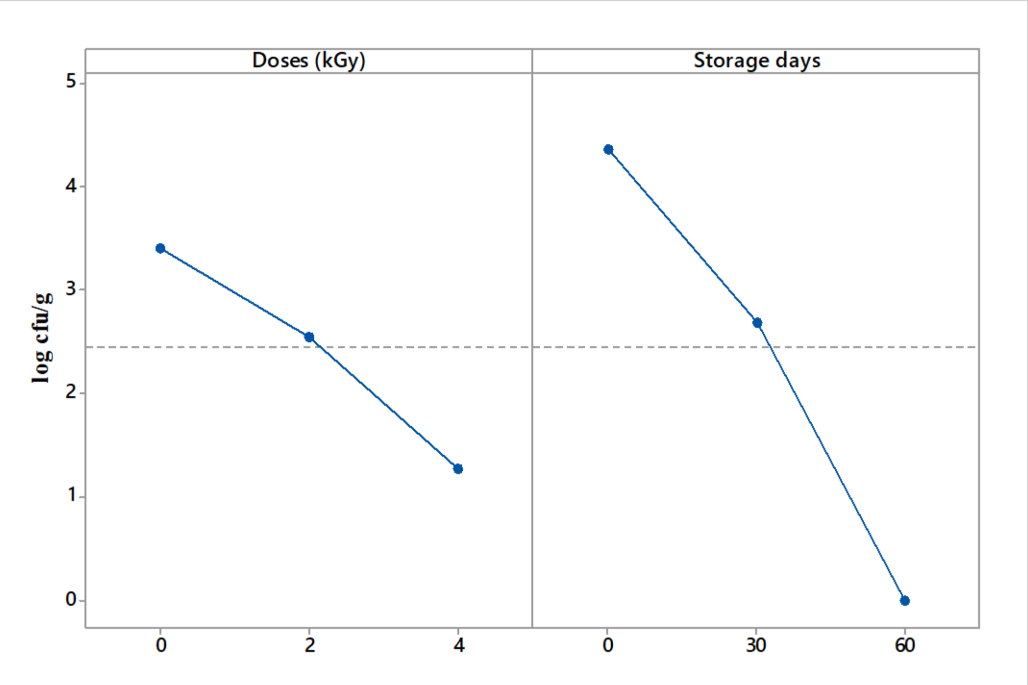

Fig. 4.9. Effect of gamma irradiation and storage on the survival of *S. aureus* at 28±2 °C

4.5 Optimization of the effect of gamma irradiation and storage on the quality and components of legon-18 pepper samples (Central Composite Design)

4.5.1 L* values

From the estimated regression coefficient (Appendix LXII and LXIII, and Fig. 4.4) for the lightness (brightness) of the pepper samples, the effect of the doses of gamma irradiation applied to the samples was not significant (p>0.05). The estimated regression coefficient for the samples stored at 4 °C (Appendices LXIV, LXV), indicated that the impact of the doses on the lightness or brightness of the colour of the pepper samples was not significant (p>0.05). Effect of storage weeks was significant (p<0.05). The observed pattern might be due to the effect of oxidation of the carotenoids in the samples (Schweiggert et al., 2005). Longer storage days would lead to further 'darkening' of the samples (Kim et al., 2004).

The impact of the storage weeks on the lightness of the pepper samples were significant ($p<0.05$). Increasing the storage days thus will have more impact on the brightness of the colour of the pepper than looking at the doses on the pepper samples (Kim et al., 2004). This indicates the impact of the storage weeks on the samples on the samples that were stored at 28±2 °C. The regression fitted the model at 98.6%.

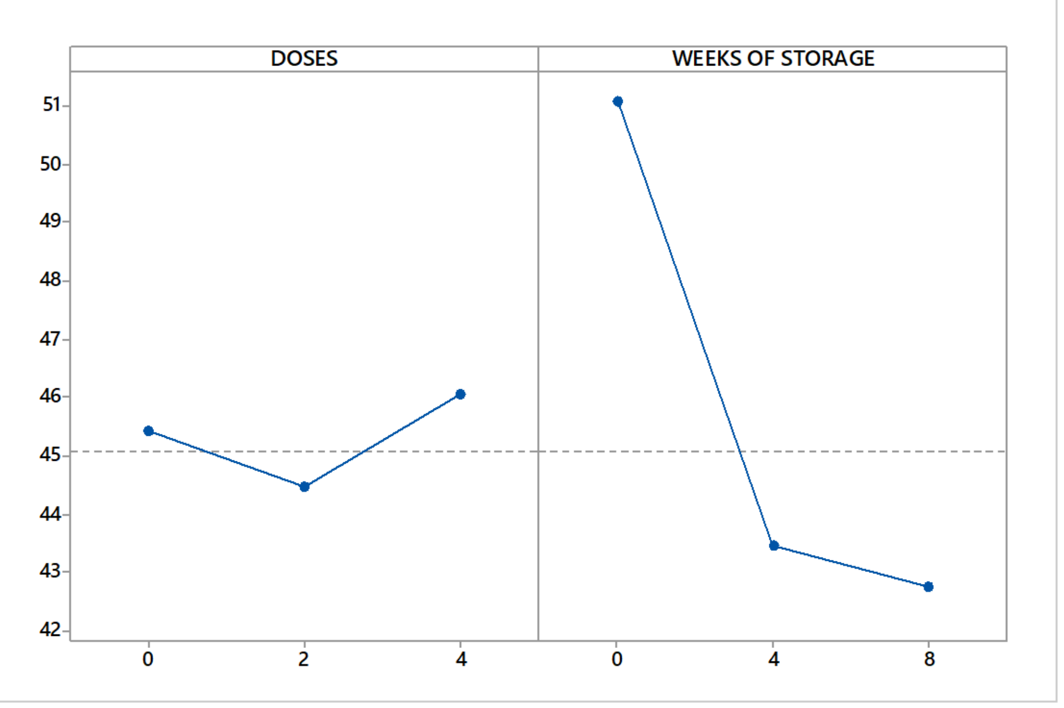

Fig. 4.10. L* values after gamma irradiation and during storage stored at 4 °C

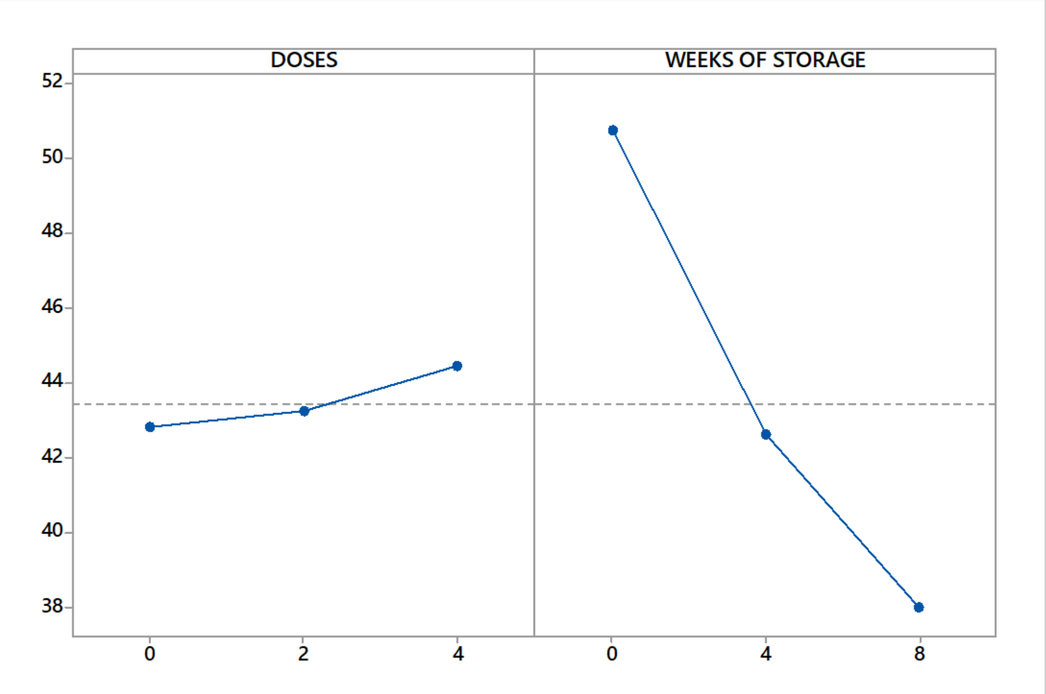

Fig. 4.11. L* values after gamma irradiation and during storage at 28±2 °C

4.5.2 a* values

The coefficient of regression (appendices LXVI and LXVII, and Fig.4.18) for the doses was significant ($p<0.05$) indicting bleaching effect of the gamma irradiation on the redness of the samples at 28±2 °C indicating that the higher the doses applied the higher the redness of the samples. Though storage weeks significantly ($p<0.05$) affected the redness of the samples, the coefficient of the regression indicates a 'reduction' effect on the redness of the samples. This implies that the longer the samples are stored, the darker (redness of the samples reduces) the samples will become (Almela et al., 2002). There was a dose-week interaction effect ($p<0.05$), which implies that the redness of the samples of Legon-18 is affected by both the doses and weeks combined which is similar to literature **(**Cheon et al., 2015; Kim, 2012)**.**

The regression coefficients, analysis of variance (ANOVA) for the redness of the pepper samples are displayed in appendix XLVI, XLVII and interactive effect from Fig. 4.13 for the samples that were stored at 4 °C. There was a significant ($p<0.05$) effect of the doses on the colour from the regression analysis. The dose-dependent effect was conspicuous, however, the regression coefficient for the impact of the weeks of storage was negative and significant ($p<0.05$). The observed pattern may be attributed to the effect of gamma irradiation on the pigments responsible for the redness (a* values) as well as the effect of oxidation of those pigments **(**Guadarrama-Lezama et al., 2014; Giuffrida et al., 2014; Kim et al., 2006; Perez-Galvez and Minguez-Mosquera, 2001; Tang and Chen, 1999).

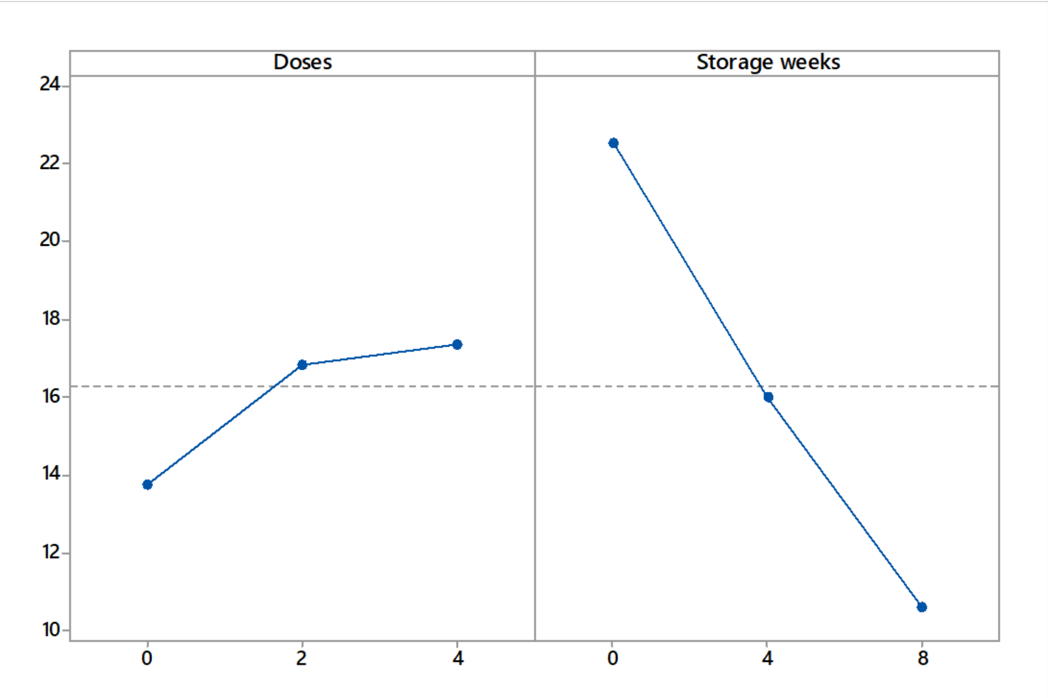

Fig. 4.12. a* values after gamma irradiation and during storage at 4 °C

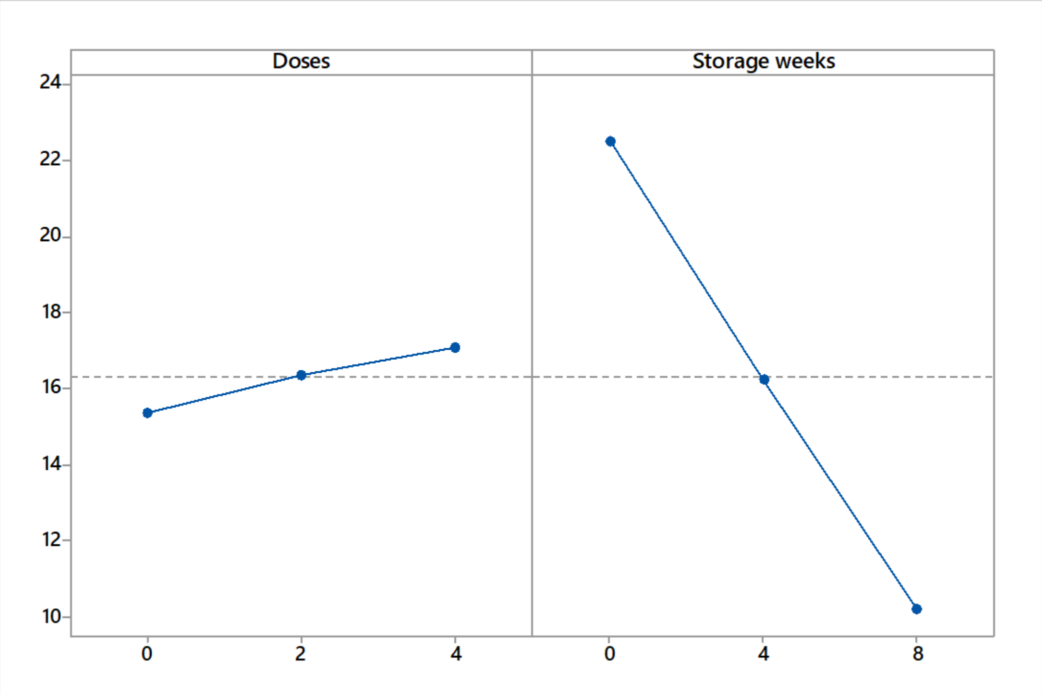

Fig. 4.13. a* values after gamma irradiation and during storage at 28±2 °C

4.5.3 b* values

The effect of gamma irradiation doses, weeks and the interactive effect of these factors are displayed at appendix LXVIII, LXIX and Fig. 4.14 for the samples that were stored at 28±2 °C. There was a significant effect ($p<0.05$) of gamma irradiation doses, weeks and the dose-weeks interactions. The yellowness of the samples stored at 4 °C recorded regression coefficients and interactive effects that are displayed in appendix LXX, LXXI and Fig. 4.15. There was a significant effect ($p<0.05$) of the doses on the effect of the yellowness of the samples, an indication of the dose-dependent effect on the yellowness of the samples. The negative value recorded in the weeks, though significant ($p<0.05$) indicates that storage weeks led to the reduction in the yellowness of the samples. The observed effects of the doses, gamma irradiation and weeks of storage may be due to the breakdown of the pigments responsible for the yellowness of the samples as well as the effect of storage temperature on the rate of deterioration (Kim et al., 2005; Rico et al., 2010)

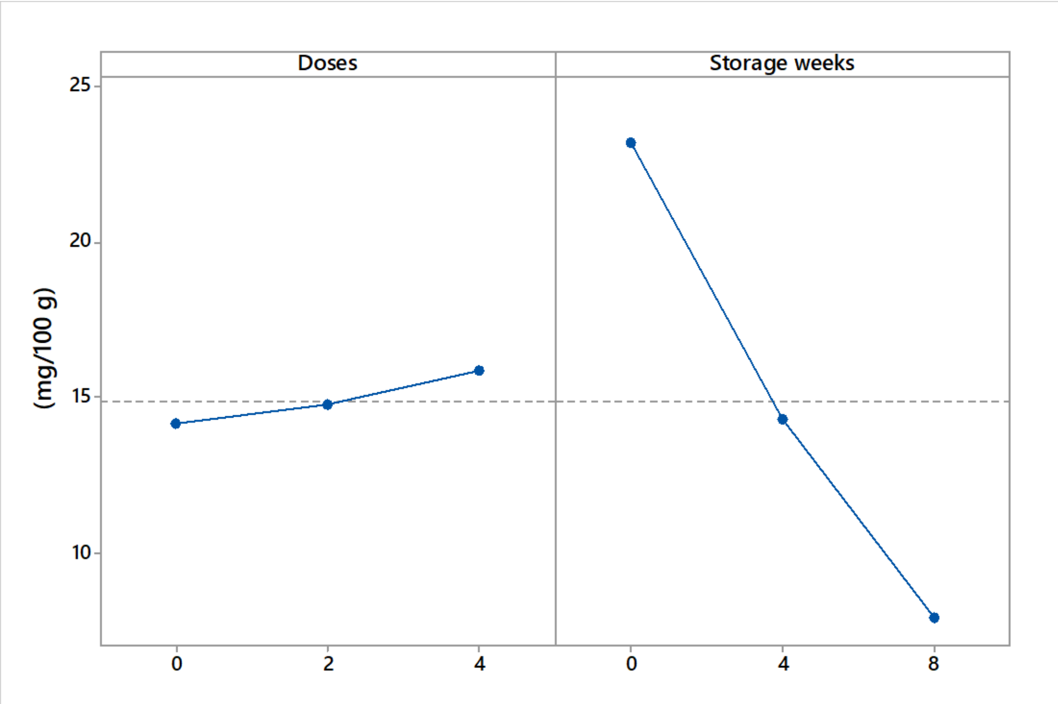

Fig. **4.14.** b* values after gamma irradiation and during storage at 4 °C

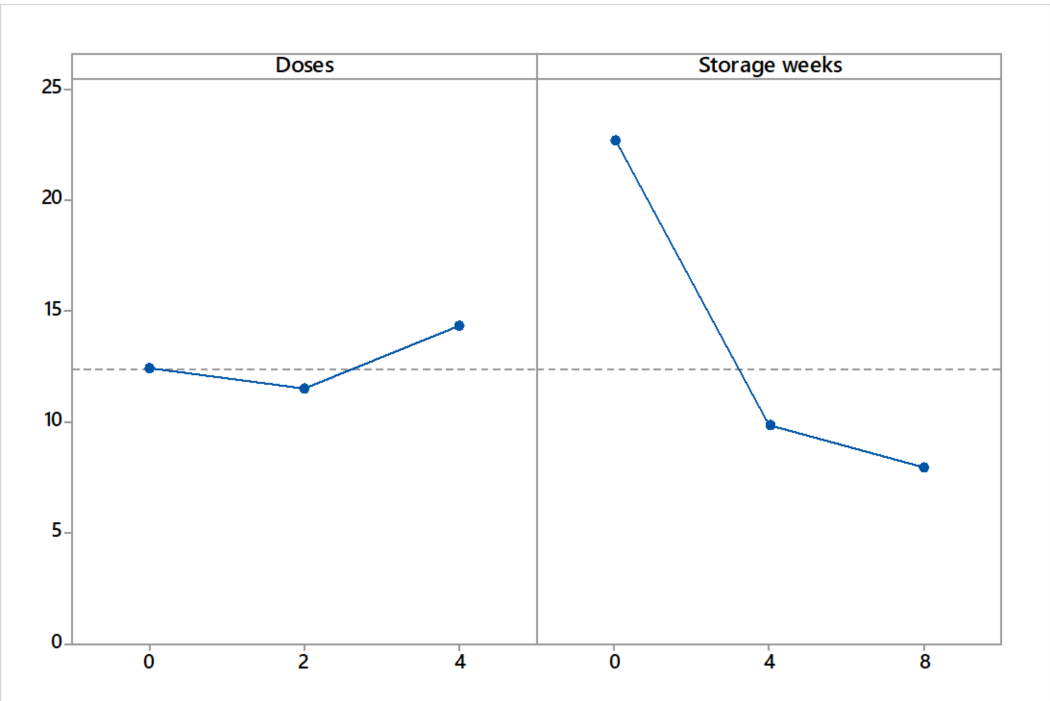

Fig. **4.15.** b* values after gamma irradiation and during storage at 28±2 °C

4.5.4 Chroma

The estimated coefficients of the regression for the chroma of the samples, ANOVA for the chroma as well as the interactive effect of the doses and weeks are displayed in appendix XXXV, XXXVI and Fig. 4.18 and appendix XXXVII, XXXVIII and Fig. 4.17 for the samples that were stored at 28±2 ^oC and 4 ^oC respectively**.** The effect of doses, weeks and interactive effect on the chroma of the samples were significant ($p<0.05$) for the samples at both temperatures. The positive regression coefficient for the doses indicates the effect of 'bleaching'. Thus, increasing the doses would lead to higher chroma values in the samples, however, the negative coefficient of regression for the weeks indicates that increasing the number of weeks will lead to lower chroma values. The interactive effect of the dose and weeks was also negative depicting a reducing effect on the chroma of the pepper samples with time for samples stored at both temperatures (Schweiggert et al., 2005).

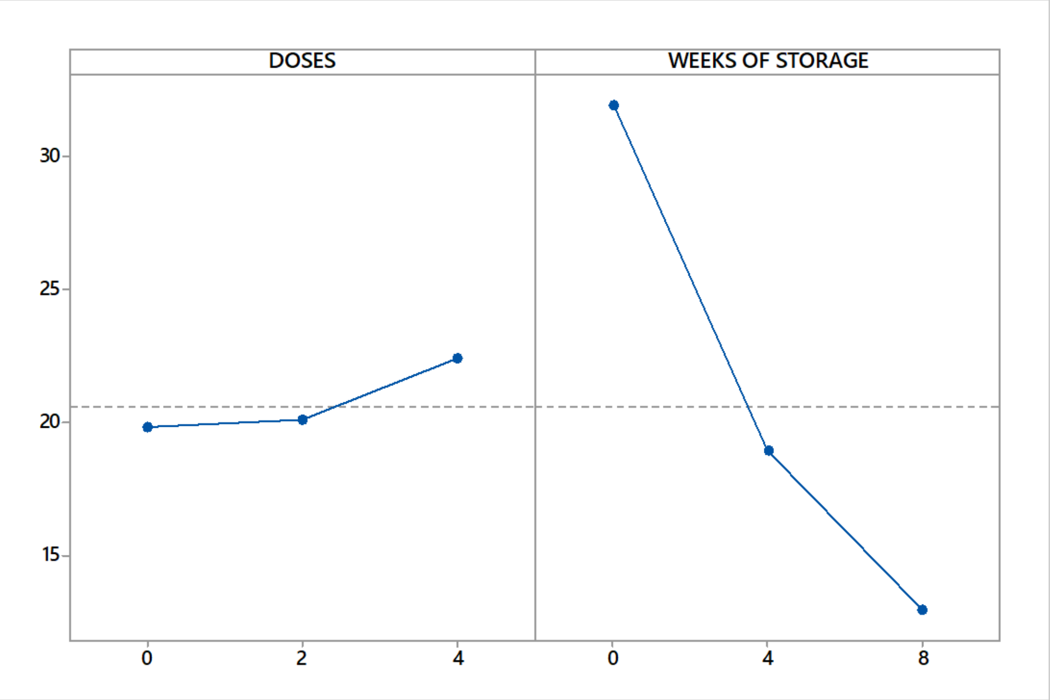

Fig. 4.16. Chroma after gamma irradiation and during storage at 4 ^oC

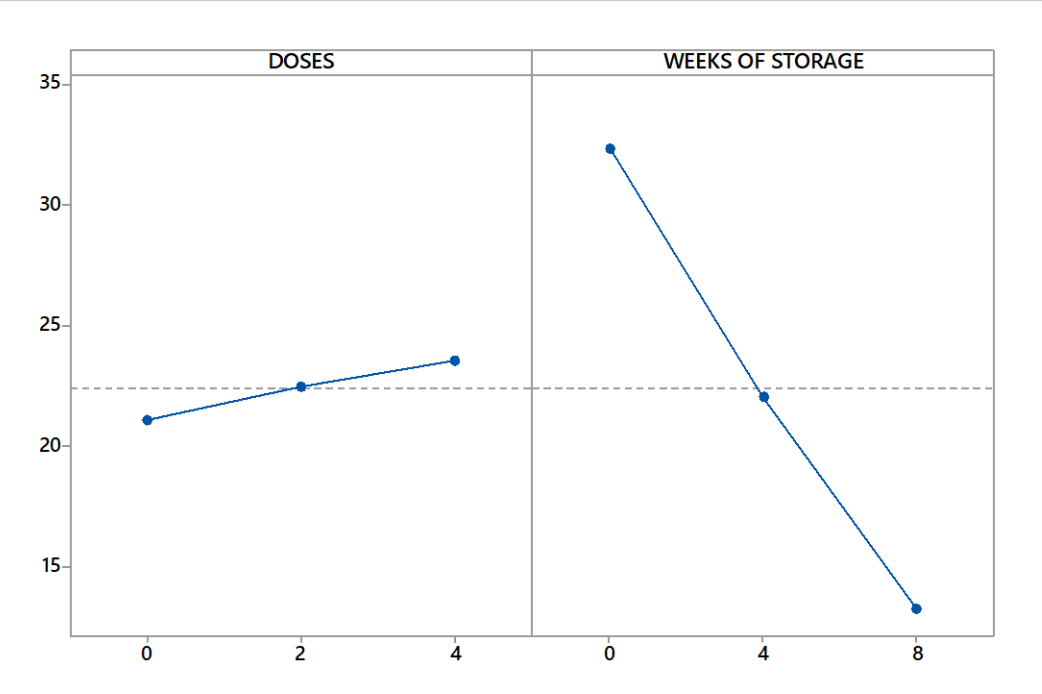

Fig. 4.17. Chroma after gamma irradiation and during storage at 28±2 °C

4.5.5 Browning index

The regression coefficients, the ANOVA as well as the interactive effect of both doses applied and the weeks at both storage conditions are depicted in appendices XXXI to XXXIV and Fig. 4.19 and 4.20. The impact of the doses on the browning index of the pepper samples stored at 28±2 °C was not significant ($p>0.05$) indicating that in optimization of the impact of gamma irradiation, the browning index is not necessarily dependent on the doses applied, however the browning index is dependent on the storage weeks ($p<0.05$) which led to the reduction in the browning index of the pepper samples. The effect of the doses and weeks (interactive effect) of the pepper samples was not significant ($p>0.05$) but had a reducing effect on the browning index. The effect of the gamma irradiation and the doses led to the reduction in the browning index of the pepper samples.

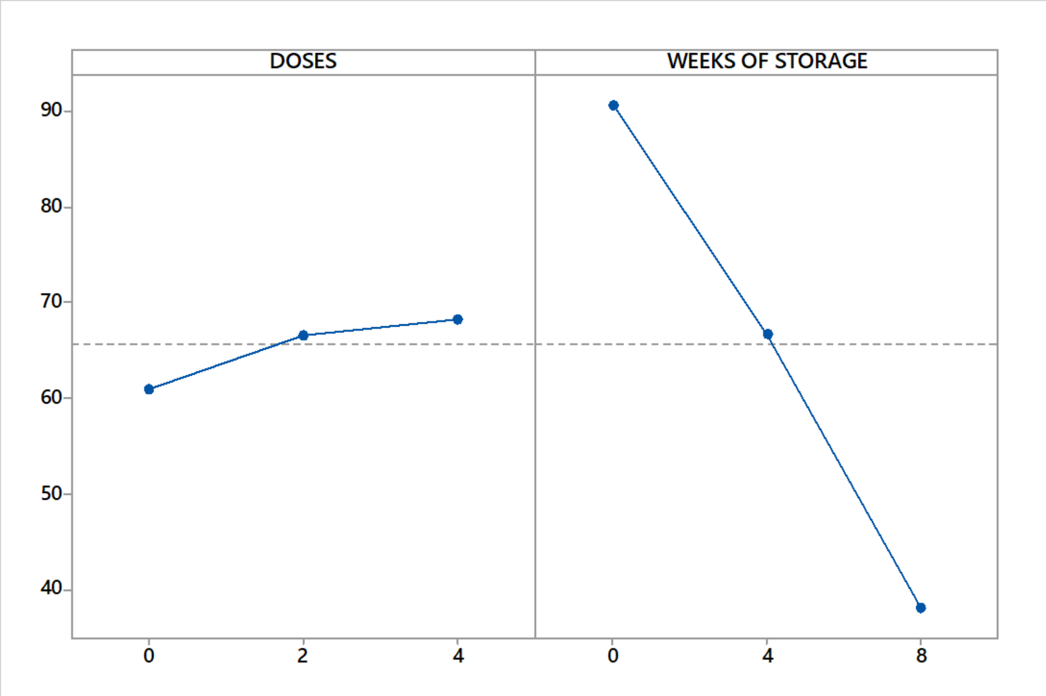

Fig. 4.18. Browning index after gamma irradiation and during storage at 4 °C

Samples that were stored at 4 °C were affected by the doses of gamma irradiation applied ($p<0.05$). The combined effect of the doses and storage weeks on the browning led to a reduction in the browning index of the pepper samples which was statistically ($p>0.05$). The effect of the storage weeks led to a reduction ($p<0.05$) in the browning index of the samples. The dose-dependent effect caused a higher browning index in the samples that were stored at this temperature. This indicates that the longer the storage period the less the browning index of the pepper samples which may be due higher degradation or oxidation of the pigments of the samples (Schweiggert et al., 2005). The browning index of the samples depended on the storage weeks. Increasing the weeks of storage or reducing the weeks of storage will affect the browning index of the samples (Schweiggert et al., 2005).

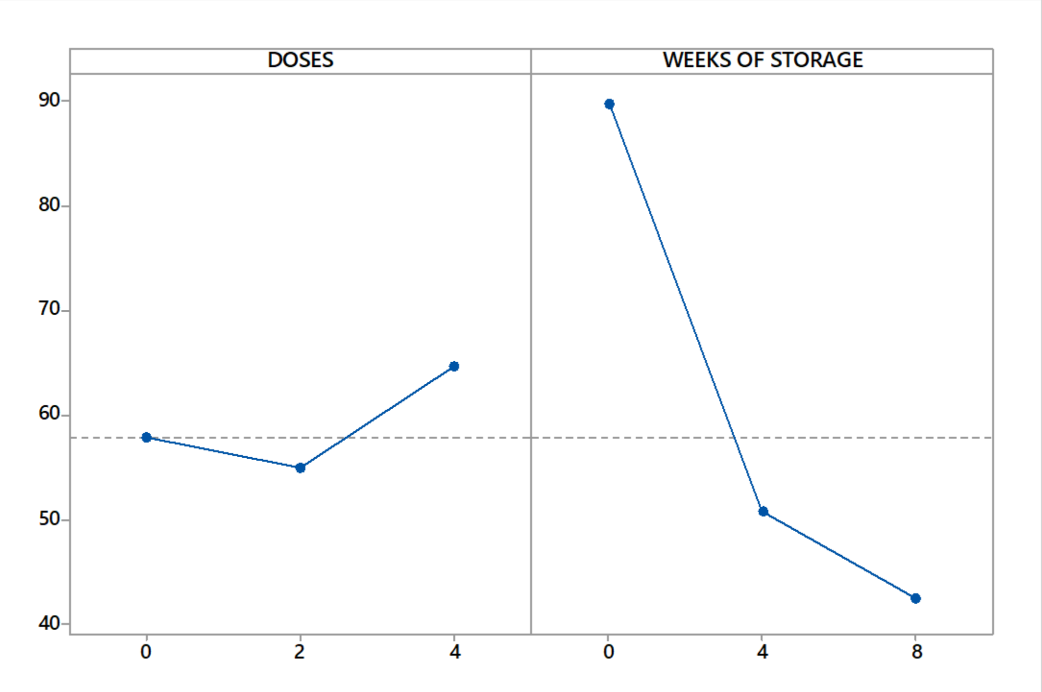

Fig. 4.19. Browning index after gamma irradiation and during storage at 28±2 °C

4.5.6 Total colour difference

The total colour difference of the samples which indicates the change in the colour of the samples from the onset to the end of the experiment was optimized. The estimated regression coefficient, the ANOVA and the interactive effect of the doses of gamma irradiation are indicated in appendices XLIII to XLVI and Fig. 4.21 and 4.22.

The parameters that affected the total colour differences at both temperatures were not statistically significant ($p>0.05$) except the weeks of storage ($p<0.05$). Total colour difference increase with weeks of storage may be attributed to the oxidation and degradation of the pigments responsible for the colour of the samples (Schweiggert et al., 2005; Topuz, et al., 2009).

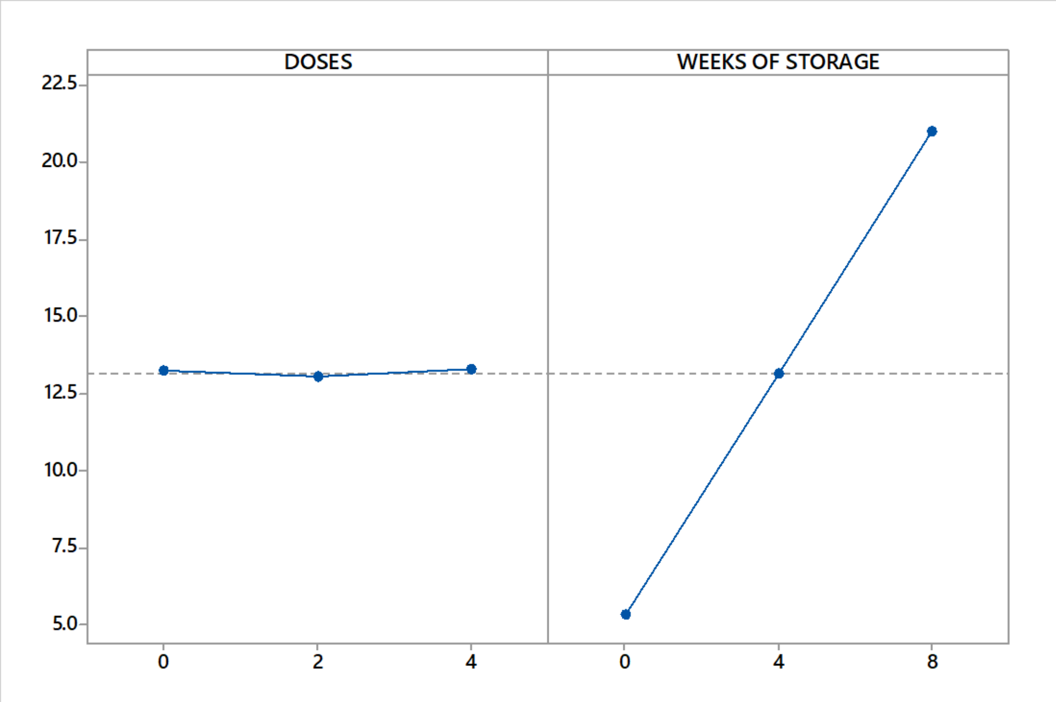

Fig. 4. 20. Total Colour Difference after gamma irradiation and during storage at 4 °C

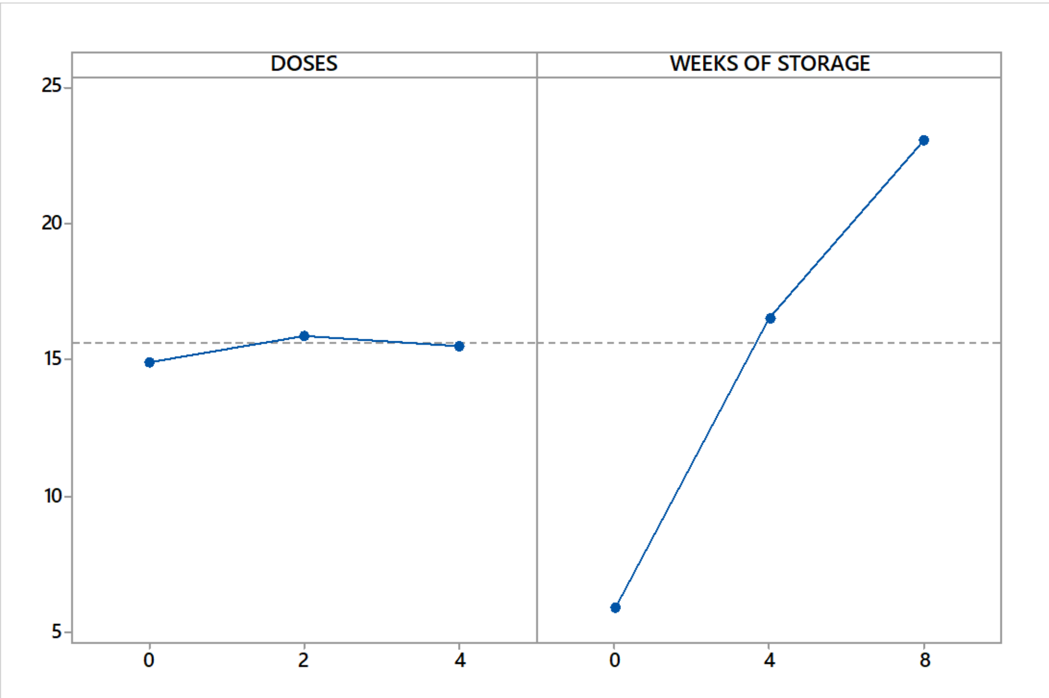

Fig. 4.21. Total Colour Difference after gamma irradiation and during storage at 28±2 °C

4.5.7 Hue

The optimization of the process parameters that affected the hue of the pepper samples is indicated in appendices XXXIX to XLIII as well as the interactive effect in Fig. 4.23 and

4.24stored at 28±2 °C and 4 °C. Weeks of storage had a significant ($p<0.05$) effect on the hue of the samples that were stored at both temperatures, however with a reducing effect. The lower values recorded may be attributed to the breakdown of the pigments responsible for the colour of the samples (Schweiggert et al., 2005). In view of this observation, longer weeks of storage may lead to lower values at both storage temperatures.

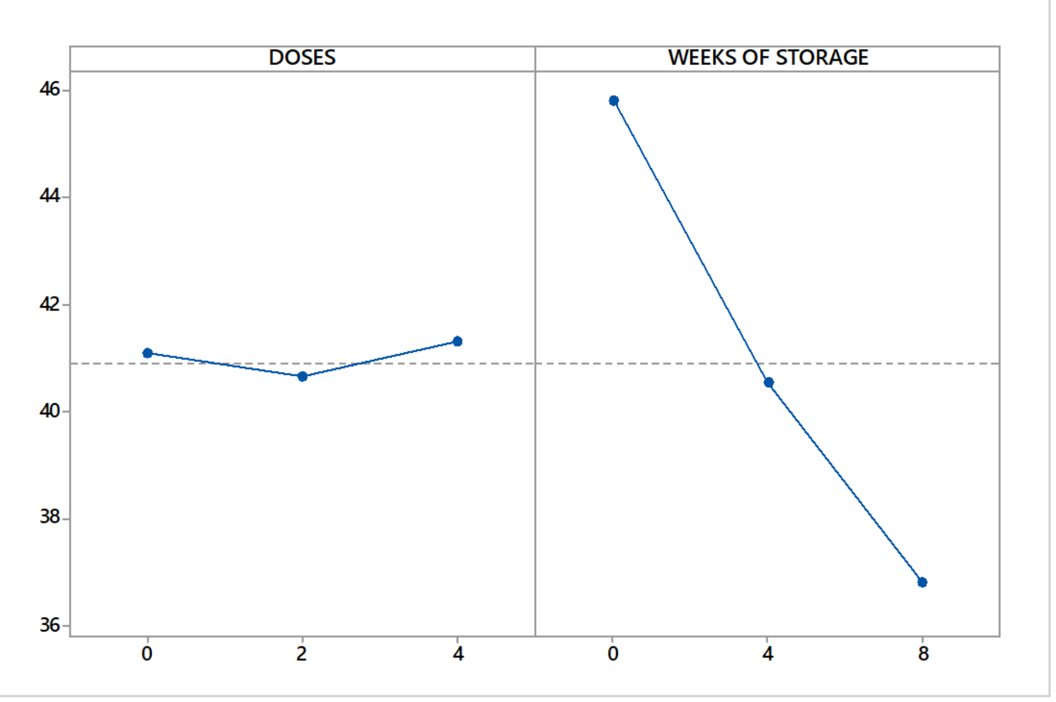

Fig. 4. 22. Hue after gamma irradiation and storage at 4 °C

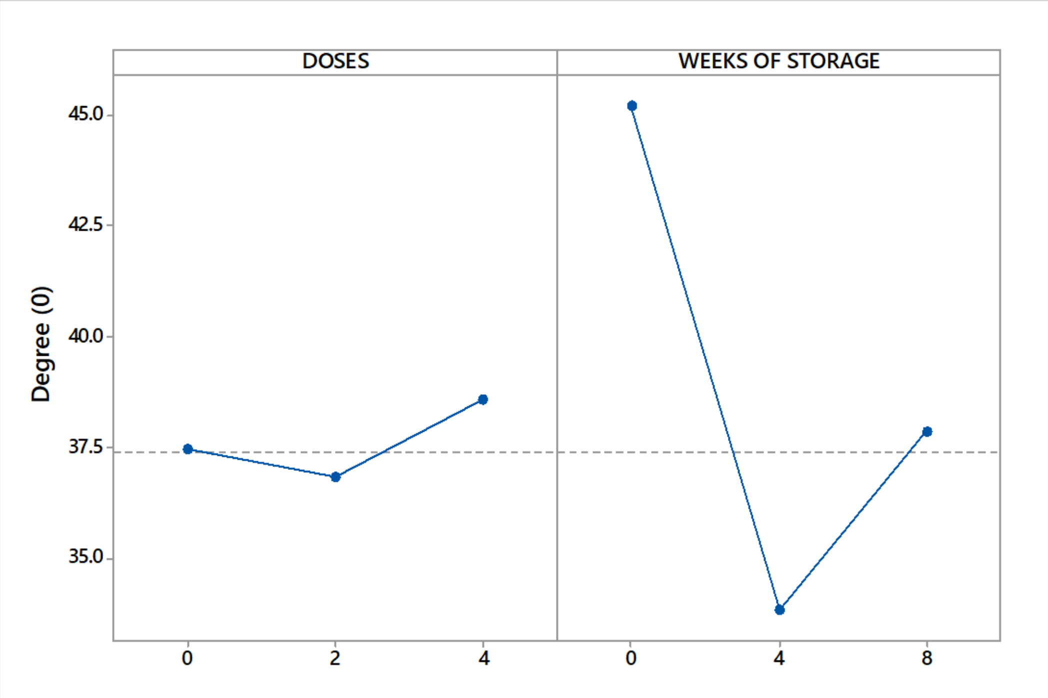

Fig. 4.23. Hue after gamma irradiation and storage at 28±2 °C

4.5.8 pH

The regression coefficient of the pH of the samples are depicted in appendices XC to XCIII as well as the interactive effect of doses and storage weeks at Fig. 4.25 and 4.26. The weeks of storage had a significant effect on the pH of the samples at both storage temperatures **(**4 °C and 28±2 °C). The values recorded due to storage weeks might be due to the breakdown of organic acids (Atuobi-Yeboah et al., 2016). The pH of the samples stored at different temperatures could only be reduced with storage weeks. The samples may become less acidic during a longer storage time.

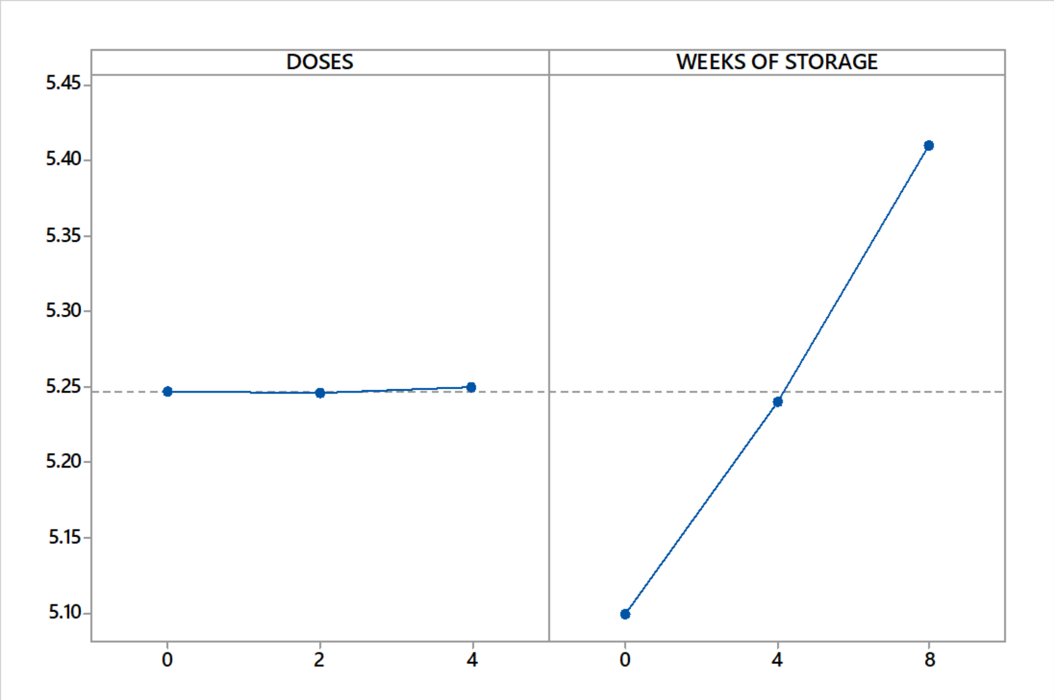

Fig. 4.24. pH after gamma irradiation and during storage at 28±2 °C

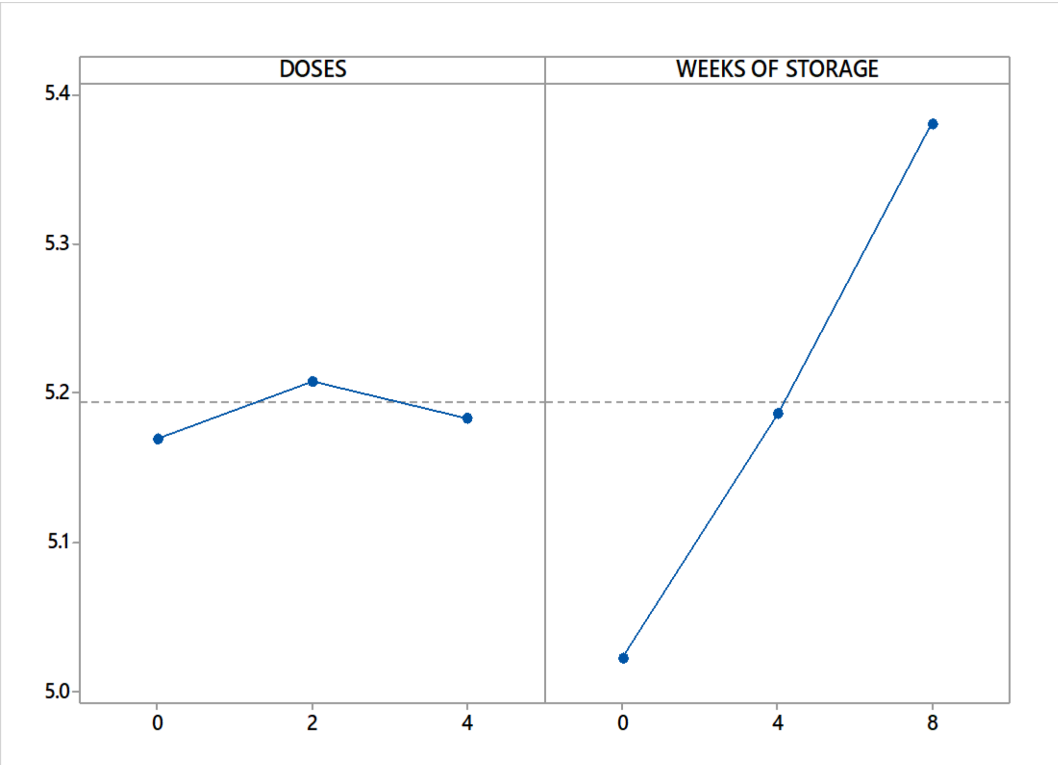

Fig. 4.25. pH after gamma irradiation and during storage at 4 °C

4.5.9 Moisture content

The regression coefficients for the moisture content of the samples that were stored at both temperatures are depicted in appendices XCVI to XCIX and figures 4.27 and 4.28. There was a significant effect ($p<0.05$) of the doses on the moisture content for the samples that were stored 28±2 °C. There was no significant effect ($p>0.05$) of the interaction of the weeks and doses as well as the weeks for the samples stored at 28±2 °C and 4 °C. The effect of the interaction of doses and weeks at both storage conditions led to a general reduction in the moisture content of the samples ($p>0.05$) which had been indicated previously. The observed effect of irradiation, and irradiation and storage weeks, and doses and on the moisture content may be due to depolymerization of some structural components of samples stored at both temperatures (Rico et al., 2010).

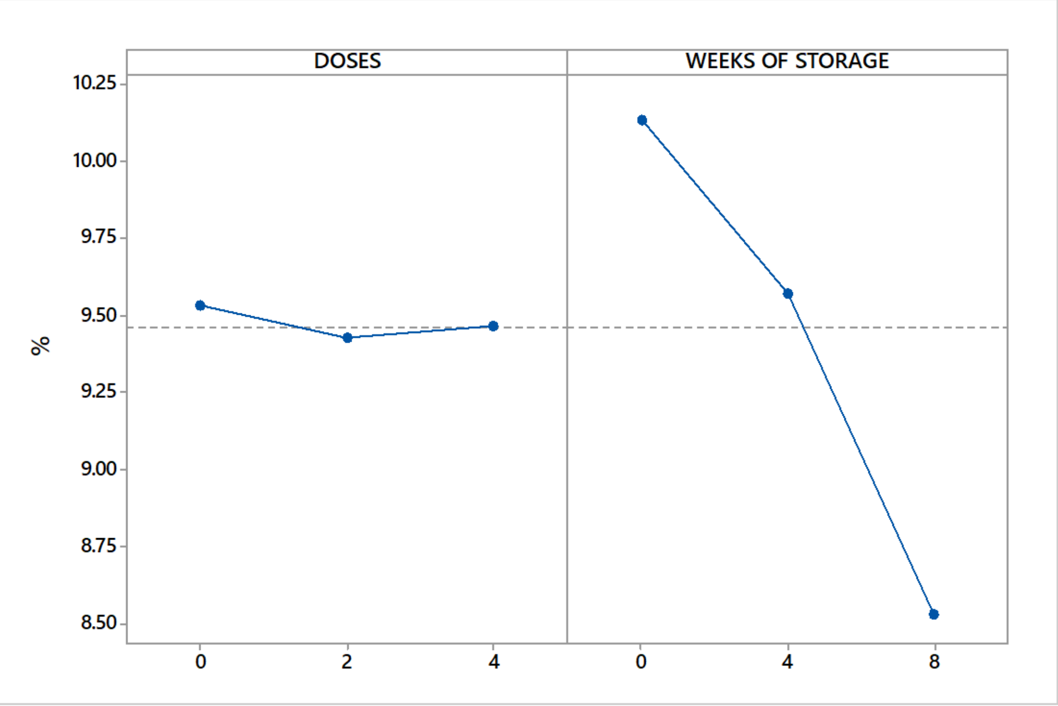

Fig. 4.26. Moisture content (%) after gamma irradiation and during storage at 4 °C

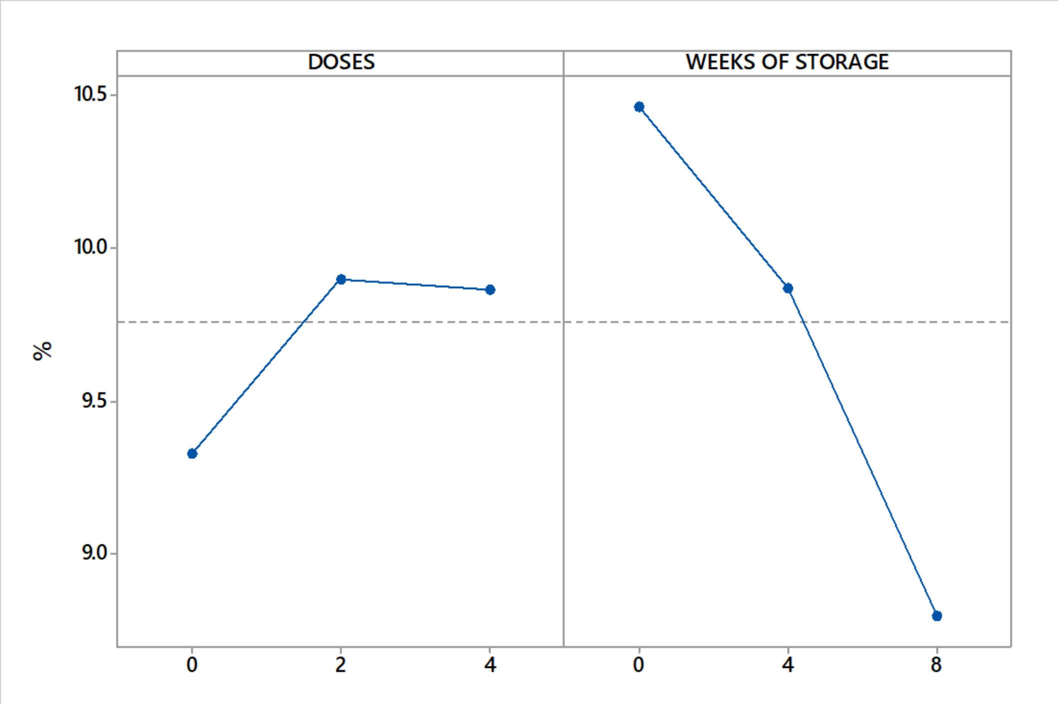

Fig. 4.27. Moisture content (%) after gamma irradiation and during storage at 28±2 °C

4.5.10 Titratable acidity

Appendices XCIV, XCV, LXXXVIII and LXXXIX, Fig. 4.29 and 4.30 indicates the results of the central composite design for the titratable acidity of the samples. The regression coefficients for the TTA of the samples stored at both temperatures were significant only in terms of the storage weeks ($p<0.05$). The observed phenomenon may be due to the conversion of organic acids to sugars (Liu et al., 2010; Rico et al., 2010). Longer weeks of storage weeks will lead to lower values.

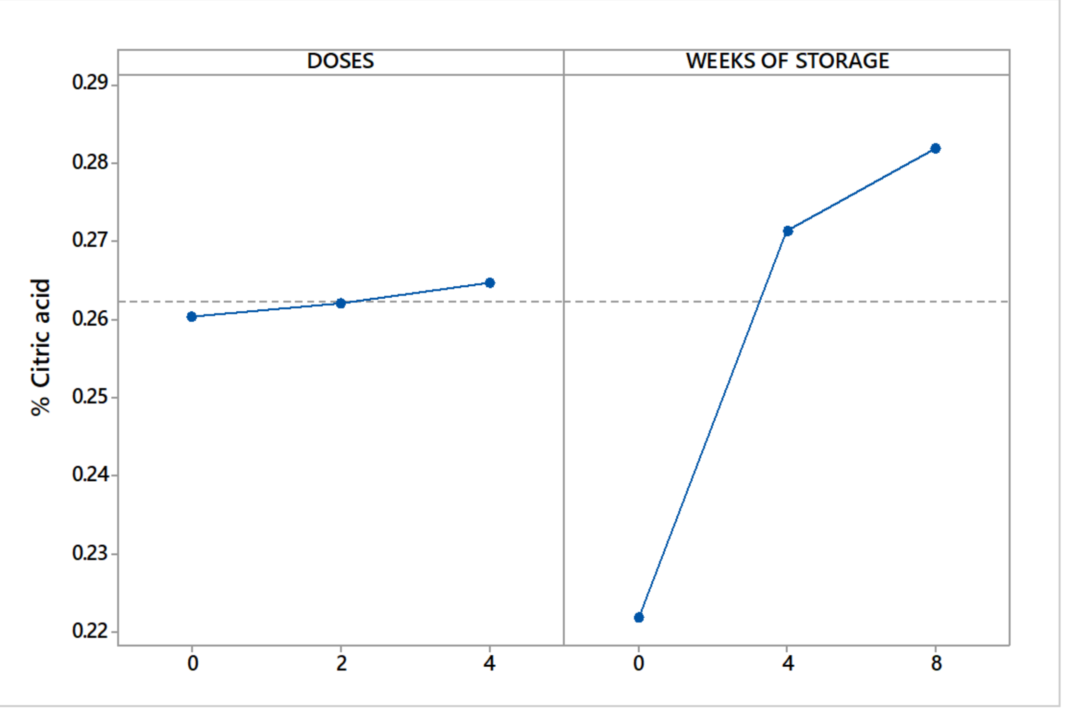

Fig. 4.28. Titratable acidity after gamma irradiation and during storage at 4 °C

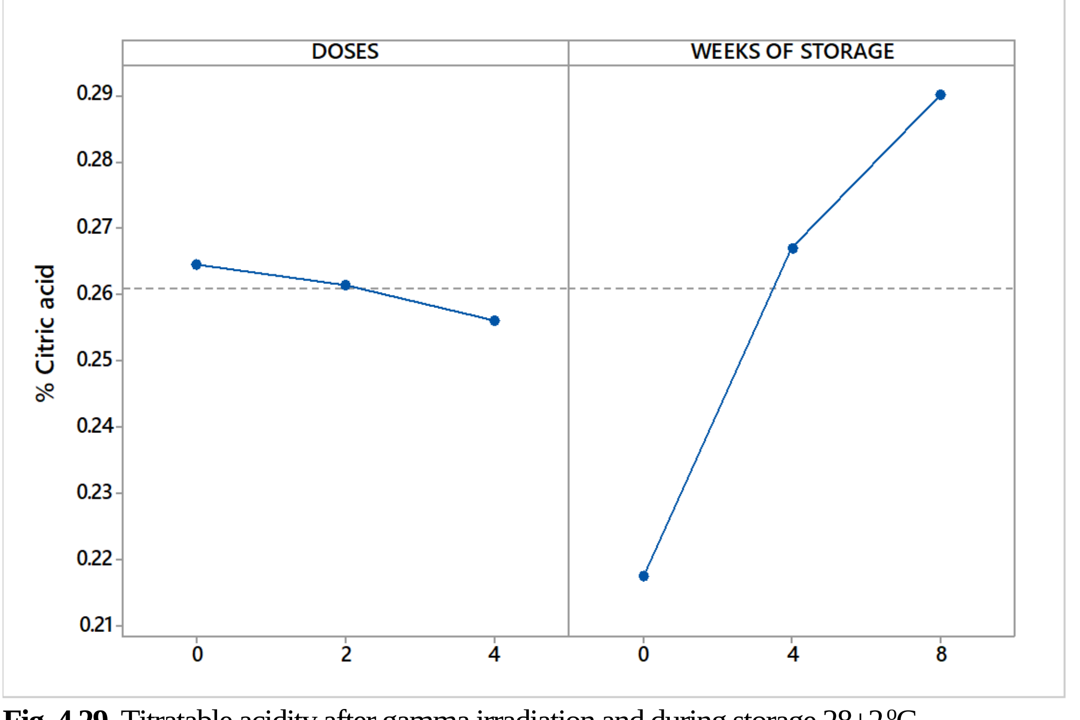

Fig. 4.29. Titratable acidity after gamma irradiation and during storage 28±2 °C

4.5.11 Capsaicin

The regression coefficients as well as the ANOVA of all the samples are depicted in appendices LVII to LXI and Fig. 4.31 and 4.32. The doses of gamma irradiation applied and the storage weeks had significant effect ($p<0.05$) on the capsaicin content of the pepper samples at both temperatures. The observed reduction in the capsaicin content may be due to the oxidation of the capsaicin caused by residual enzymatic activity and the milling process (Wang et al., 2009). The negative values obtained for both the weeks of storage and the interactive effect is an indication of the impact of gamma irradiation and storage weeks that will lead to a reduction in the capsaicin content of the pepper samples with time. Hence, the longer the storage time the less the content of the capsaicin in the pepper samples irrespective of the storage temperature employed.

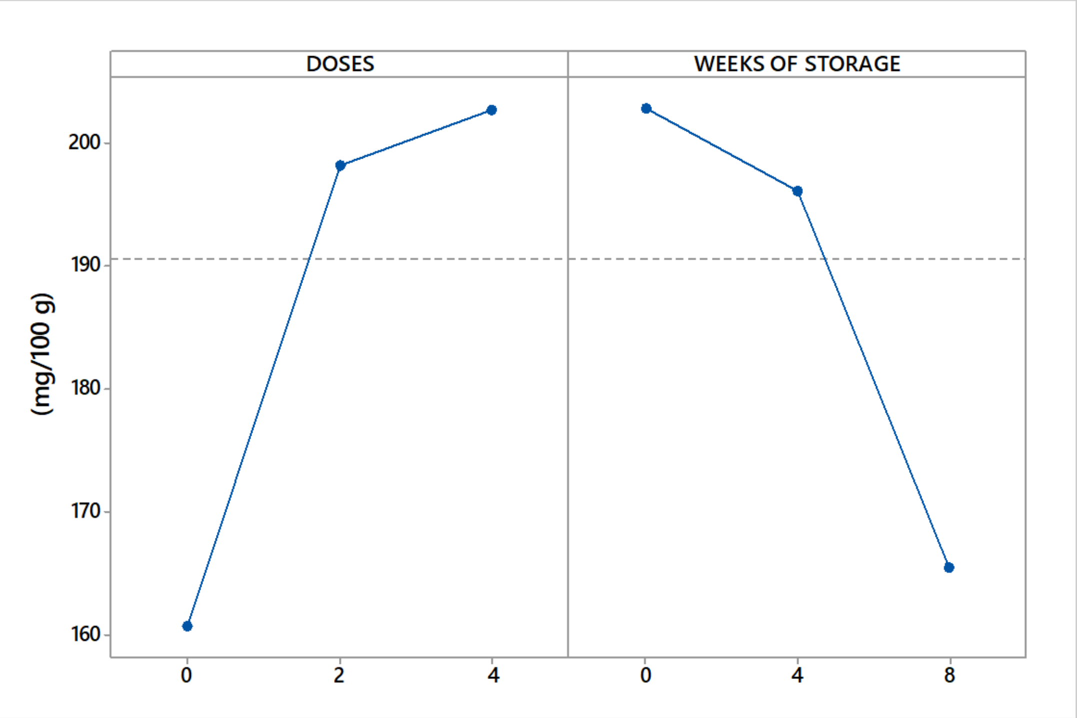

Fig. 4.30. Capsaicin content after gamma irradiation and during storage at 4 ºC

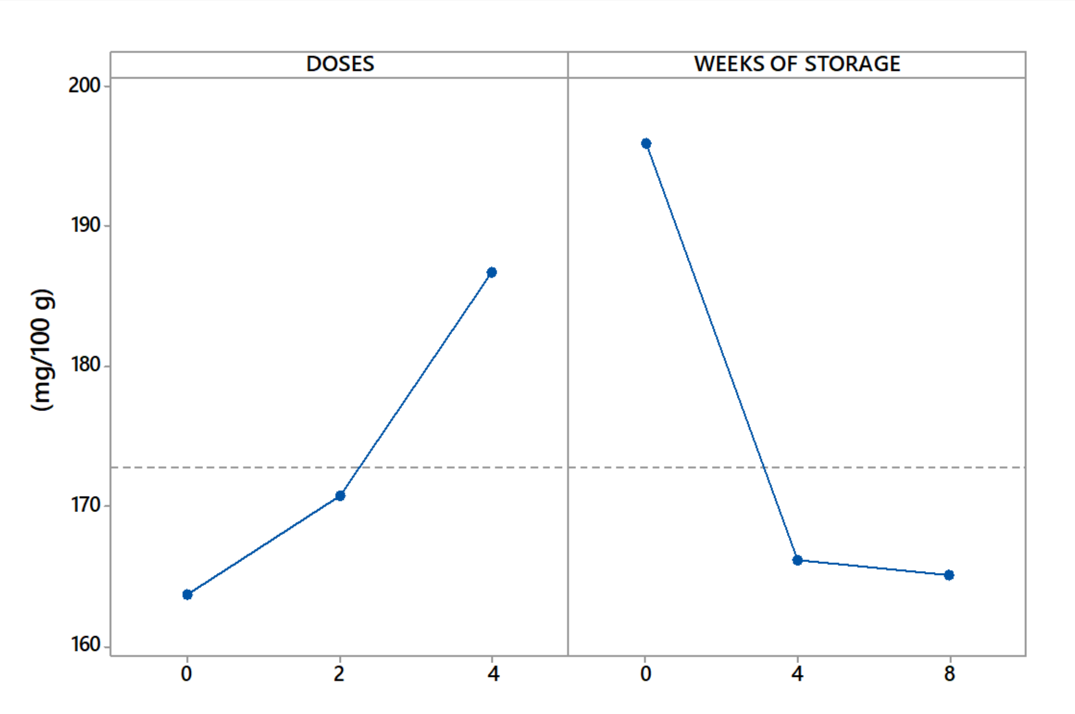

Fig. 4.31. Capsaicin content after gamma irradiation and during storage at 28±2 °C

4.5.12 Dihydrocapsaicin

The regression coefficients, the ANOVA and the interactive effect of doses and weeks for the impact of gamma on the dihydrocapsaicin are displayed in appendices LXXVI to LXXIX and Fig. 4.33 and 4.34. The effect of gamma irradiation doses on the dihydrocapsaicin content of the pepper samples for both temperatures **(**28±2 °C and 4 °C) was significant (<0.05). However, there was a negative effect ($p<0.05$) of weeks or storage for both temperature regimes was observed. There was a significant interactive effect of gamma irradiation doses and storage weeks for both temperatures of storage ($p<0.05$). The observed pattern is similar as stated in capsaicin (Wang et al., 2009, Giuffrida et al., 2014). Higher irradiation doses may lead to higher dihydrocapsaicin content but a reduced content with longer storage periods for both storage temperatures.

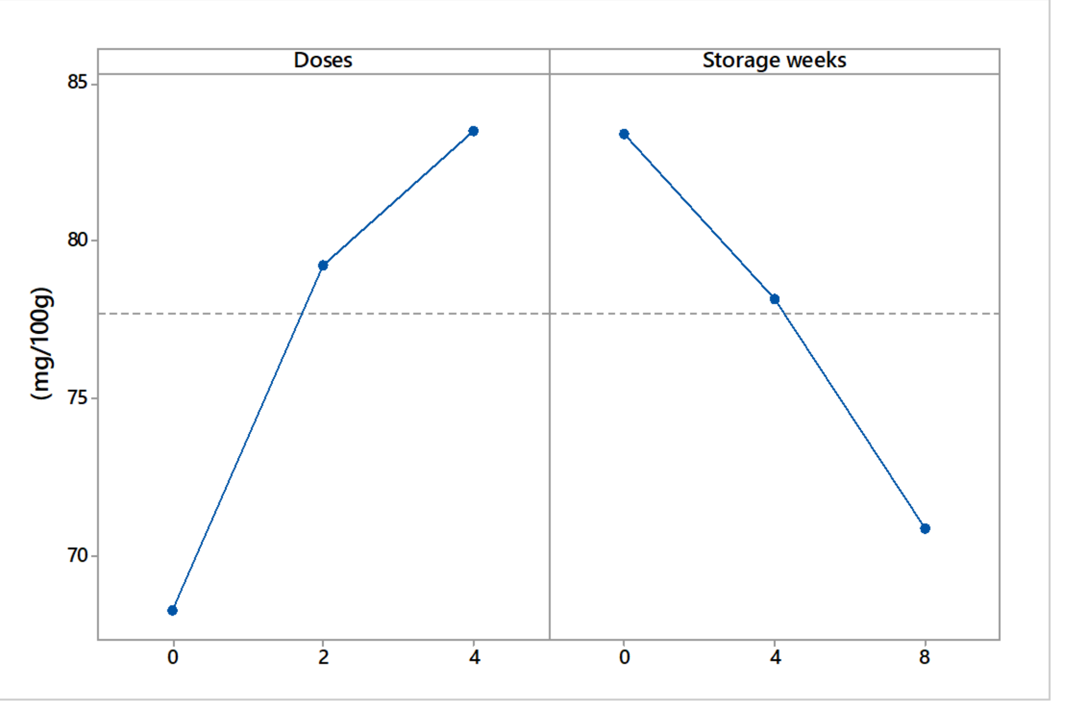

Fig. 4.32. Dihydrocapsaicin content after gamma irradiation and during storage at 4 °C

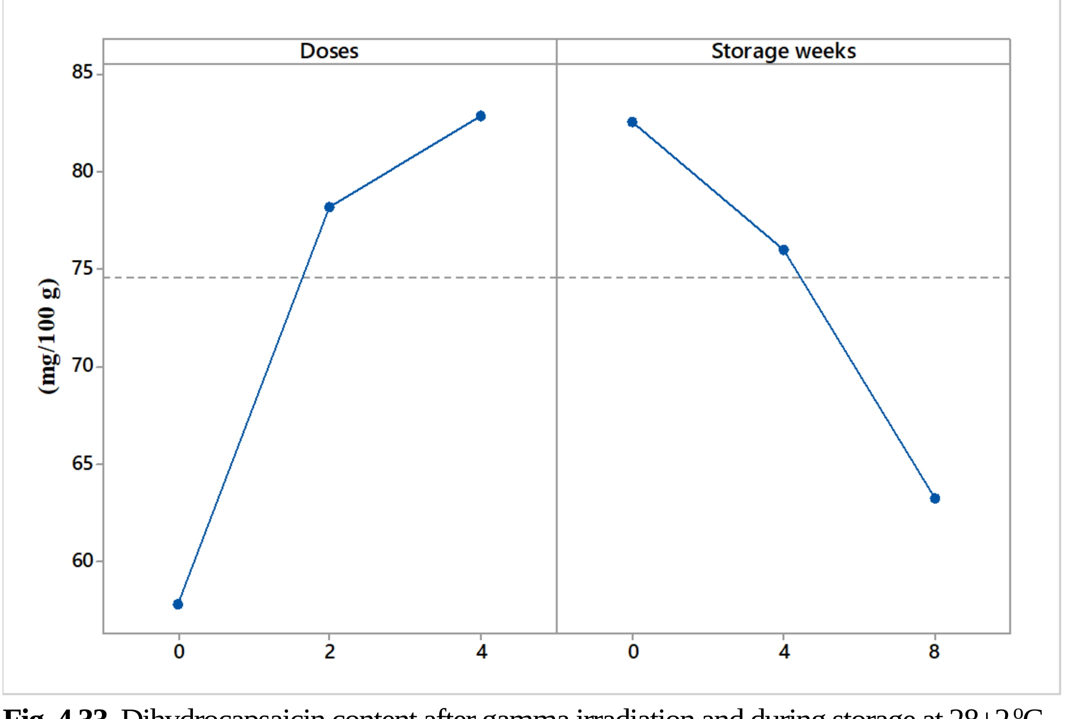

Fig. 4.33. Dihydrocapsaicin content after gamma irradiation and during storage at 28±2 °C

4.5.13 Total capsaicin

The total capsaicinoid content of the samples was based on the addition of the dihydrocapsaicin and capsaicin (Kim et al, 2004). Regression coefficients, ANOVA, the interactive effect of the samples can be found in appendices LXXX to LXXXIII. The doses of gamma irradiation had a significant effect on the total capsaicinoid content of the samples ($p<0.05$). This indicates that the content increased ($p<0.05$) with the doses applied irrespective of the temperature and weeks of storage ($p>0.05$). The weeks of storage led to a reduction in the total capsaicinoid content of the samples but not significant ($p>0.05$). The observed pattern may be due to the behaviour of the capsaicinoids investigated (Wang et al., 2009, Giuffrida et al., 2014).

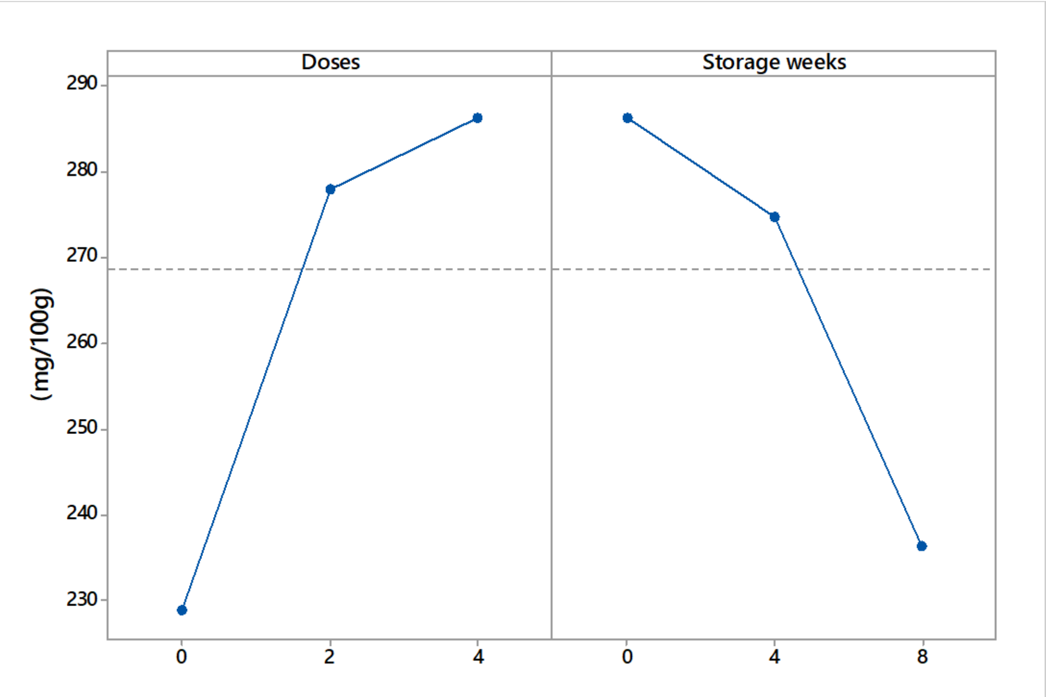

Fig. 4.34. Total capsaicinoids content after gamma irradiation and during storage at 4 °C

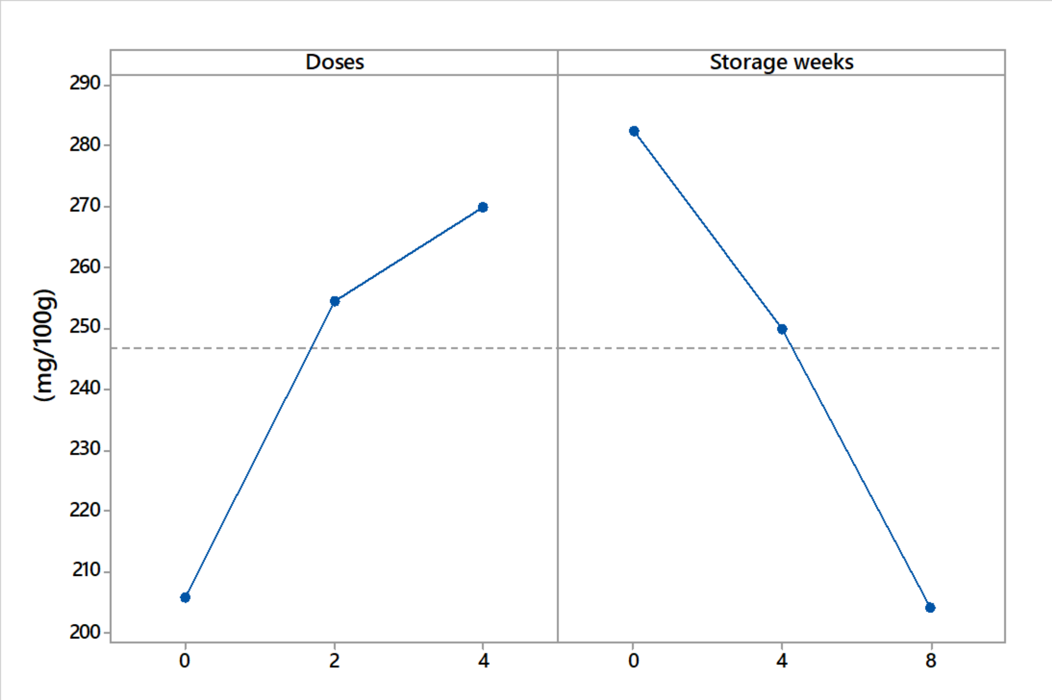

Fig. 4.35. Total capsaicinoids content after gamma irradiation and during storage at 28±2 °C

4.5.14 Scoville Heat Units (SHU)

The regression coefficients, ANOVA and interactive effect of the doses and weeks are indicated in appendices LXXXIV to LXXXVII and Fig. 4.37 and 4.38 for the sample stored at both temperature regimes **(**28±2 °C and 4 °C). There was no significant impact ($p>0.05$) of the doses and storage weeks on the SHU for the samples that were stored at 28±2 °C for effect of doses of irradiation and the weeks of storage as well as the interactive effect of the doses and weeks. However, a reduction of the SHU in the samples was observed irrespective of the storage temperature. A significant effect of gamma irradiation (doses) as well as the weeks of storage on the SHU was observed in the samples that were stored at 4 °C.

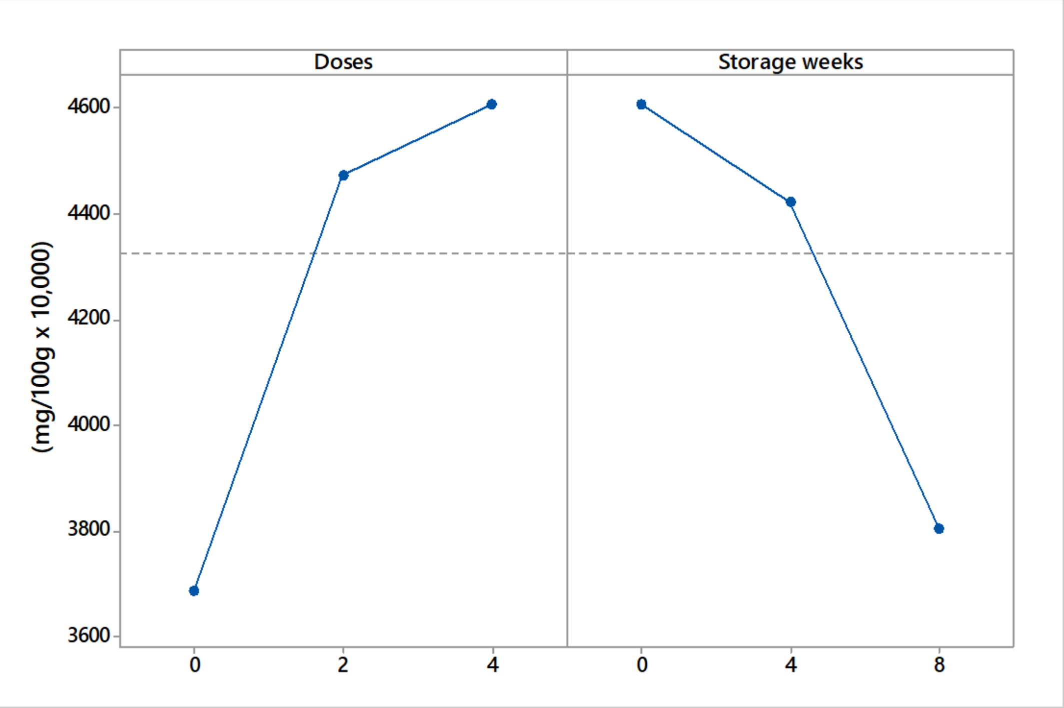

Fig. 4.36. SHU after gamma irradiation and during storage at 4 °C

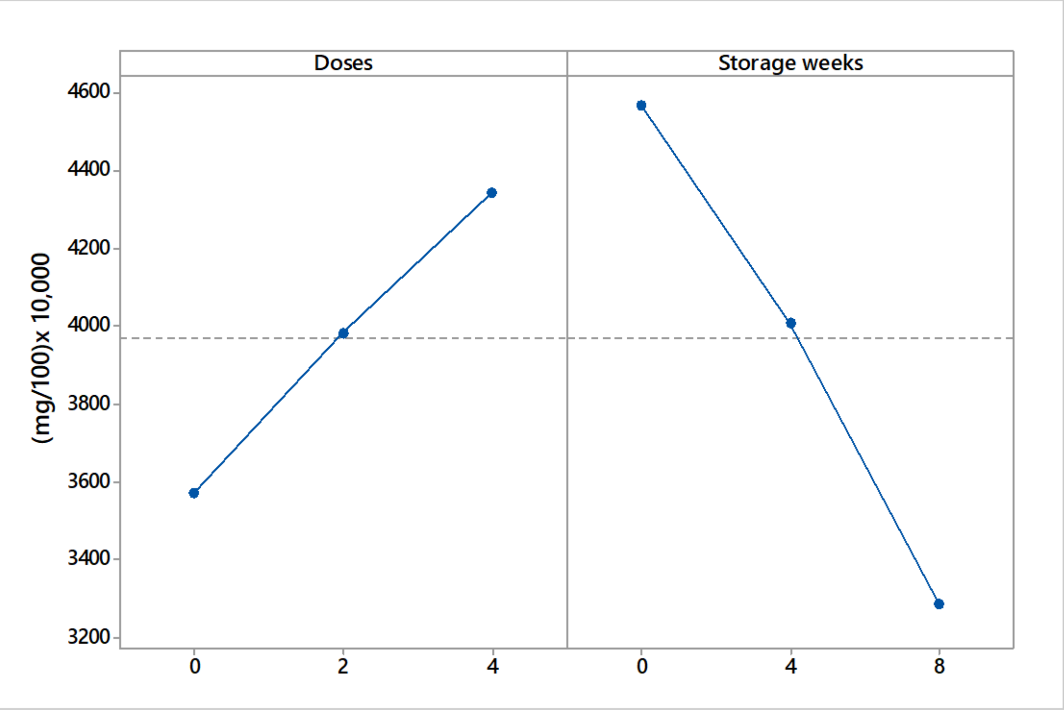

Fig. 4.37. SHU after gamma irradiation and during storage at 28±2 °C

The higher the dose, the higher the SHU (a dose dependent effect on the SHU) of the samples. However, there was a reduction in the SHU per storage weeks. The observed pattern is similar to what was observed in total capsaicinoids (Giuffrida et al., 2014; Wang et al., 2009).

4.5.15 Beta carotene

The carotenoids investigated in this samples were beta carotene, beta cryptoxanthin and capsanthin. The regression coefficients, ANOVA and interactive effect of the doses and weeks of storage for the beta carotene content of the samples can be found in appendices LI to LIII, Fig. 4.39 and 4.40 for the samples stored at 28±2 ^oC and 4 ^oC. Effect of gamma irradiation was significant ($p<0.05$) on the beta carotene content in the samples stored at 28±2 ^oC but not in the samples that were stored at 4 ^oC. The effect of the weeks of storage was significant ($p<0.05$) for all the samples that were stored at the various temperatures. Beta carotene content reduced with storage. The interactive effect of doses and weeks led to reduction in the content of beta carotene in the samples irrespective of the storage temperatures.

These observations may be attributed to the effects of storage temperature, oxidation of the components of the pigments and its structure and the secondary effects of gamma irradiation **(**Guadarrama-Lezama et al., 2014; Giuffrida et al., 2014; Kim et al., 2006; Perez-Galvez and Minguez-Mosquera, 2001; Tang and Chen, 1999; Goda et al., 1995).

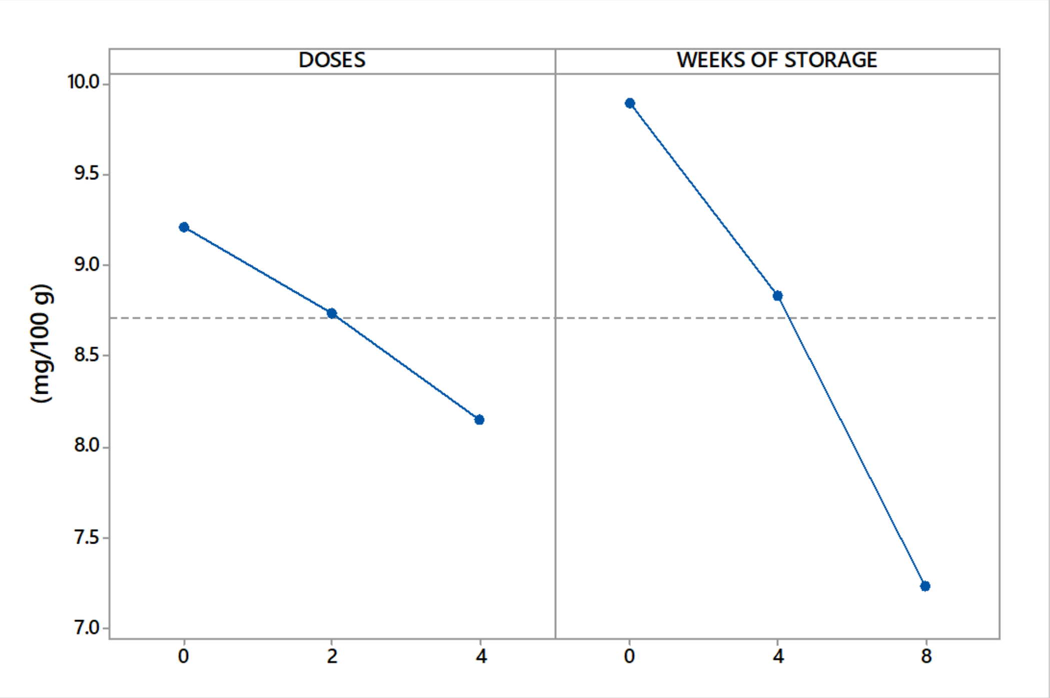

Fig. 4.38. Beta carotene content after gamma irradiation and during storage at 4 °C

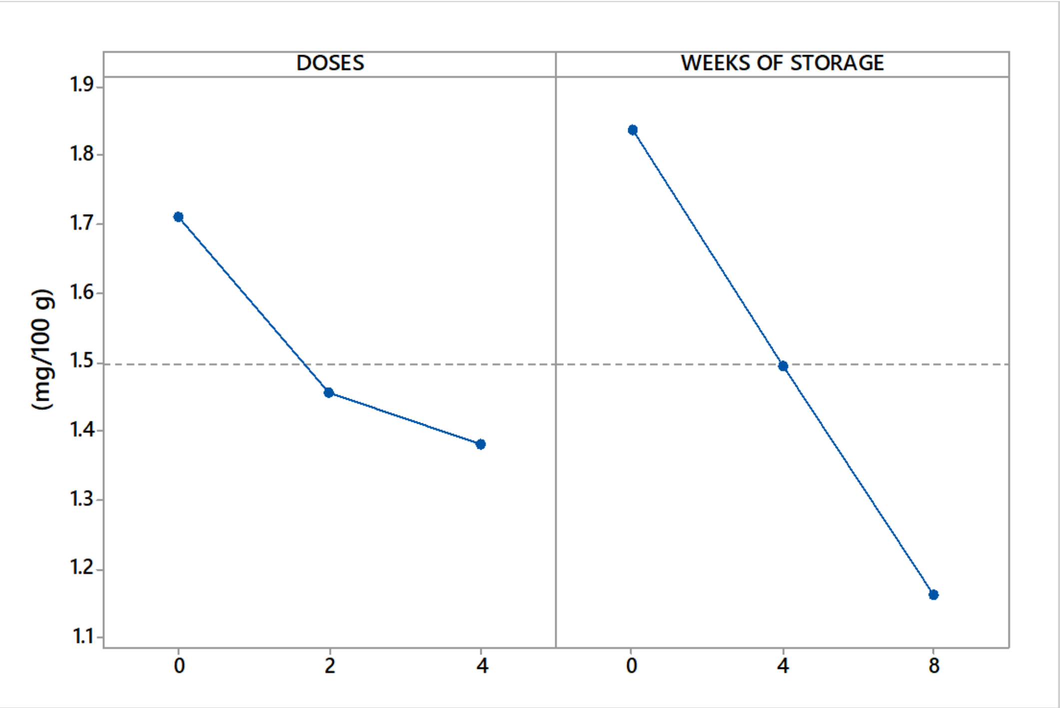

Fig. 4.39. Beta carotene content after gamma irradiation and during storage at 28±2 °C

4.5.16 Beta cryptoxanthin

Beta cryptoxanthin content in the samples were affected significantly ($p<0.05$) by the doses of gamma irradiation applied to the samples, the weeks of storage and the interactive effect of the doses and weeks of storage irrespective of the temperatures of storage employed (appendices LXXII to LXXV, Fig. 4.41 and 4.42). The doses led to the general reduction in the beta cryptoxanthin content of the samples as well as the storage weeks. These observations in beta cryptoxanthin are similar to beta carotene (Guadarrama-Lezama et al., 2014; Giuffrida et al., 2014; Kim et al., 2006; Perez-Galvez and Minguez-Mosquera, 2001; Goda et al., 1995; Tang and Chen, 1999).

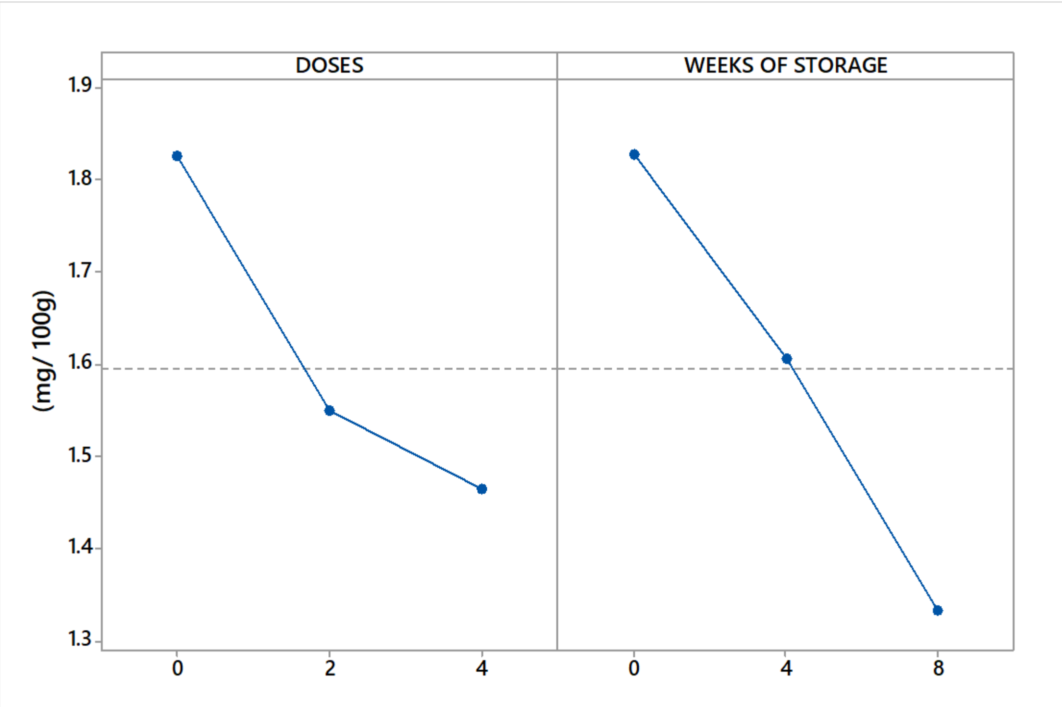

Fig. 4.40. Beta cryptoxanthin content after gamma irradiation and during storage at 4 °C

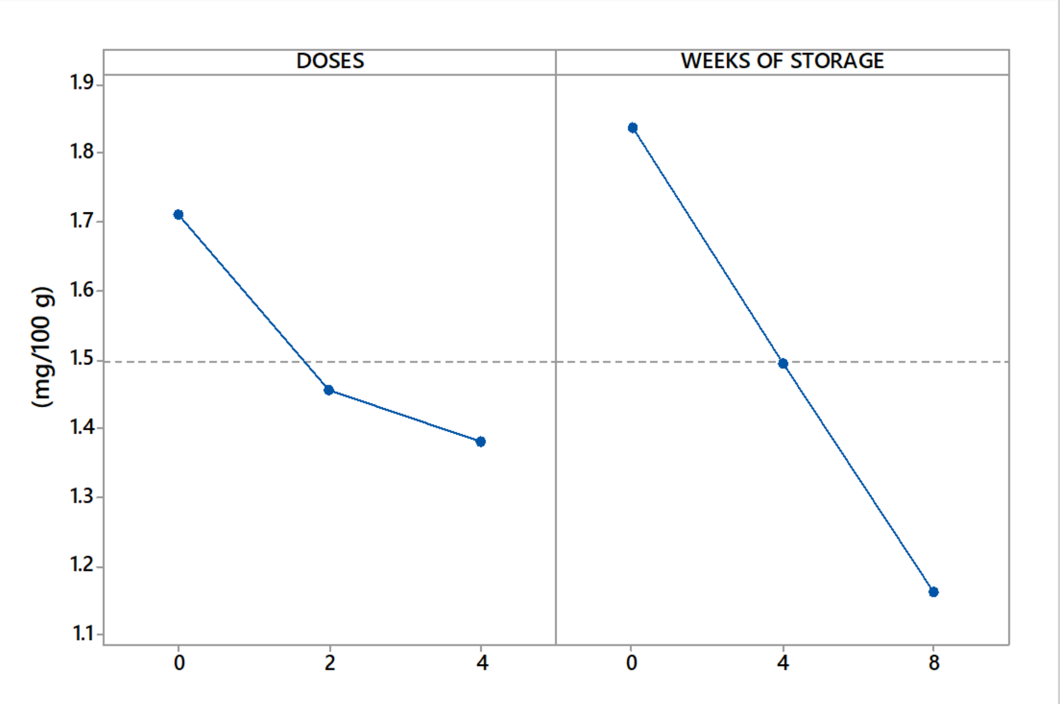

Fig. 4.41. Beta cryptoxanthin content after gamma irradiation and during storage at 28±2 °C.

4.5.17 Capsanthin

The capsanthin content of the samples were affected ($p<0.05$) by the doses and the weeks of storage and (appendices XLVII to L). These led to the general reduction of the content of capsanthin in the samples irrespective of the temperature of storage. However, there was no significant ($p>0.05$) effect of the interaction of the doses and the weeks (appendices XLVII to L; Fig. 4.43 to 4.44). The observed phenomenon in capsanthin is similar to beta carotene (Guadarrama-Lezama et al., 2014; Giuffrida et al., 2014; Kim et al., 2006; Perez-Galvez and Minguez-Mosquera, 2001 Tang and Chen, 1999; Goda et al., 1995).

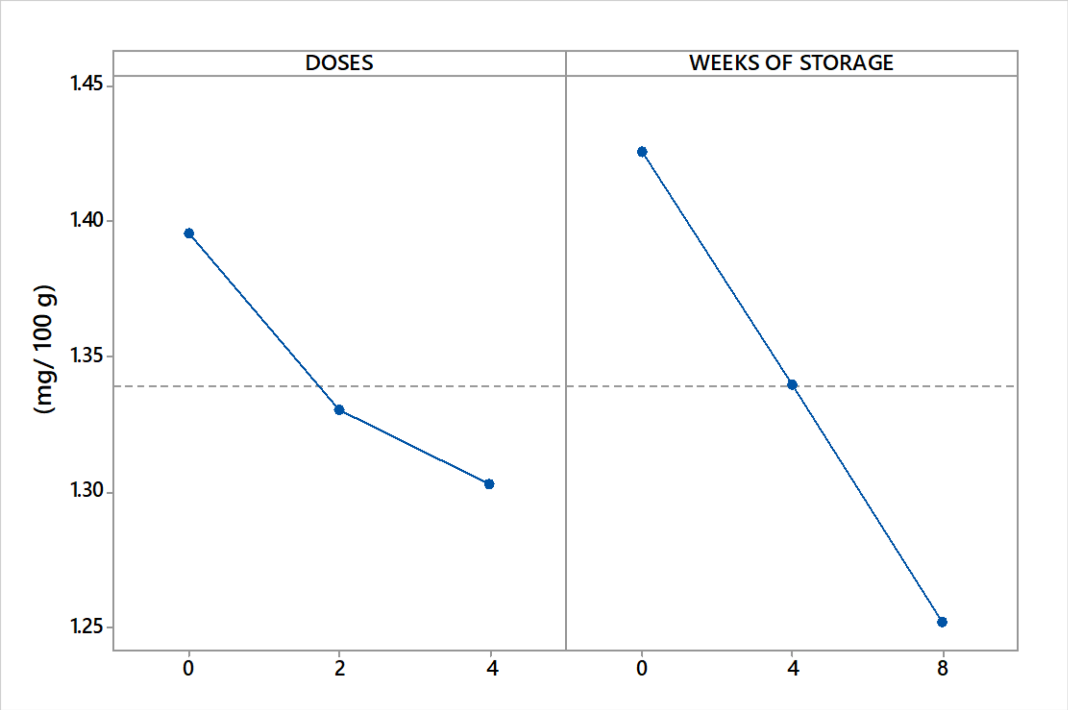

Fig. 4.42. Capsanthin content after gamma irradiation and during storage at 4 ºC.

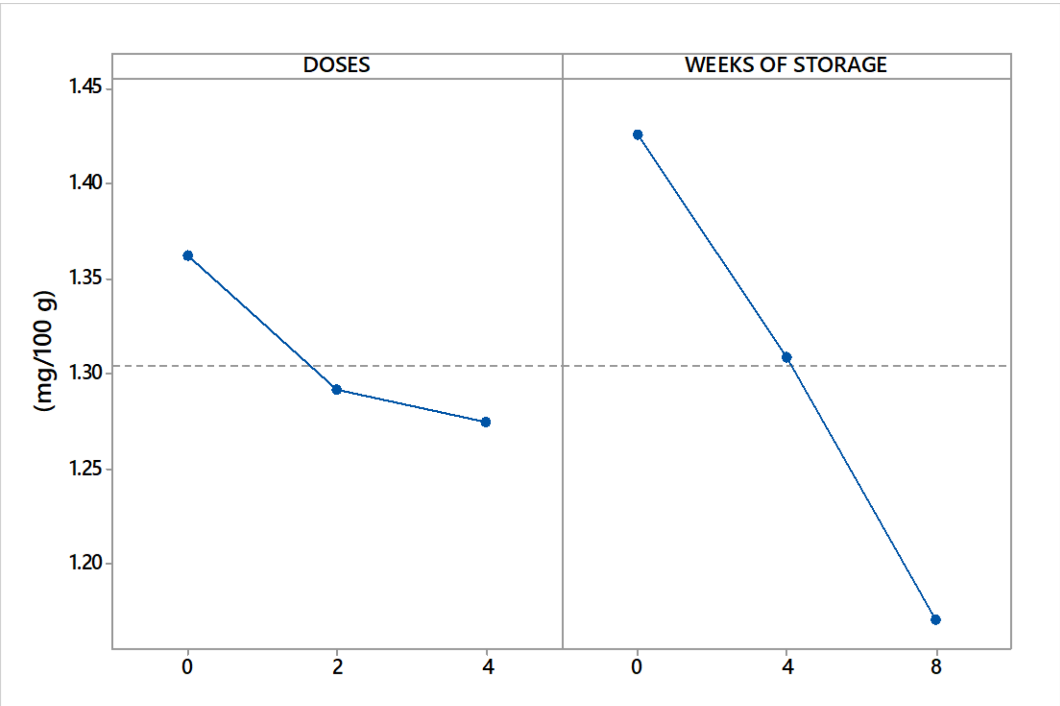

Fig. 4.43. Capsanthin content of gamma irradiation and during storage in Legon-18 stored at 28±2 ºC.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The study was conducted to determine the inactivation effect of gamma irradiation on selected foodborne pathogens associated with low moisture foods in *Capsicum annuum* (Legon-18 pepper) powder and its effect on the quality parameters of the pepper powder. Gamma irradiation, storage temperature and period had significant ($p<0.05$) effects on the inactivation of all the pathogens. Inactivation of the pathogens was dose-dependent. As gamma irradiation dosage increased inactivation rates of microorganisms on the powdered pepper also increased. This was probably due to the level of cellular injuries caused by the increasing doses of gamma irradiation, inability of injured microorganisms to adapt to their surroundings. Post-irradiation radiolysis in the matrix and the effect of storage temperature all may have contributed to the increased rate of microbial inactivation. It was observed that inactivation was more pronounced in the gram-negative microorganisms as compared with the gram-positives probably due to differences in the structural components of gram negatives. Gram-positives have double-stranded DNA which makes them resistant to gamma irradiation as compared with the gram-negatives. Inactivation also increased with increasing storage time. This increased inactivation with progression of storage suggests that lower doses of gamma irradiation can be used for the inactivation of the pathogens if the product will be stored for a longer period. The progression of inactivation with storage could be due to the inability of the pathogens to repair injuries which occurred due to the effects of gamma irradiation and its post effects such as increased radiolysis.

On the quality of the pepper samples the doses of gamma irradiation, the storage temperature and the period of storage significantly ($p<0.05$) affected the colour components of the pepper samples. The dose-dependent effect on the carotenoids (beta carotene, beta cryptoxanthin and capsanthin) determined had a corresponding effect on the colour components of the samples. The red (a* values) components of the samples reduced with storage. The carotenoids (beta carotene and beta cryptoxanthin) responsible for the yellowness of the samples also reduced with storage due to both primary and secondary effect of gamma irradiation, oxidation and temperature. The capsanthin content reduced during storage which had a corresponding effect on the b* values too.

Hue, chroma, total colour change (or difference) and browning index of the samples were all affected by the gamma irradiation, storage and temperature. Due to the degradation of the pigments in the samples responsible for the redness, yellowness and brightness of the colour components, a corresponding effect on the hue, chroma, total colour change and browning index during storage was observed.

The hotness of the pepper samples was based on the presence of dihydrocapsaicin and capsaicin. The hotness of the samples increased due to the effect of gamma irradiation. A dose-dependent effect was observed ($p<0.05$) which led to increased hotness of the pepper samples (Capsaicin and dihydrocapsaicin, total capsaicinoids and Scoville Heat Units) after irradiation. There was a reduction in the two capsaicinoids content of the samples which had a corresponding effect on the total capsaicinoids as well as the Scoville Heat Units.

The carotenoids in the samples were also affected by the irradiation and the length of storage period. There was a decreasing effect which was dose and length of storage-dependent.

5.2 Conclusions

The results of the study suggest that gamma irradiation could be used to decontaminate microbial pathogens in pepper powder. The effects vary with the dosage of the irradiation. The impact of irradiation on the inactivation progresses during storage of the pepper samples. Inactivation by gamma irradiation is more pronounced in gram-negative microorganisms than in the gram-positives organisms.

Gamma irradiation had effects on the quality parameters of pepper powder, specifically on the color components and hotness index. The color parameters of L*, a* and b* values increased with increasing doses of gamma irradiation immediately after irradiation, however, these values reduced during storage which was more pronounced at 28 ^{o}C. A corresponding effect of gamma irradiation and storage on L*, a* and b* values were observed in the hue, chroma, browning index and total colour change (difference) of the samples. Capsaicinoids, total capsaicinoids and SHU values varied with irradiation doses which reduced during storage. The carotenoids analyzed reduced with increasing doses of gamma irradiation as well as increasing time of storage. All the quality parameters measured reduced with storage.

5.3 Recommendations

1. Gamma irradiation at 5 kGy can be used as an immediate decontaminating dose for Legon-18 pepper. However, 2 kGy can be used for long storage period for less effects of gamma irradiation on the quality parameters.
2. A study should be conducted on the effect of gamma irradiation on the biochemical pathways of macromolecules of the pepper samples.
3. Further studies should be conducted on the effect of gamma irradiation on the flavour compounds and sensory properties of Legon-18 pepper powder.

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APPENDICES

Appendix I: Estimated Regression Coefficients for *Salmonella* Typhimurium at 4 °C

Term	Coefficient	SE Coefficient	T	P-value
Constant	6.49945	0.592225	10.975	0*
Doses	-1.01628	0.454897	-2.234	0.061**
Days	-0.01864	0.030326	-0.615	0.558**
Dose *Doses	0.15147	0.100218	1.511	0.174**
Days*Days	-0.00045	0.000445	-1.008	0.347**
Doses* Days	-0.01021	0.005552	-1.839	0.109**
S=0.6662	R^2=92.50%	R^2 (adjusted)= 87.20%		

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

$$log\ cfu/g = 6.49945 - 1.01628x - 0.01864y + 0.15147x^2 - 0.00045y^2 - 0.01021xy$$

Where x=doses of gamma irradiation, y=days of storage

Appendix II: Analysis of Variance for *Salmonella* Typhimurium at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F ratio	P-value
Regression	5	38.4606	38.46057	7.69211	17.33	0.001*
Linear	2	35.8491	2.64949	1.32475	2.98	0.116**
Square	2	1.1109	1.11088	0.55544	1.25	0.343**
interaction	1	1.5006	1.50062	1.50062	3.38	0.109**
Residual error	7	3.1068	3.10683	0.44383		
Lack of fit	3	3.0786	3.07855	1.02618	145.15	0*
Pure Error	4	0.0283	0.02828	0.00707		
Total	12	41.5674				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix III: Estimated Regression Coefficients for *Salmonella* Typhimurium at 28±2 °C

Term	Coefficient	SE Coefficient	T	P value
Constant	6.69101	0.25276	26.472	0*
Doses	-0.98093	0.194149	-5.052	0.001*
Days	-0.05778	0.012943	-4.464	0.003*
Dose *Doses	0.06763	0.042773	1.581	0.158
Days*Days	-0.00082	0.00019	-4.293	0.004*
Doses* Days	0.01021	0.002369	4.308	0.004*
S= 0.2843	R^2=98.80%	R^2 (adjusted)= 98.00%		

Values marked *are statistically significant ($p<0.05$).

$$log\ cfu/g = 6.69101 - 0.98093x - 0.05778y + 0.06763x^2 - 0.00082y^2 + 0.01021xy$$

Where x=doses of gamma irradiation, y=days of storage

Appendix IV: Analysis of Variance for *Salmonella* Typhimurium at 28±2 ºC

Source	DF	Seq SS	Adj. SS	Adj. MS	F ratio	P value
Regression	5	47.1599	47.15987	9.43197	116.66	0*
Linear	2	44.169	4.37994	2.18997	27.09	0.001*
Square	2	1.4902	1.49023	0.74511	9.22	0.011*
interaction	1	1.5006	1.50063	1.50063	18.56	0.004*
Residual error	7	0.5659	0.56593	0.08085		
Lack of fit	3	0.5305	0.53053	0.17684	19.98	0.007*
Pure Error	4	0.0354	0.0354	0.00885		
Total	12	47.7258				

Values marked *are statistically significant ($p<0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MSS-Adjusted mean sum of squares.

Appendix V: Estimated Regression Coefficients for *Escherichia coli* at 4 ºC

Term	Coefficient	SE Coefficient	T	P value
Constant	6.62348	0.175951	37.644	0*
Doses	-0.86001	0.135151	-6.363	0*
Days	-0.08678	0.00901	-9.631	0*
Dose *Doses	0.01448	0.029775	0.486	0.642**
Days*Days	-0.00038	0.000132	-2.872	0.024*
Doses* Days	0.01313	0.001649	7.957	0*
S=0.1979	R^2=99.40%	R^2 (adjusted)= 98.90%		

Values marked *are statistically significant ($p<0.05$).

log cfu/g = $6.62348-0.86001x -0.08678y + 0.01448x^2-0.00038y^2-0.01313xy$
Where x=doses of gamma irradiation, y=days of storage

Appendix VI: Analysis of Variance for *Escherichia coli* at 4 ºC

Source	DF	Seq SS	Adj. SS	Adj MS	F ratio	P value
Regression	5	44.3224	44.32239	8.86448	226.27	0*
Linear	2	41.5017	6.15866	3.07933	78.6	0*
Square	2	0.3401	0.3401	0.17005	4.34	0.059**
interaction	1	2.4806	2.48063	2.48063	63.32	0*
Residual error	7	0.2742	0.27424	0.03918		
Lack of fit	3	0.21	0.20996	0.06999	4.36	0.095**
Pure Error	4	0.0643	0.06428	0.01607		
Total	12	44.5966				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix VII: Estimated Regression Coefficients for *Escherichia coli* at 28±2 ºC

Term	Coefficient	SE Coefficient	T	P value
Constant	6.26468	0.18587	33.705	0*
Doses	-1.04197	0.142769	-7.298	0*
Days	-0.10613	0.009518	-11.151	0*
Dose *Doses	0.02039	0.031453	0.648	0.538**
Days*Days	0.00004	0.00014	0.251	0.809**
Doses* Days	0.01604	0.001742	9.207	0*
S=0.2091	R^2=99.20%		R^2 (adjusted)= 98.60%	

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

log cfu/g = $6.26468-1.04197x -0.10613y + 0.02039x^2 +0.00004y^2-0.01604xy$
Where x=doses of gamma irradiation, y=days of storage

Appendix VIII: Analysis of Variance for *Escherichia coli* at 28±2 ºC

Source	DF	Seq SS	Adj. SS	Adj. MS	F ratio	P value
Regression	5	37.1975	37.1975	7.4395	170.17	0*
Linear	2	33.4608	9.15531	4.57765	104.71	0*
Square	2	0.031	0.03104	0.01552	0.35	0.713**
interaction	1	3.7056	3.70563	3.70563	84.76	0*
Residual error	7	0.306	0.30603	0.04372		
Lack of fit	3	0.2679	0.26791	0.0893	9.37	0.028*
Pure Error	4	0.0381	0.03812	0.00953		
Total	12	37.5035				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix IX: Estimated Regression Coefficients for *Bacillus cereus* at 4 ºC

Term	Coefficient	SE Coefficient	T	P value

Constant	5.88842	0.295015	19.96	0*
Doses	-0.45068	0.226606	-1.989	0.087**
Days	-0.0166	0.015107	-1.099	0.308**
Dose *Doses	0.05944	0.049923	1.191	0.273**
Days*Days	-0.00007	0.000222	-0.312	0.764**
Doses* Days	-0.00537	0.002766	-1.944	0.093**
S= 0.3319	R^2=92.30%		R^2 (adjusted)= 86.90%	

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

log cfu/g = $5.88842-0.45068x -0.0166y +0.05944x^2-0.00007y^2-0.00537xy$
Where x=doses of gamma irradiation, y=days of storage

Appendix X: Analysis of Variance for *Bacillus cereus* at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F ratio	P value
Regression	5	9.2929	9.29291	1.858583	16.88	0.001*
Linear	2	8.7182	0.66389	0.331943	3.01	0.114**
Square	2	0.1587	0.15872	0.079361	0.72	0.519**
interaction	1	0.416	0.41602	0.416025	3.78	0.093**
Residual error	7	0.771	0.77096	0.110138		
Lack of fit	3	0.7516	0.75164	0.250548	51.87	0.001**
Pure Error	4	0.0193	0.01932	0.00483		
Total	12	10.0639				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XI: Estimated Regression Coefficients for *Bacillus cereus* at 28±2 °C

Term	Coefficient	SE Coefficient	T	P value
Constant	6.20129	0.212514	29.181	0*
Doses	-0.92846	0.163235	-5.688	0.001*
Days	0.01171	0.010882	1.076	0.317**
Dose *Doses	0.14534	0.035962	4.042	0.005*
Days*Days	-0.00057	0.00016	-3.571	0.009*
Doses* Days	-0.00571	0.001992	-2.865	0.024*
S=0.2391	R^2 = 97.30%		R^2 (adjusted)= 95.40%	

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

log cfu/g = $6.20129-0.92846x+ 0.01171y +0.14534x^2-0.00057y^2-0.00571xy$
Where x=doses of gamma irradiation, y=days of storage

Appendix XII: Analysis of Variance for *Bacillus cereus* at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F ratio	P value
Regression	5	14.3486	14.34858	2.869715	50.21	0*

Linear	2	12.6701	1.85037	0.925187	16.19	0.002*
Square	2	1.2093	1.20927	0.604633	10.58	0.008*
interaction	1	0.4692	0.46923	0.469225	8.21	0.024*
Residual error	7	0.4001	0.40006	0.057151		
Lack of fit	3	0.3801	0.38014	0.126712	25.44	0.005*
Pure Error	4	0.0199	0.01992	0.00498		
Total	12	14.7486				

Values marked *are statistically significant ($p<0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MSS-Adjusted mean sum of squares.

Appendix XIII: Estimated Regression Coefficients for *Listeria monocytogenes* at 4 °C

Term	Coefficient	SE Coefficient	T	P value
Constant	6.40977	0.436974	14.669	0*
Doses	-1.42181	0.335646	-4.236	0.004*
Days	-0.01718	0.022376	-0.768	0.468**
Dose *Doses	0.27608	0.073946	3.734	0.007*
Days*Days	-0.00028	0.000329	-0.848	0.425**
Doses* Days	-0.0145	0.004096	-3.54	0.009*
S=0.4916	R^2= 96.10%		R^2 (adjusted)= 93.30%	

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$

log cfu/g = $6.40977-1.42181x-0.01718y+0.27608x^2-0.00028y^2-0.0145xy$
Where x=doses of gamma irradiation, y=days of storage

Appendix XIV: Analysis of Variance *Listeria monocytogenes* at 4 °C

Source	DF	Seq SS	Adj. SS	Adj.MS	F ratio	P value
Regression	5	0.009	41.43633	8.28727	34.3	0*
Linear	2	34.9472	4.8597	2.42985	10.06	0.009*
Square	2	3.4615	3.46152	1.73076	7.16	0.02*
interaction	1	3.0276	3.0276	3.0276	12.53	0.009*
Residual error	7	1.6914	1.69144	0.24163		
Lack of fit	3	1.6632	1.66316	0.55439	78.41	0.001*
Pure Error	4	0.0283	0.02828	0.00707		
Total	12	43.1278				

Values marked *are statistically significant ($p<0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MSS-Adjusted mean sum of squares.

Appendix XV: Estimated Regression Coefficients for *Listeria monocytogenes* at 28±2 °C

Term	Coefficient	SE Coefficient	T	P value
Constant	6.01029	0.37126	16.189	0*
Doses	-1.51086	0.28517	-5.298	0.001*
Days	-0.01395	0.019011	-0.734	0.487**

Dose *Doses	0.29522	0.062826	4.699	0.002*
Days*Days	-0.00028	0.000279	-0.991	0.355**
Doses* Days	-0.01325	0.00348	-3.807	0.007*
S=0.4176	R^2=96.80%		R^2(adjusted)= 94.50%	

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

log cfu/g = 6.01029-1.51086*x*-0.01395*y*+0.29522x^2-0.00028y^2-0.01325*xy*
Where x=doses of gamma irradiation, y=days of storage

Appendix XVI: Analysis of Variance for *Listeria monocytogenes* at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj.MS	F ratio	P value
Regression	5	36.7905	36.79052	7.3581	42.19	0*
Linear	2	30.281	5.34927	2.67463	15.33	0.003*
Square	2	3.9815	3.98145	1.99073	11.41	0.006*
interaction	1	2.5281	2.5281	2.5281	14.49	0.007*
Residual error	7	1.221	1.22096	0.17442		
Lack of fit	3	1.1848	1.18476	0.39492	43.64	0.002*
Pure Error	4	0.0362	0.0362	0.00905		
Total	12					

Values marked *are statistically significant (p<0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XVII: Estimated Regression Coefficients for *Staphylococcus aureus* at 4 °C

Term	Coefficient	SE Coefficient	T	P value
Constant	6.22641	0.326483	19.071	0*
Doses	-0.9313	0.250776	-3.714	0.008*
Days	-0.06736	0.016718	-4.029	0.005*
Dose *Doses	-0.00207	0.055248	-0.037	0.971**
Days*Days	-0.00054	0.000246	-2.187	0.065**
Doses* Days	0.01354	0.003061	4.425	0.003*
S	R^2=97.60%		R^2 (adjusted)= 95.90%	

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

log cfu/g = 6.22641-0.9313*x*-0.06736*y*-0.00207x^2-0.00054y^2+0.01354*xy*
Where x=doses of gamma irradiation, y=days of storage

Appendix XVIII: Analysis of Variance for *Staphylococcus aureus* at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F ratio	P value
Regression	5	38.6157	38.61567	7.72313	57.26	0*
Linear	2	35.2104	4.82983	2.41491	17.9	0.002*
Square	2	0.7646	0.76463	0.38232	2.83	0.125**

interaction	1	2.6406	2.64063	2.64063	19.58	0.003*
Residual error	7	0.9442	0.9442	0.13489		
Lack of fit	3	0.9049	0.90488	0.30163	30.68	0.003*
Pure Error	4	0.0393	0.03932	0.00983		
Total	12	39.5599				

Values marked *are statistically significant ($p<0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XIX: Estimated Regression Coefficients for *Staphylococcus aureus* at 28±2 °C

Term	**Coefficient**	**SE Coefficient**	**T**	**P value**
Constant	6.65463	0.525041	12.674	0*
Doses	-1.33263	0.403292	-3.304	0.013*
Days	-0.03545	0.026886	-1.319	0.229**
Dose *Doses	0.11409	0.088849	1.284	0.24**
Days*Days	-0.00025	0.000395	-0.643	0.541**
Doses* Days	-0.00254	0.004922	-0.516	0.621**
S=0.5906	R^2=94.10%	R^2 (adjusted)= 90.00%		

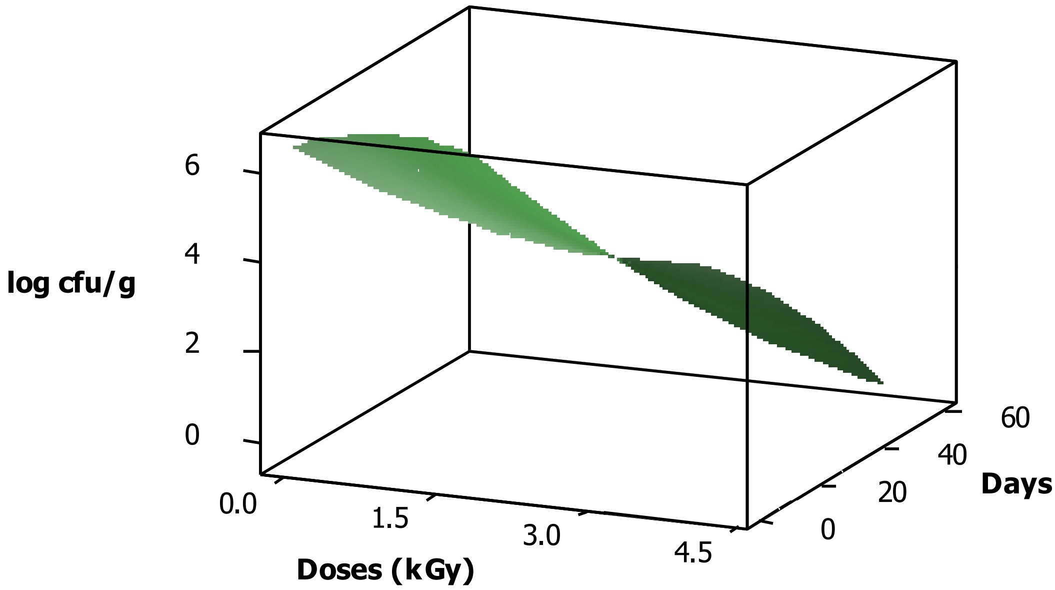
Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

log cfu/g = $6.65463-1.33263x-0.03545y+0.11409x^2-0.00025y^2+-0.00254xy$
Where x=doses of gamma irradiation, y=days of storage

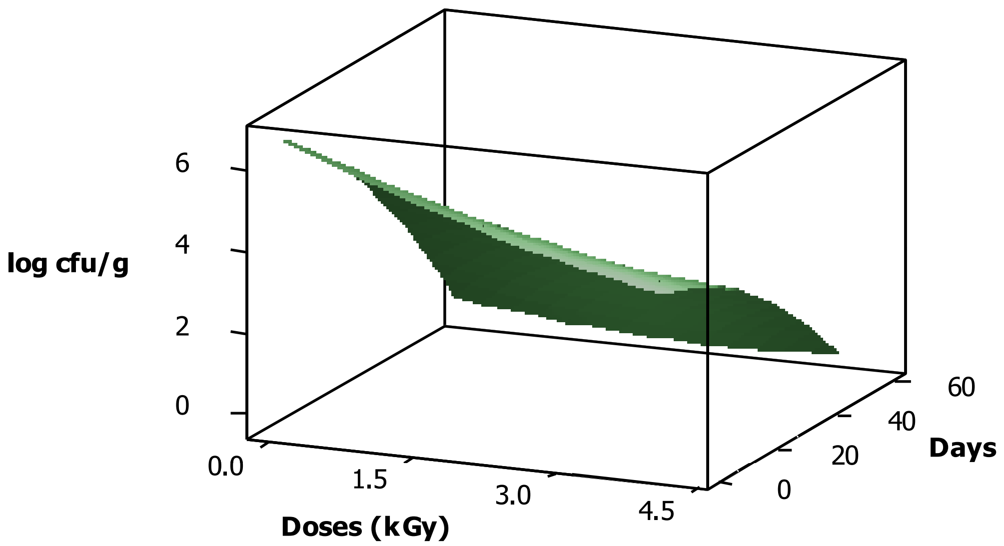
Appendix XX: Analysis of Variance for *Staphylococcus aureus* at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F ratio	P value
Regression	5	39.2524	39.25239	7.85048	22.5	0*
Linear	2	38.5744	5.03934	2.51967	7.22	0.02*
Square	2	0.5849	0.58494	0.29247	0.84	0.472**
interaction	1	0.093	0.09302	0.09302	0.27	0.621**
Residual error	7	2.4419	2.44192	0.34885		
Lack of fit	3	2.4221	2.42212	0.80737	163.11	0*
Pure Error	4	0.0198	0.0198	0.00495		
Total	12	41.6943				

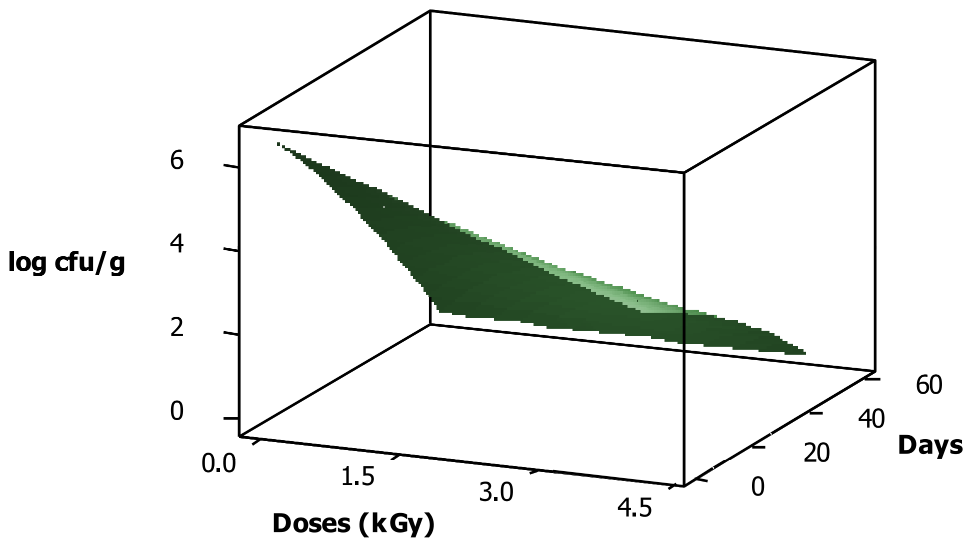
Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.



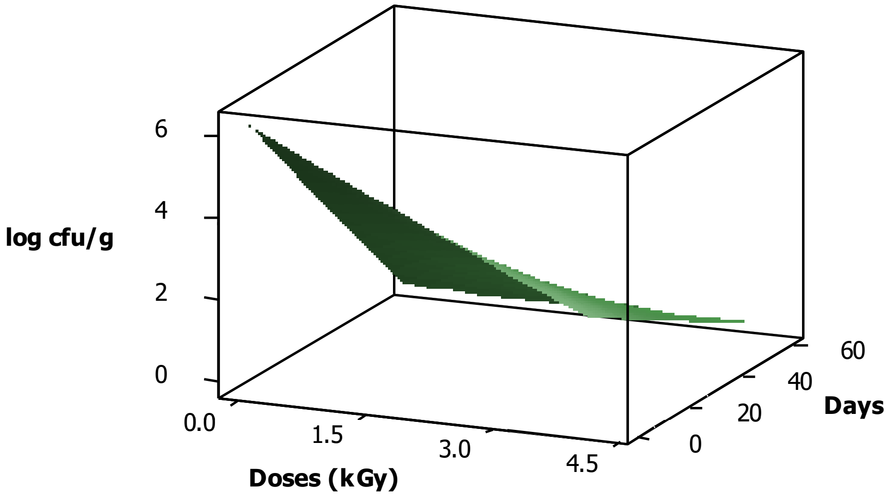
Appendix XXI: Effect of gamma irradiation and storage on the inactivation of S. Typhimurium at 4 °C



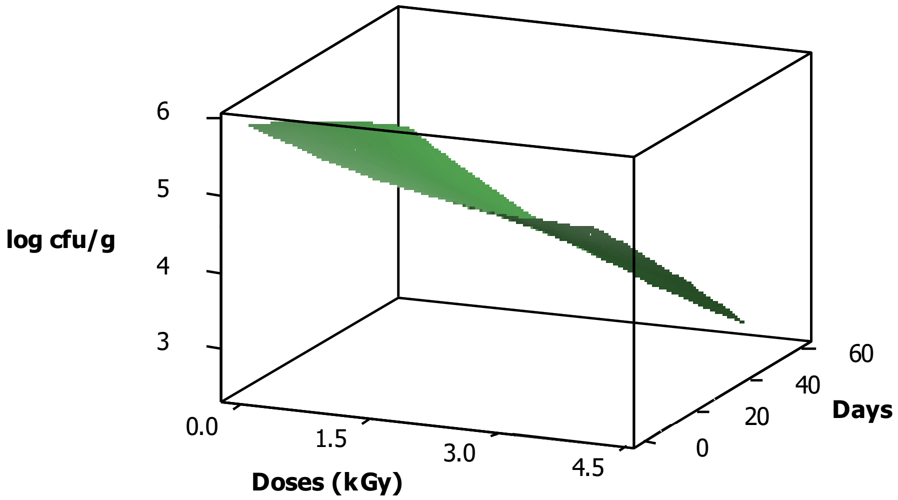
Appendix XXII: Effect of gamma irradiation and storage on the inactivation of *S. typhirium* at 28±2 °C



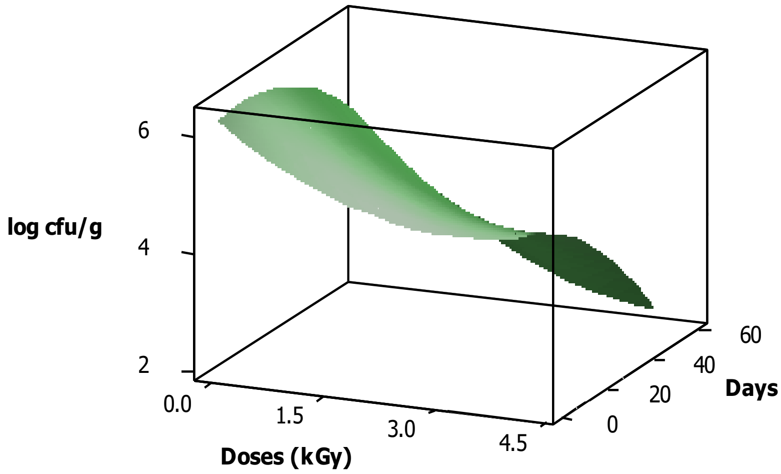
Appendix XXIII: Response surface for the inactivation *E. coli* at 4 °C



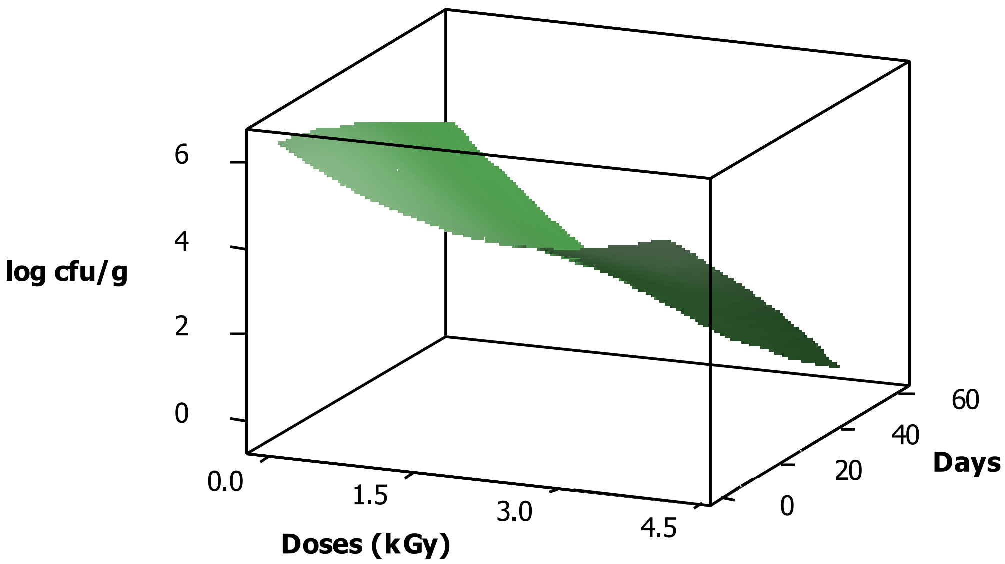
Appendix XXIV: Effect of gamma irradiation and storage on the inactivation of *E. coli* at 28±2 °C



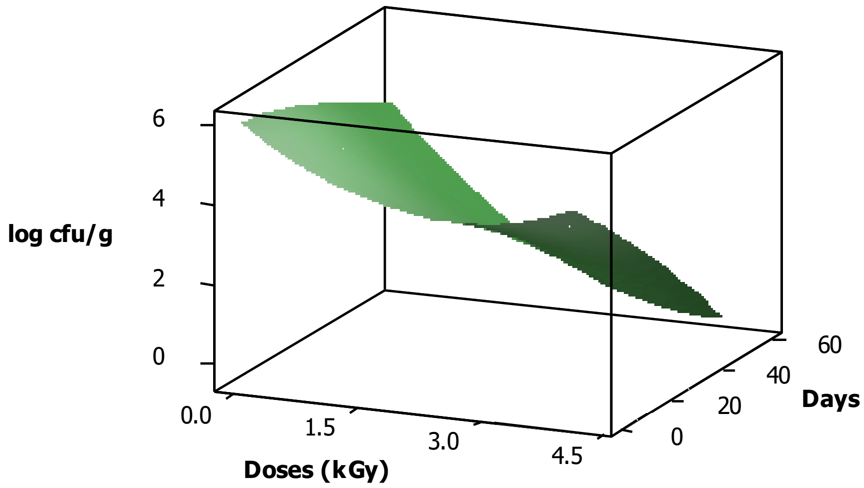
Appendix XXV: Effect of gamma irradiation and storage on the inactivation of *B. cereus* at 4 °C



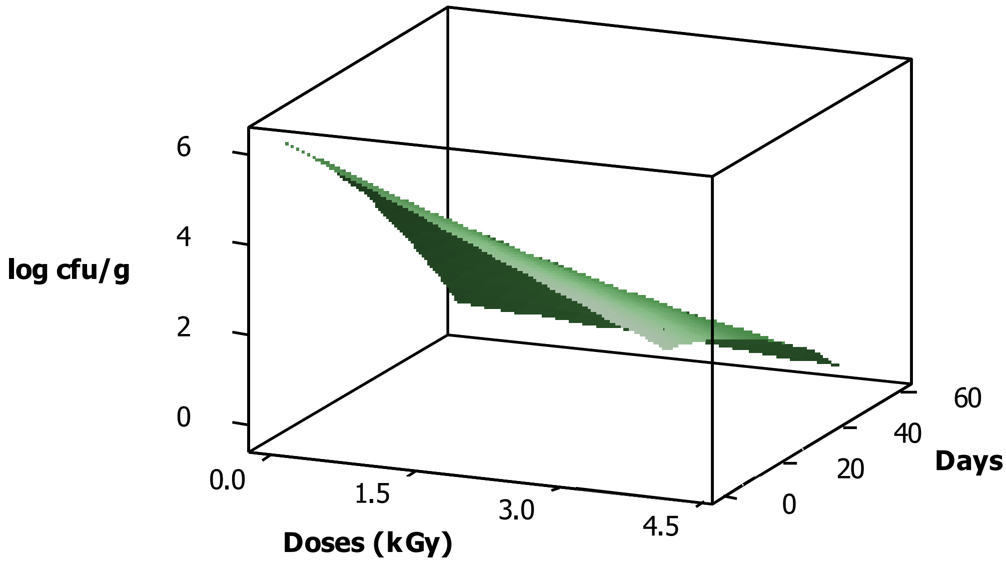
Appendix XXVI: Effect of gamma irradiation and storage on the inactivation of *B. cereus* at 28±2 °C



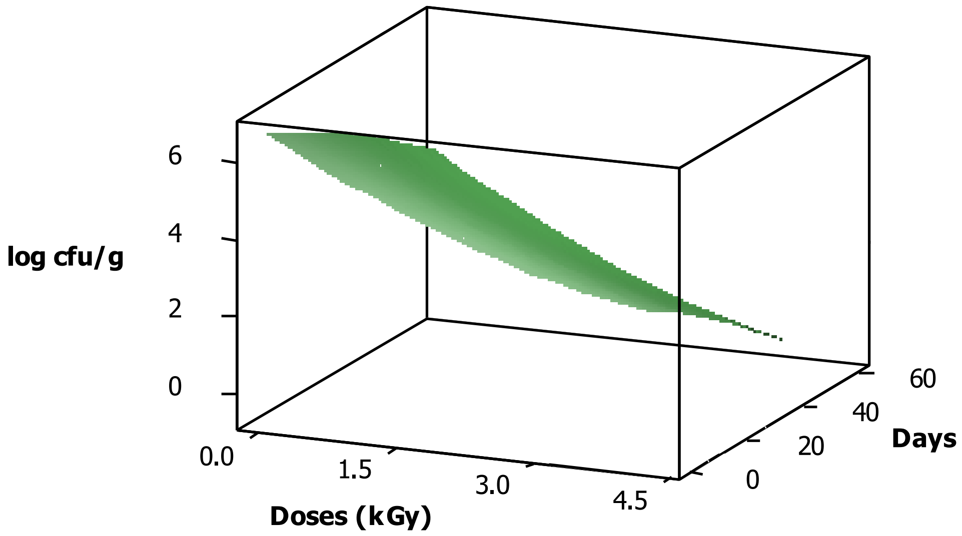
Appendix XXVII: Effect of gamma irradiation and storage on the inactivation of *L. monocytogenes* at 4 °C



Appendix XXVIII: Effect of gamma irradiation and storage on the inactivation of *L. monocytogenes* at 28±2 °C



Appendix XXIX: Effect of gamma irradiation and storage on the inactivation of *S. aureus* 28±2 °C



Appendix XXX: Effect of gamma irradiation and storage on the inactivation of *S. aureus* at 4 ºC

Appendix XXXI. Estimated Regression Coefficient for browning index in Legon-18 irradiated at 28±2 ºC

Term	Coefficient	SE Coefficient	T	P
Constant	84.598	2.17134	38.961	0*
Doses	2.1451	1.66784	1.286	0.239**
Weeks	-12.9643	0.83392	-15.546	0*
Dose *Doses	0.152	0.36744	0.414	0.692**
weeks*weeks	0.9451	0.09186	10.289	0*
Doses* weeks	-0.2613	0.15266	-1.712	0.131**
S	R^2 =99.00%	R^2 (adjusted) 98.30%		

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Browning index= $84.598+ 2.1451x-12.9643y+0.152x^2-0.9451y^2-0.2613xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XXXII. Analysis of variance for browning index of Legon-18 in irradiated samples at 28±2 °C

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Regression	5	4221.26	4221.26	844.252	141.50	0.000*
Linear	2	3441.18	1451.21	725.603	121.62	0.000*
Square	2	762.60	762.60	381.299	63.91	0.000*
Interaction	1	17.48	17.48	17.477	2.93	0.131*
Residual error	7	41.76	41.76	5.966		
Lack of fit	3	6.20	6.20	2.066	0.23	0.870**
Pure error	4	35.57	35.57	8.892		
Total	12	4263.02				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XXXIII. Estimated Regression Coefficients for browning index in Legon-18 irradiated pepper samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	85.6683	0.73843	116.015	0.000*
Doses	3.6037	0.56720	6.353	0.000*
Weeks	-5.4006	0.28360	-19.043	0.000*
Doses*Doses	-0.3242	0.12496	-2.594	0.036*
Weeks*Weeks	-0.1180	0.03124	-3.777	0.007*
Doses*Weeks	-0.1158	0.05192	-2.230	0.061**
S = 0.8307		R^2 = 99.9%	R^2 (adj) = 99.8%	

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Browning index= $85.6683+ 3.6037x-5.4006y-0.3242x^2-0.1180y^2-0.1158xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XXXIV. Analysis of Variance for browning index in Legon-18 irradiated pepper samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	4259.45	4259.446	851.889	1234.58	0.000*
Linear	2	4233.04	257.816	128.908	186.82	0.000*
Square	2	22.97	22.973	11.487	16.65	0.002*
Interaction	1	3.43	3.432	3.432	4.97	0.061**
Residual Error	7	4.83	4.830	0.690		
Lack-of-Fit	3	3.73	3.732	1.244	4.53	0.089**
Pure Error	4	1.10	1.098	0.274		
Total	12	4264.28				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XXXV. Estimated Regression Coefficient for Chroma of Legon-18 irradiated pepper samples 28±2 °C stored

Term	Coefficient	SE Coefficient	T	P
Constant	30.1161	0.129921	231.803	0.000*
Doses	1.2196	0.099794	12.221	0.000*
Weeks	-4.0645	0.049897	-81.457	0.000*
Doses*Doses	-0.0871	0.021986	-3.963	0.005*
Weeks*Weeks	0.2258	0.005496	41.089	0.000*
Doses*Weeks	-0.0583	0.009134	-6.387	0.000*
	R^2 = 100.0%	R^2 (adj) = 100.0%		

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Chroma= $30.1161+1.2196x-4.0645y-0.0871x^2+0.2258y^2-0.0583xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XXXVI. Analysis of Variance for Chroma of Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	591.341	591.341	118.2681	5536.88	0.000*
Linear	2	550.993	141.749	70.8746	3318.08	0.000*
Square	2	39.476	39.476	19.7382	924.07	0.000*
interaction	1	0.871	0.871	0.8714	40.8	0*
Residual error	7	0.15	0.15	0.0214		0*
Lack of fit	3	0.147	0.147	0.049	75.23	0.001*
*Pure Error	4	0.003	0.003	0.0007		
Total	12	591.49				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XXXVII. Estimated Regression Coefficient for Chroma Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	30.6021	0.211195	144.9	0*
Doses	1.2544	0.162222	7.733	0*
Weeks	-2.7764	0.081111	-34.224	0*
Dose *Doses	-0.1192	0.035739	-3.336	0.012*
weeks*weeks	0.059	0.008935	6.604	0*
Doses* weeks	-0.0374	0.014849	-2.519	0.04*
S= 0.2376	R^2=99.90%	R^2 (adjusted)= 99.90%		

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Chroma= 30.6021+1.2544x-2.7764y-0.1192x^2+0.059y^2-0.0374xy
Where x=doses of gamma irradiation, y=weeks of storage

Appendix XXXVIII. Analysis of Variance for Chroma of Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	555.726	555.7260	111.1452	1969.15	0.000*
Linear	2	552.862	66.4109	33.2055	588.30	0.000*
Square	2	2.506	2.5059	1.2529	22.20	0.001*
Interaction	1	0.358	0.3582	0.3582	6.35	0.040*
Residual Error	7	0.395	0.3951	0.0564		
Lack-of-Fit	3	0.392	0.3920	0.1307	166.05	0.000*
Pure Error	4	0.003	0.0031	0.0008		
Total	12	556.121				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XXXIX. Estimated Regression Coefficient for hue of Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	43.8198	3.6064	12.151	0.000*
Doses	2.4231	2.7701	0.875	0.411**
Weeks	-5.1340	1.3851	-3.707	0.008*
Doses*Doses	-0.5143	0.6103	-0.843	0.427**
Weeks*Weeks	0.5318	0.1526	3.486	0.010*
Doses*Weeks	-0.0202	0.2536	-0.079	0.939**
S = 4.057	R^2 =71.4%	R^2 (adj) = 51.0%		

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).
Hue= 43.8198+2.4231x-5.1340-0.5143x^2+0.5318y^2-0.0202xy
Where x=doses of gamma irradiation, y=weeks of storage

Appendix XL. Analysis of Variance for hue of Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	287.797	287.797	57.559	3.50	0.067**
Linear	2	83.212	227.415	113.708	6.91	0.022*
Square	2	204.481	204.481	102.240	6.21	0.028*
Interaction	1	0.104	0.104	0.104	0.01	0.939**
Residual Error	7	115.210	115.210	16.459		
Lack-of-Fit	3	10.835	10.835	3.612	0.14	0.932*
Pure Error	4	104.375	104.375	26.094		
Total	12	403.007				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XLI. Estimated Regression Coefficient for hue of Legon-18 samples irradiated and stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	45.9633	0.32947	139.505	0.000*
Doses	-0.3098	0.25307	-1.224	0.260**
Weeks	-1.4909	0.12654	-11.782	0.000*
Doses*Doses	0.0723	0.05575	1.297	0.236**
Weeks*Weeks	0.0412	0.01394	2.958	0.021*
Doses*Weeks	0.0189	0.02316	0.815	0.442**
S=0.3706 R^2 =99.2% R^2 (adj)= 98.7%				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

$Hue = 45.9633 - 0.3098x - 1.4909y + 0.0723x^2 + 0.0412y^2 + 0.0189xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XLII. Analysis of Variance for hue for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	123.432	123.4323	24.6865	179.71	0.000*
Linear	2	121.195	20.4519	10.2260	74.44	0.000*
Square	2	2.146	2.1464	1.0732	7.81	0.016*
Interaction	1	0.091	0.0912	0.0912	0.66	0.442**
Residual Error	7	0.962	0.9616	0.1374		
Lack-of-Fit	3	0.872	0.8719	0.2906	12.96	0.016*
Pure Error	4	0.090	0.0897	0.0224		
Total	12	124.394				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XLIII. Estimated Regression Coefficient for total colour difference for Legon-18 samples irradiated and stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	5.54376	0.235670	23.523	0.000*
Doses	0.09114	0.181022	0.503	0.630**
Weeks	3.22515	0.090511	35.633	0.000*
Doses*Doses	0.02994	0.039881	0.751	0.477**
Weeks*Weeks	-0.13183	0.009970	-13.222	0.000*
Doses*Weeks	-0.01563	0.016569	-0.943	0.377**
S=0.2651	R^2 = 99.9%		R^2 (adj) = 99.8%	

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Total colour difference= $5.54376+0.09114x+3.22515y+0.02994x^2-0.13183y^2-0.01563xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XLIV. Analysis of Variance for total colour difference for Legon-18 samples stored at 28±2 °C

Source	**DF**	**Seq SS**	**Adj. SS**	**Adj. MS**	**F**	**P**
Regression	5	453.739	453.7394	90.7479	1291.16	0.000*
Linear	2	439.879	92.0750	46.0375	655.02	0.000*
Square	2	13.798	13.7976	6.8988	98.16	0.000*
Interaction	1	0.063	0.0625	0.0625	0.89	0.377**
Residual Error	7	0.492	0.4920	0.0703		
Lack-of-Fit	3	0.400	0.3998	0.1333	5.78	0.062**
Pure Error	4	0.092	0.0922	0.0230		
Total	12	454.231				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XLV. Estimated Regression Coefficient for total colour difference for Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	5.70076	0.24785	23.001	0.000*
Doses	-0.36858	0.19038	-1.936	0.094**
Weeks	1.91146	0.09519	20.081	0.000*
Doses*Doses	0.05726	0.04194	1.365	0.214**
Weeks*Weeks	-0.00350	0.01049	-0.334	0.748**
Doses*Weeks	0.03872	0.01743	2.222	0.062**
S = 0.2788	R^2= 99.9%	R^2 (adj) = 99.7%		

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Total colour difference= 5.70076-0.36858x+1.91146y+0.05726x^2-0.00350y^2+0.03872xy

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XLVI. Analysis of Variance for total colour difference for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	369.676	369.6761	73.9352	951.10	0.000*
Linear	2	369.144	31.4838	15.7419	202.50	0.000*
Square	2	0.148	0.1480	0.0740	0.95	0.431**
Interaction	1	0.384	0.3838	0.3838	4.94	0.062**
Residual Error	7	0.544	0.5442	0.0777		
Lack-of-Fit	3	0.534	0.5344	0.1781	72.92	0.001*
Pure Error	4	0.010	0.0098	0.0024		
Total	12	370.220				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XLVII. Estimated Regression Coefficient for capsanthin for Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	1.48425	0.011196	132.567	0.000*
Doses	-0.05904	0.008600	-6.865	0.000*
Weeks	-0.02035	0.004300	-4.734	0.002*
Doses*Doses	0.00887	0.001895	4.684	0.002*
Weeks*Weeks	-0.00153	0.000474	-3.233	0.014*
Doses*Weeks	0.00041	0.000787	0.516	0.622**
S = 0.01259		R^2 = 99.0%	R^2 (adj) = 98.3%	

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Capsanthin content (mg/100g)= 1.48425-0.05904x-0.02035y+0.00887x^2-0.00153y^2+0.00041xy

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XLVIII. Analysis of Variance for capsanthin for Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.112469	0.112469	0.022494	141.80	0.000*
Linear	2	0.108556	0.013040	0.006520	41.10	0.000*
Square	2	0.003870	0.003870	0.001935	12.20	0.005**
Interaction	1	0.000042	0.000042	0.000042	0.27	0.622**
Residual Error	7	0.001110	0.001110	0.000159		
Lack-of-Fit	3	0.001090	0.001090	0.000363	72.69	0.001*
Pure Error	4	0.000020	0.000020	0.000005		
Total	12	0.113579				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XLIX. Estimated Regression Coefficient for Capsanthin for Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	1.47634	0.008836	167.079	0.000*
Doses	-0.04407	0.006787	-6.493	0.000*
Weeks	-0.01633	0.003394	-4.811	0.002*
Doses*Doses	0.00557	0.001495	3.724	0.007*
Weeks*Weeks	-0.00058	0.000374	-1.542	0.167**
Doses*Weeks	-0.00034	0.000621	-0.553	0.597**
S = 0.009940 R^2 = 98.8% R^2 (adj) = 98.0%				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Capsanthin content (mg/100g)= $1.47634-0.04407x-0.01633y+0.00557x^2-0.00058y^2-0.00034xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix L. Analysis of Variance for Capsanthin in Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.059177	0.059177	0.011835	119.78	0.000*
Linear	2	0.057774	0.007651	0.003825	38.72	0.000*
Square	2	0.001372	0.001372	0.000686	6.94	0.022*
Interaction	1	0.000030	0.000030	0.000030	0.31	0.597**
Residual Error	7	0.000692	0.000692	0.000099		
Lack-of-Fit	3	0.000688	0.000688	0.000229	286.85	0.000*
Pure Error	4	0.000003	0.000003	0.000001		
Total	12	0.059868				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LI. Estimated Regression Coefficient for beta carotene for Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	10.3257	0.070274	146.936	0.000*
Doses	-0.3569	0.053978	-6.612	0.000*
Weeks	-0.3122	0.026989	-11.568	0.000*
Doses*Doses	0.0442	0.011892	3.714	0.008**
Weeks*Weeks	-0.0113	0.002973	-3.791	0.007**
Doses*Weeks	-0.0195	0.004941	-3.947	0.006**

S = 0.07905 R^2 = 99.8% R^2 (adj) = 99.6%

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Beta carotene content (mg/100g) = $10.3257-0.3569x-0.3122y+0.0442x^2-0.0113^2-0.0195xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LII. Analysis of Variance for beta carotene in irradiated Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	20.5274	20.52740	4.105480	656.95	0.000*
Linear	2	20.3026	1.29817	0.649087	103.87	0.000*
Square	2	0.1275	0.12748	0.063739	10.20	0.008*
Interaction	1	0.0973	0.09734	0.097344	15.58	0.006*
Residual Error	7	0.0437	0.04374	0.006249		
Lack-of-Fit	3	0.0437	0.04374	0.014581	18225.74	0.000*
Pure Error	4	0.0000	0.00000	0.000001		
Total	12	20.5711				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LIII. Estimated Regression Coefficient for beta carotene for Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	10.1730	0.122230	83.228	0.000*
Doses	-0.1829	0.093887	-1.948	0.092**
Weeks	-0.1203	0.046943	-2.562	0.037*
Doses*Doses	0.0135	0.020684	0.652	0.535**
Weeks*Weeks	-0.0180	0.005171	-3.476	0.010*
Doses*Weeks	-0.0342	0.008594	-3.985	0.005*

S = 0.1375 R^2 = 99.0% R^2 (adj) = 98.3%

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Beta carotene content (mg/100g) = $10.1730-0.1829x-0.1203y+0.0135x^2-0.0180y^2-0.0342xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LIV. Analysis of Variance for beta carotene

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	12.8529	12.852901	2.570580	135.97	0.000*
Linear	2	12.3142	0.232467	0.116233	6.15	0.029*
Square	2	0.2384	0.238393	0.119196	6.30	0.027*
Interaction	1	0.3003	0.300304	0.300304	15.88	0.005*
Residual Error	7	0.1323	0.132342	0.018906		
Lack-of-Fit	3	0.1322	0.132240	0.044080	1728.63	0.000*
Pure Error	4	0.0001	0.000102	0.000026		
Total	12	12.9852				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LIV. Estimated Regression Coefficient for beta cryptoxanthin in Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	2.08787	0.023685	88.153	0.000*
Doses	-0.21145	0.018193	-11.623	0.000*
Weeks	-0.08044	0.009096	-8.843	0.000*
Doses*Doses	0.02591	0.004008	6.463	0.000*
Weeks*Weeks	-0.00212	0.001002	-2.113	0.072**
Doses*Weeks	0.00650	0.001665	3.903	0.006*
S = 0.02664 R^2 = 99.4%	R^2 (adj) = 99.0%			

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Beta cryptoxanthin content (mg/100g) = $2.08787-0.21145x-0.08044y+0.02591x^2-0.00212y^2+0.00650xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LVI. Analysis of Variance for beta cryptoxanthin for Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.884731	0.884731	0.176946	249.26	0.000*
Linear	2	0.844158	0.179721	0.089861	126.59	0.000*
Square	2	0.029756	0.029756	0.014878	20.96	0.001*
Interaction	1	0.010816	0.010816	0.010816	15.24	0.006*
Residual Error	7	0.004969	0.004969	0.000710		
Lack-of-Fit	3	0.004574	0.004574	0.001525	15.45	0.012*
Pure Error	4	0.000395	0.000395	0.000099		
Total	12	0.889700				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LVIII. Estimated Regression Coefficient for capsaicin in Legon-18 samples stored at 28±2 °C

Term	**Coefficient**	**SE Coefficient**	**T**	**P**
Constant	167.560	7.5796	22.107	0.000*
Doses	15.149	5.8220	2.602	0.035*
Weeks	-7.081	2.9110	-2.433	0.045*
Doses*Doses	-0.291	1.2826	-0.227	0.827**
Weeks*Weeks	0.919	0.3207	2.866	0.024*
Doses*Weeks	-2.061	0.5329	-3.867	0.006*
S = 8.527 R^2 = 88.6% R^2 (adj) = 80.5%				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Capsaicin *content (mg/100g)* = $167.560+15.149x-7.081y-0.291x^2+0.919y^2-2.061xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LIX. Analysis of Variance for capsaicin in Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	3963.02	3963.02	792.60	10.90	0.003*
Linear	2	2214.98	794.33	397.16	5.46	0.037*
Square	2	660.79	660.79	330.39	4.54	0.054**
Interaction	1	1087.25	1087.25	1087.25	14.96	0.006*
Residual Error	7	508.91	508.91	72.70		
Lack-of-Fit	3	508.85	508.85	169.62	10711.54	0.000*
Pure Error	4	0.06	0.06	0.02		
Total	12	4471.93				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LX. Estimated Regression Coefficient for capsaicin in Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	178.959	2.8531	62.725	0.000*
Doses	23.610	2.1915	10.774	0.000*
Weeks	-1.811	1.0958	-1.653	0.142**
Doses*Doses	-3.498	0.4828	-7.246	0.000*
Weeks*Weeks	-0.413	0.1207	-3.420	0.011*
Doses*Weeks	0.220	0.2006	1.096	0.309**
S = 3.210	R^2 = 98.8%		R^2 (adj) = 97.9%	

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Appendix LXI. Analysis of Variance for capsaicin in Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	5754.75	5754.75	1150.95	111.73	0.000*
Linear	2	4741.43	1195.72	597.86	58.04	0.000*
Square	2	1000.95	1000.95	500.47	48.59	0.000*
Interaction	1	12.38	12.38	12.38	1.20	0.309**
Residual Error	7	72.11	72.11	10.30		
Lack-of-Fit	3	31.58	31.58	10.53	1.04	0.466**
Pure Error	4	40.53	40.53	10.13		
Total	12	5826.86				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXII. Estimated Regression Coefficient for l* values in Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	50.2698	0.63236	79.496	0.000*
Doses	0.4747	0.48572	0.977	0.361**
Weeks	-2.6318	0.24286	-10.837	0.000*
Doses*Doses	-0.0739	0.10701	-0.690	0.512**
Weeks*Weeks	0.1159	0.02675	4.333	0.003*
Doses*Weeks	0.0569	0.04446	1.279	0.242**
S = 0.7114 R^2 = 98.6%	R^2 (adj) = 97.7%			

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

L*-values = $50.2698+0.4747x-2.6318y-0.0739x^2+0.1159y^2+0.0569xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXIII. Analysis of Variance for l* values for Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	257.793	257.7933	51.5587	101.89	0.000*
Linear	2	246.921	59.7378	29.8689	59.03	0.000*
Square	2	10.044	10.0441	5.0221	9.92	0.009*
Interaction	1	0.828	0.8281	0.8281	1.64	0.242**
Residual Error	7	3.542	3.5422	0.5060		
Lack-of-Fit	3	0.254	0.2542	0.0847	0.10	0.954**
Pure Error	4	3.288	3.2880	0.8220		
Total	12	261.336				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXIV. Estimated Regression Coefficient for l* values in Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	50.7642	0.149170	340.312	0.000*
Doses	0.2187	0.114579	1.909	0.098**
Weeks	-2.7785	0.057290	-48.500	0.000*
Doses*Doses	-0.0162	0.025243	-0.644	0.540**
Weeks*Weeks	0.2169	0.006311	34.366	0.000*
Doses*Weeks	0.0009	0.010488	0.089	0.931**

S = 0.1678 R^2 = 99.9% R^2 (adj) = 99.8%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

L*-values = $50.7642+0.2187x-2.7785y-0.0162x^2+0.2169y^2+0.0009xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXV. Analysis of Variance for l* values for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	143.122	143.1221	28.6244	1016.55	0.000*
Linear	2	104.762	67.2545	33.6273	1194.22	0.000*
Square	2	38.360	38.3598	19.1799	681.15	0.000*
Interaction	1	0.000	0.0002	0.0002	0.01	0.931**
Residual Error	7	0.197	0.1971	0.0282		
Lack-of-Fit	3	0.174	0.1741	0.0580	10.09	0.025*
Pure Error	4	0.023	0.0230	0.0057		
Total	12	143.319				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXVI. Estimated Regression Coefficient for a* values for Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	21.3658	0.111355	191.871	0.000*
Doses	0.7704	0.085534	9.007	0.000*
Weeks	-1.5885	0.042767	-37.144	0.000*
Doses*Doses	-0.0600	0.018844	-3.184	0.015*
Weeks*Weeks	0.0134	0.004711	2.852	0.025*
Doses*Weeks	-0.0259	0.007829	-3.313	0.013*
S = 0.1253	R^2 = 100.0%	R^2 (adj) = 99.9%		

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

a* values = 21.3658+0.7704*x*-1.5885*y*-0.0600x^2+0.0134y^2-0.0259*xy*

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXVII. Analysis of Variance for a* values for Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	230.334	230.3337	46.0667	2935.75	0.000*
Linear	2	229.953	21.7945	10.8972	694.46	0.000*
Square	2	0.208	0.2084	0.1042	6.64	0.024*
Interaction	1	0.172	0.1722	0.1722	10.98	0.013*
Residual Error	7	0.110	0.1098	0.0157		
Lack-of-Fit	3	0.108	0.1084	0.0361	103.28	0.000*
Pure Error	4	0.001	0.0014	0.0003		
Total	12	230.444				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXVI. Estimated Regression Coefficient for a* values in Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	19.9285	1.40078	14.227	0.000*
Doses	2.7600	1.07596	2.565	0.037*
Weeks	-2.0608	0.53798	-3.831	0.006*
Doses*Doses	-0.4393	0.23704	-1.853	0.106**
Weeks*Weeks	0.0783	0.05926	1.321	0.228**
Doses*Weeks	-0.0259	0.09849	-0.263	0.800**

S = 1.576 R^2 = 93.3% R^2 (adj) = 88.5%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

L*-values = 19.9285+2.7600x-1.5885y-0.0600x^2+0.0134y^2-0.0259xy

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXVII. Analysis of Variance for a* values in for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	241.261	241.2615	48.2523	19.43	0.001*
Linear	2	231.462	46.0868	23.0434	9.28	0.011*
Square	2	9.627	9.6271	4.8135	1.94	0.214*
Interaction	1	0.172	0.1722	0.1722	0.07	0.800**
Residual Error	7	17.381	17.3814	2.4831		
Lack-of-Fit	3	17.380	17.3798	5.7933	14483.20	0.000*
Pure Error	4	0.002	0.0016	0.0004		
Total	12	258.643				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXVIII. Estimated Regression Coefficient for b* values in for Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	21.2059	0.129684	163.519	0.000*
Doses	0.9602	0.099612	9.640	0.000*
Weeks	-4.5270	0.049806	-90.891	0.000*
Doses*Doses	-0.0625	0.021946	-2.846	0.025*
Weeks*Weeks	0.3497	0.005486	63.739	0.000*
Doses*Weeks	-0.0566	0.009118	-6.204	0.000*

S = 0.1459 R^2 = 100.0% R^2 (adj) = 99.9%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

b* values = $21.2059+0.9602x-4.5270y-0.0625x^2+0.3497y^2-0.0566xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXIX. Analysis of Variance for b* values in for Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	430.250	430.250	86.0499	4043.23	0.000*
Linear	2	331.527	176.381	88.1903	4143.80	0.000*
Square	2	97.903	97.903	48.9516	2300.09	0.000*
Interaction	1	0.819	0.819	0.8190	38.48	0.000*
Residual Error	7	0.149	0.149	0.0213		
Lack-of-Fit	3	0.136	0.136	0.0454	14.28	0.013*
Pure Error	4	0.013	0.013	0.0032		
Total	12	430.399				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXX. Estimated Regression Coefficient for b* values in for Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	22.0177	0.176663	124.631	0.000*
Doses	0.7916	0.135697	5.833	0.001*
Weeks	-2.5201	0.067849	-37.142	0.000*
Doses*Doses	-0.0636	0.029895	-2.128	0.071**
Weeks*Weeks	0.0841	0.007474	11.252	0.000*
Doses*Weeks	-0.0272	0.012421	-2.189	0.065**
S = 0.1987	R^2 = 99.9%	R^2 (adj) = 99.9%		

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

b* values = $22.0177+0.7916x-2.5201y-0.0636x^2+0.0841y^2-0.0272xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXI. Analysis of Variance for b* values for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	356.976	356.9762	71.3952	1807.72	0.000*
Linear	2	351.572	54.4858	27.2429	689.79	0.000*
Square	2	5.215	5.2154	2.6077	66.03	0.000*
Interaction	1	0.189	0.1892	0.1892	4.79	0.065**
Residual Error	7	0.276	0.2765	0.0395		
Lack-of-Fit	3	0.259	0.2593	0.0864	20.10	0.007*
Pure Error	4	0.017	0.0172	0.0043		
Total	12	357.253				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXII. Estimated Regression Coefficient for beta cryptoxanthin in for Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	2.08787	0.023685	88.153	0.000*
Doses	-0.21145	0.018193	-11.623	0.000*
Weeks	-0.08044	0.009096	-8.843	0.000*
Doses*Doses	0.02591	0.004008	6.463	0.000*
Weeks*Weeks	-0.00212	0.001002	-2.113	0.072**
Doses*Weeks	0.00650	0.001665	3.903	0.006*

S = 0.02664 R^2 = 99.4% R^2 (adj) = 99.0%

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXIII. Analysis of Variance for beta cryptoxanthin in Legon-18 samples irradiated and stored 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.884731	0.884731	0.176946	249.26	0.000*
Linear	2	0.844158	0.179721	0.089861	126.59	0.000*
Square	2	0.029756	0.029756	0.014878	20.96	0.001*
Interaction	1	0.010816	0.010816	0.010816	15.24	0.006*
Residual Error	7	0.004969	0.004969	0.000710		
Lack-of-Fit	3	0.004574	0.004574	0.001525	15.45	0.012*
Pure Error	4	0.000395	0.000395	0.000099		
Total	12	0.889700				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXIV. Estimated Regression Coefficient for beta cryptoxanthin for Legon-18 samples stored at 4 ºC

Term	Coefficient	SE Coefficient	T	P
Constant	2.11232	0.019755	106.926	0.000*
Doses	-0.24443	0.015174	-16.109	0.000*
Weeks	-0.04159	0.007587	-5.482	0.001*
Doses*Doses	0.03068	0.003343	9.178	0.000*
Weeks*Weeks	-0.00449	0.000836	-5.368	0.001*
Doses*Weeks	0.00784	0.001389	5.647	0.001*
S = 0.02222 R^2 = 99.4% R^2 (adj) = 99.1%				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Beta cryptoxanthin (mg/100g) = $2.11232-0.24443x-0.04159y+0.03068x^2-0.00449y^2+0.00784xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXV. Analysis of Variance for beta cryptoxanthin for Legon-18 samples stored at 4 ºC

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.621762	0.621762	0.124352	251.80	0.000*
Linear	2	0.562391	0.161323	0.080661	163.33	0.000*
Square	2	0.043621	0.043621	0.021810	44.16	0.000*
Interaction	1	0.015750	0.015750	0.015750	31.89	0.001*
Residual Error	7	0.003457	0.003457	0.000494		
Lack-of-Fit	3	0.003310	0.003310	0.001103	29.98	0.003*
Pure Error	4	0.000147	0.000147	0.000037		
Total	12	0.625219				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXVI. Estimated Regression Coefficient for dihydrocapsaicin for Legon-18 samples stored at 28±2°C

Term	Coefficient	SE Coefficient	T	P
Constant	75.1353	3.1039	24.206	0.000*
Doses	10.2371	2.3842	4.294	0.004*
Weeks	-4.2696	1.1921	-3.582	0.009*
Doses*Doses	-1.9507	0.5253	-3.714	0.008*
Weeks*Weeks	-0.0077	0.1313	-0.059	0.955**
Doses*Weeks	0.9569	0.2182	4.385	0.003*

S = 3.492 R^2 = 95.8% R^2 (adj) = 92.8%

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Dihydrocapsaicin (mg/100g) = $75.1353+10.2371x-4.2696y-1.9507x^2-0.0077y^2+0.9569xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXVII. Analysis of Variance for dihydrocapsaicin in Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	1935.51	1935.51	387.101	31.75	0.000*
Linear	2	1501.98	329.12	164.559	13.50	0.004*
Square	2	199.12	199.12	99.561	8.17	0.015*
Interaction	1	234.40	234.40	234.399	19.23	0.003*
Residual Error	7	85.34	85.34	12.192		
Lack-of-Fit	3	72.73	72.73	24.242	7.68	0.039*
Pure Error	4	12.62	12.62	3.154		
Total	12	2020.85				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXVIII. Estimated Regression Coefficient for dihydrocapsaicin in for Legon-18 samples stored at 4 °C.

Term	Coefficient	SE Coefficient	T	P
Constant	77.1818	1.45233	53.144	0.000*
Doses	5.9961	1.11555	5.375	0.001*
Weeks	-2.3500	0.55778	-4.213	0.004*
Doses*Doses	-0.8681	0.24577	-3.532	0.010*
Weeks*Weeks	0.0187	0.06144	0.305	0.769*
Doses*Weeks	0.3195	0.10211	3.129	0.017*

S = 1.634 R^2 = 97.2% R^2 (adj) = 95.2%

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Dihydrocapsaicin (mg/100g) = 77.1818+5.9961x-2.3500y-0.8681x^2+0.0187y^2+0.3195xy

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXIX. Analysis of Variance for dihydrocapsaicin in for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	643.651	643.651	128.730	48.23	0.000*
Linear	2	580.835	107.756	53.878	20.19	0.001*
Square	2	36.686	36.686	18.343	6.87	0.022*
Interaction	1	26.129	26.129	26.129	9.79	0.017*
Residual Error	7	18.684	18.684	2.669		
Lack-of-Fit	3	10.636	10.636	3.545	1.76	0.293*
Pure Error	4	8.048	8.048	2.012		
Total	12	662.335				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXX. Estimated Regression Coefficient for total capsaicinoids in for Legon-18 samples stored at 28±2°C

Term	Coefficient	SE Coefficient	T	P
Constant	253.819	14.8591	17.082	0.000*
Doses	27.972	11.4135	2.451	0.044*
Weeks	-11.842	5.7067	-2.075	0.077**
Doses*Doses	-4.107	2.5145	-1.633	0.146**
Weeks*Weeks	-0.019	0.6286	-0.030	0.977**
Doses*Weeks	1.107	1.0447	1.059	0.325**
S = 16.72	R^2 = 89.4%	R^2 (adj) = 81.8%		

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05).

Total capsaicinoids (mg/100g) = 253.819+27.972x-11.842y-4.107x^2-0.019y^2+1.107xy

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXXI. Analysis of Variance for total capsaicinoids in Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	16500.3	16500.30	3300.06	11.81	0.003*
Linear	2	15302.4	2486.60	1243.30	4.45	0.057**
Square	2	884.4	884.43	442.21	1.58	0.271**
Interaction	1	313.5	313.52	313.52	1.12	0.325**
Residual Error	7	1955.8	1955.81	279.40		
Lack-of-Fit	3	30.5	30.51	10.17	0.02	0.995*
Pure Error	4	1925.3	1925.31	481.33		
Total	12	18456.1				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXXII. Estimated Regression Coefficient for total capsaicinoids in Legon-18 pepper samples stored at 4 °C

Term	**Coefficient**	**SE Coefficient**	**T**	**P**
Constant	256.030	3.5836	71.445	0.000*
Doses	29.938	2.7526	10.876	0.000*
Weeks	-3.996	1.3763	-2.903	0.023*
Doses*Doses	-4.449	0.6064	-7.337	0.000*
Weeks*Weeks	-0.415	0.1516	-2.735	0.029*
Doses*Weeks	0.539	0.2520	2.141	0.070**

S = 4.031 R^2 = 98.9% R^2 (adj) = 98.1%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Total capsaicinoids (mg/100g) = $256.030+29.938x-3.996y-4.449x^2-0.415y^2+0.539xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXXIII. Analysis of Variance for total capsaicinoids in for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	10169.3	10169.28	2033.86	125.15	0.000*
Linear	2	8638.7	1944.16	972.08	59.82	0.000*
Square	2	1456.1	1456.14	728.07	44.80	0.000*
Interaction	1	74.5	74.47	74.47	4.58	0.070**
Residual Error	7	113.8	113.76	16.25		
Lack-of-Fit	3	67.2	67.20	22.40	1.92	0.267**
Pure Error	4	46.6	46.56	11.64		
Total	12	10283.0				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXXIV. Estimated Regression Coefficient for SHU for Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	4340.98	217.382	19.969	0.000*
Doses	105.47	166.975	0.632	0.548**
Weeks	-155.02	83.487	-1.857	0.106**
Doses*Doses	2.54	36.786	0.069	0.947**
Weeks*Weeks	-5.51	9.197	-0.599	0.568**
Doses*Weeks	19.41	15.284	1.270	0.245**
S = 244.5	R^2 = 89.3%	R^2 (adj) = 81.6%		

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

SHU = $4340.98+105.47x-155.02y+2.54x^2-5.51y^2+19.41xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXXV. Analysis of Variance for SHU for Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	3481352	3481352	696270	11.64	0.003*
Linear	2	3361738	212899	106450	1.78	0.237**
Square	2	23215	23215	11607	0.19	0.828**
Interaction	1	96399	96399	96399	1.61	0.245**
Residual Error	7	418594	418594	59799		
Lack-of-Fit	3	418545	418545	139515	11327.64	0.000*
Pure Error	4	49	49	12		
Total	12	3899946				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXXVI. Estimated Regression Coefficient for SHU in for Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	4122.08	57.699	71.441	0.000*
Doses	482.00	44.320	10.876	0.000*
Weeks	-64.33	22.160	-2.903	0.023*
Doses*Doses	-71.63	9.764	-7.336	0.000*
Weeks*Weeks	-6.68	2.441	-2.735	0.029*
Doses*Weeks	8.68	4.057	2.141	0.070**

S = 64.91 R^2 = 98.9% R^2 (adj) = 98.1%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

$SHU = 4122.08+482.00x-64.33y-71.63x^2-6.68y^2+8.68xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXXVII. Analysis of Variance for SHU in for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	2635999	2635999	527200	125.14	0.000*
Linear	2	2239230	503956	251978	59.81	0.000*
Square	2	377466	377466	188733	44.80	0.000*
Interaction	1	19304	19304	19304	4.58	0.070**
Residual Error	7	29491	29491	4213		
Lack-of-Fit	3	17421	17421	5807	1.92	0.267**
Pure Error	4	12069	12069	3017		
Total	12	2665490				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix LXXXVIII. Estimated Regression Coefficient for total titratable acidity in Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	0.213326	0.008200	26.016	0.000*
Doses	-0.003313	0.006298	-0.526	0.615**
Weeks	0.021291	0.003149	6.761	0.000*
Doses*Doses	0.002296	0.001388	1.655	0.142**
Weeks*Weeks	-0.001427	0.000347	-4.115	0.004*
Doses*Weeks	-0.001201	0.000577	-2.083	0.076**

S = 0.009224 R^2 = 92.4% R^2 (adj) = 86.9%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Total titratable acidity (%) = $0.213326-0.003313x+0.021291y+0.002296x^2-0.001427y^2-0.001201xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix LXXXIX. Analysis of Variance for titratable acidity in Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.007196	0.007196	0.001439	16.92	0.001*
Linear	2	0.005386	0.003917	0.001959	23.02	0.001*
Square	2	0.001441	0.001441	0.000721	8.47	0.014*
Interaction	1	0.000369	0.000369	0.000369	4.34	0.076**
Residual Error	7	0.000596	0.000596	0.000085		
Lack-of-Fit	3	0.000479	0.000479	0.000160	5.46	0.067**
Pure Error	4	0.000117	0.000117	0.000029		
Total	12	0.007792				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares

Appendix XC. Estimated Regression Coefficient for pH in for Legon-18 samples stored at 4 °C

Term	**Coefficient**	**SE Coefficient**	**T**	**P**
Constant	4.97457	0.035591	139.770	0.000*
Doses	0.06088	0.027338	2.227	0.061**
Weeks	0.03585	0.013669	2.623	0.034*
Doses*Doses	-0.01095	0.006023	-1.818	0.112**
Weeks*Weeks	0.00195	0.001506	1.295	0.236**
Doses*Weeks	-0.00344	0.002502	-1.374	0.212*

S = 0.04004 R^2 = 94.7% R^2 (adj) = 90.9%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares

$$pH = 4.97457+0.06088x+0.03585y-0.01095x^2+0.00195y^2-0.00344xy$$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XCI. Analysis of Variance for pH in Legon-18 pepper samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.200087	0.200087	0.040017	24.96	0.000*
Linear	2	0.191083	0.022599	0.011300	7.05	0.021*
Square	2	0.005978	0.005978	0.002989	1.86	0.224**
Interaction	1	0.003025	0.003025	0.003025	1.89	0.212**
Residual Error	7	0.011221	0.011221	0.001603		
Lack-of-Fit	3	0.007901	0.007901	0.002634	3.17	0.147**
Pure Error	4	0.003320	0.003320	0.000830		
Total	12	0.211308				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares

Appendix XCII. Estimated Regression Coefficient for pH of Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	5.10463	0.019366	263.590	0.000*
Doses	0.00070	0.014875	0.047	0.964**
Weeks	0.02869	0.007438	3.857	0.006*
Doses*Doses	-0.00091	0.003277	-0.276	0.790**
Weeks*Weeks	0.00102	0.000819	1.250	0.252**
Doses*Weeks	0.00094	0.001362	0.689	0.513**

S = 0.02179 R^2 = 97.8% R^2 (adj) = 96.2%

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares

$pH = 5.10463+0.00070x+0.02869y-0.00091x^2+0.00102y^2+0.00094xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XCIII. Analysis of Variance for pH of Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.145155	0.145155	0.029031	61.17	0.000*
Linear	2	0.144167	0.007279	0.003640	7.67	0.017*
Square	2	0.000763	0.000763	0.000382	0.80	0.485**
Interaction	1	0.000225	0.000225	0.000225	0.47	0.513**
Residual Error	7	0.003322	0.003322	0.000475		
Lack-of-Fit	3	0.002122	0.002122	0.000707	2.36	0.213*
Pure Error	4	0.001200	0.001200	0.000300		
Total	12	0.148477				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares

Appendix XCIV. Estimated Regression Coefficient for titratable acidity in Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	0.220313	0.008866	24.850	0.000*
Doses	-0.005062	0.006810	-0.743	0.481**
Weeks	0.017215	0.003405	5.056	0.001*
Doses*Doses	0.001132	0.001500	0.755	0.475**
Weeks*Weeks	-0.000918	0.000375	-2.447	0.044*
Doses*Weeks	-0.000400	0.000623	-0.642	0.541**

S = 0.009973 R^2 = 92.6% R^2 (adj) = 87.2%

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$).

Total titratable acidity (%) $=0.220313-0.005062x+0.017215y+0.001132x^2-0.000918y^2-0.000400xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XCV. Analysis of Variance for total titratable acidity in Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	0.008651	0.008651	0.001730	17.40	0.001*
Linear	2	0.008011	0.002543	0.001272	12.78	0.005*
Square	2	0.000599	0.000599	0.000300	3.01	0.114**
Interaction	1	0.000041	0.000041	0.000041	0.41	0.541**
Residual Error	7	0.000696	0.000696	0.000099		
Lack-of-Fit	3	0.000695	0.000695	0.000232	946.04	0.000*
Pure Error	4	0.000001	0.000001	0.000000		
Total	12	0.009347				

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares

Appendix XCVI. Estimated Regression Coefficient for moisture content in for Legon-18 samples stored at 4 °C

Term	Coefficient	SE Coefficient	T	P
Constant	9.92989	0.46088	21.545	0.000*
Doses	-0.05632	0.35401	-0.159	0.878**
Weeks	0.03017	0.17701	0.170	0.869**
Doses*Doses	0.04741	0.07799	0.608	0.562**
Weeks*Weeks	-0.01940	0.01950	-0.995	0.353**
Doses*Weeks	-0.03750	0.03240	-1.157	0.285**

S = 0.5185 R^2 = 70.5% R^2 (adj) = 49.4%

Values marked *are statistically significant (p<0.05). Values marked ** are statistically not (p>0.05). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares

Moisture content (%) = $9.92989-0.05632x + 0.03017y + 0.04741x^2-0.01940y^2-0.03750xy$

Where x=doses of gamma irradiation, y=weeks of storage

Appendix XCVII. Analysis of Variance for moisture content in for Legon-18 samples stored at 4 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	4.4892	4.48916	0.897832	3.34	0.074**
Linear	2	3.8467	0.01258	0.006292	0.02	0.977**
Square	2	0.2825	0.28249	0.141247	0.53	0.613**
Interaction	1	0.3600	0.36000	0.360000	1.34	0.285**
Residual Error	7	1.8816	1.88161	0.268801		
Lack-of-Fit	3	1.3496	1.34961	0.449870	3.38	0.135**
Pure Error	4	0.5320	0.53200	0.133000		
Total	12	6.3708				

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

Appendix XCVIII. Estimated Regression Coefficient for moisture content in for Legon-18 samples stored at 28±2 °C

Term	Coefficient	SE Coefficient	T	P
Constant	9.86839	0.232475	42.449	0.000*
Doses	0.50316	0.178567	2.818	0.026*
Weeks	-0.07342	0.089284	-0.822	0.438**
Doses*Doses	-0.06121	0.039340	-1.556	0.164**
Weeks*Weeks	-0.00905	0.009835	-0.920	0.388**
Doses*Weeks	-0.03125	0.016345	-1.912	0.097**
S=0.2615	R^2 = 91.6%	R^2 = 85.5%		

Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.

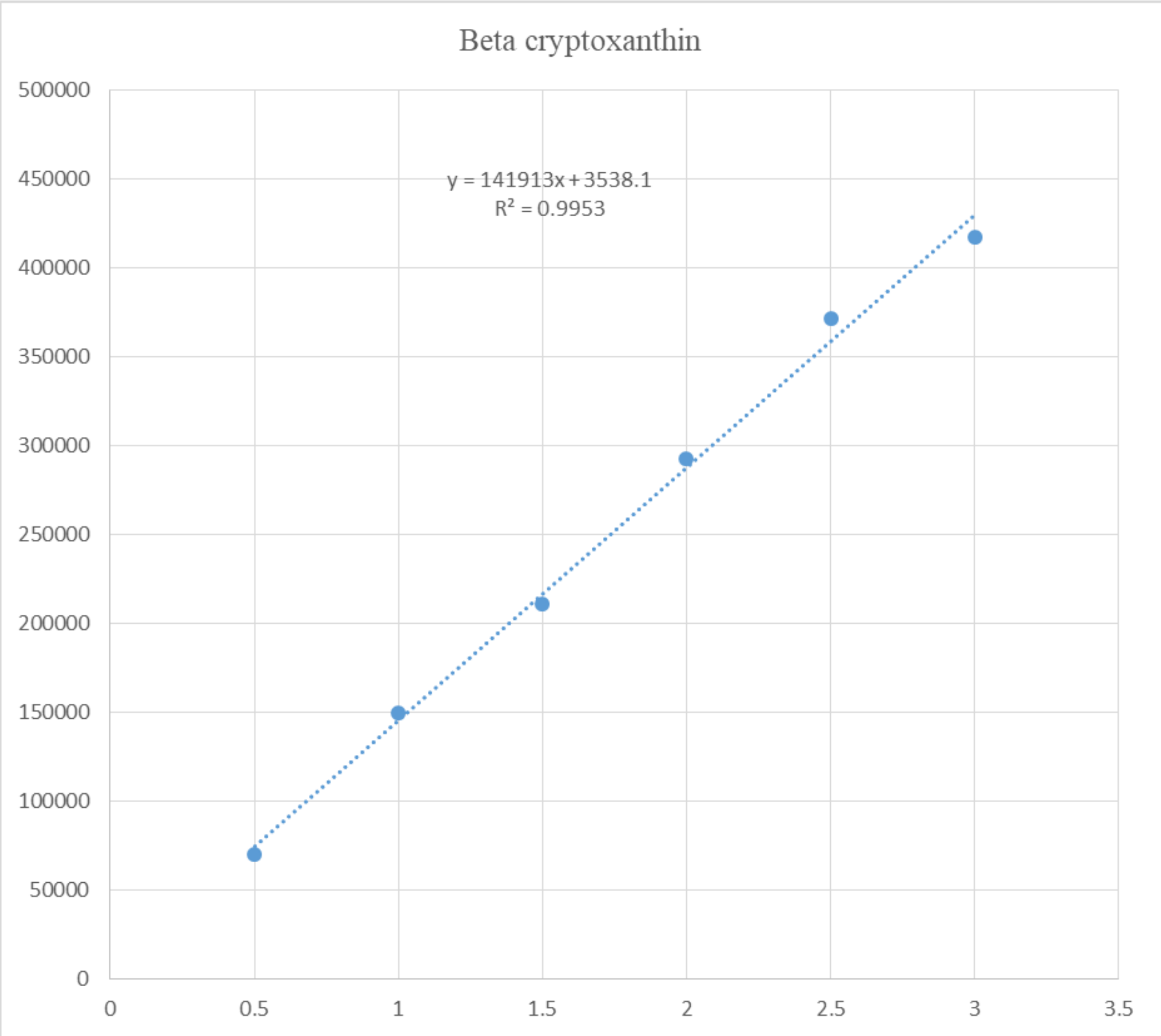
Moisture content (%) = $9.86839+0.50316x-0.07342y-0.06121x^2-0.00905y^2-0.03125xy$

Where x=doses of gamma irradiation, y=weeks of storage

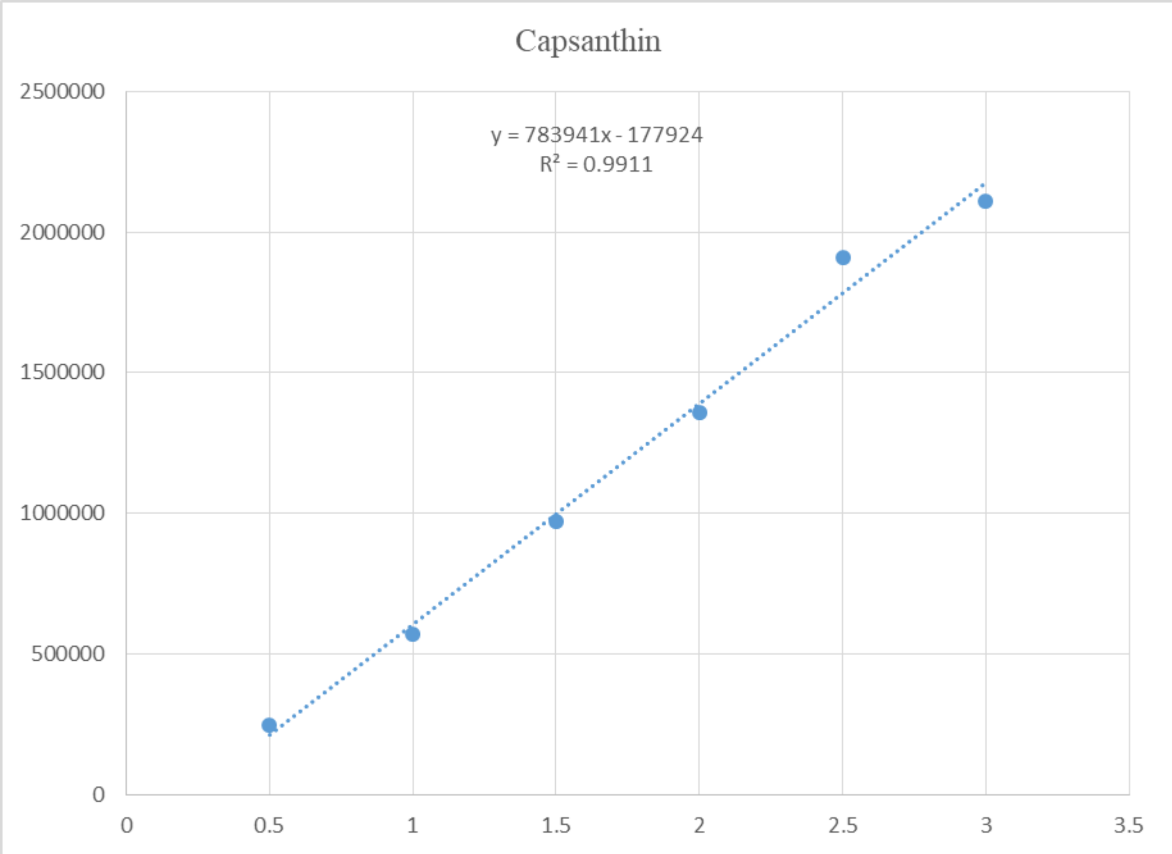
Appendix XCIX. Analysis of Variance for moisture content in for Legon-18 samples stored at 28±2 °C

Source	DF	Seq SS	Adj. SS	Adj. MS	F	P
Regression	5	5.19203	5.19203	1.03841	15.18	0.001*
Linear	2	4.59333	0.55244	0.27622	4.04	0.068**
Square	2	0.34870	0.34870	0.17435	2.55	0.147**
Interaction	1	0.25000	0.25000	0.25000	3.66	0.097**
Residual Error	7	0.47874	0.47874	0.06839		
Lack-of-Fit	3	0.08674	0.08674	0.02891	0.30	0.828**
Pure Error	4	0.39200	0.39200	0.09800		
Total	12	5.67077				

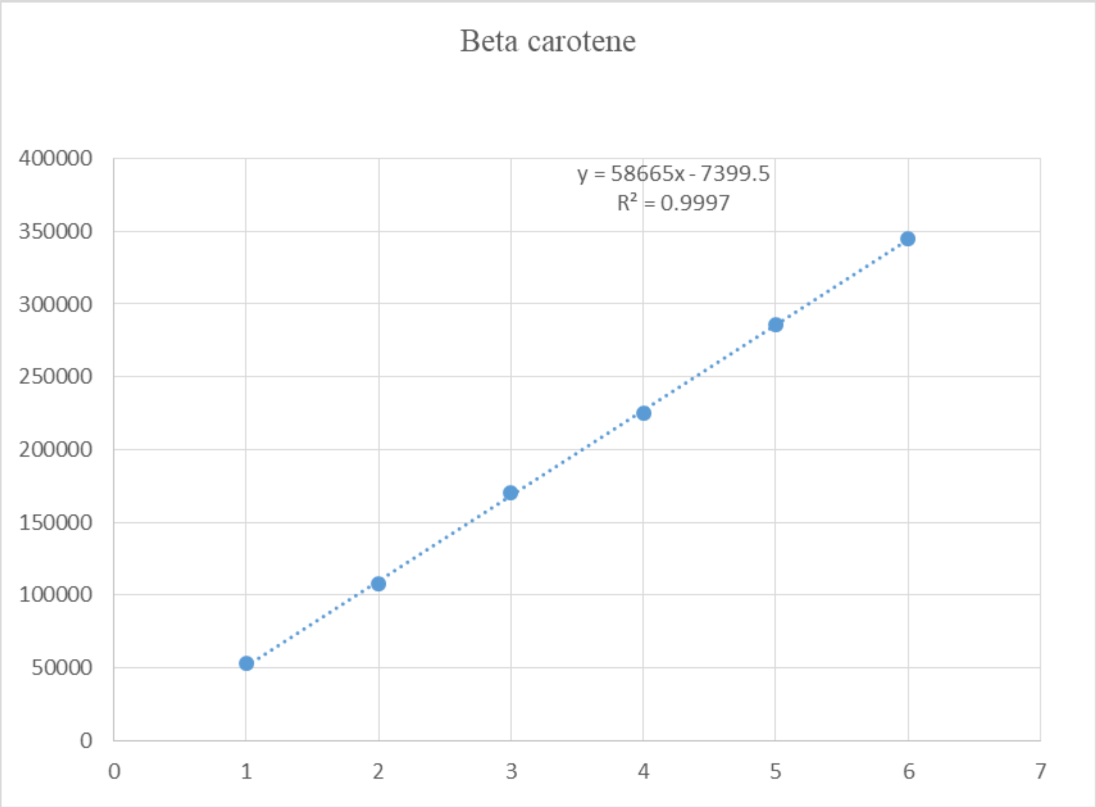
Values marked *are statistically significant ($p<0.05$). Values marked ** are statistically not ($p>0.05$). DF-degree of freedom, Adj. SS-Adjusted Sum of Squares, Adj. MS-Adjusted mean squares.



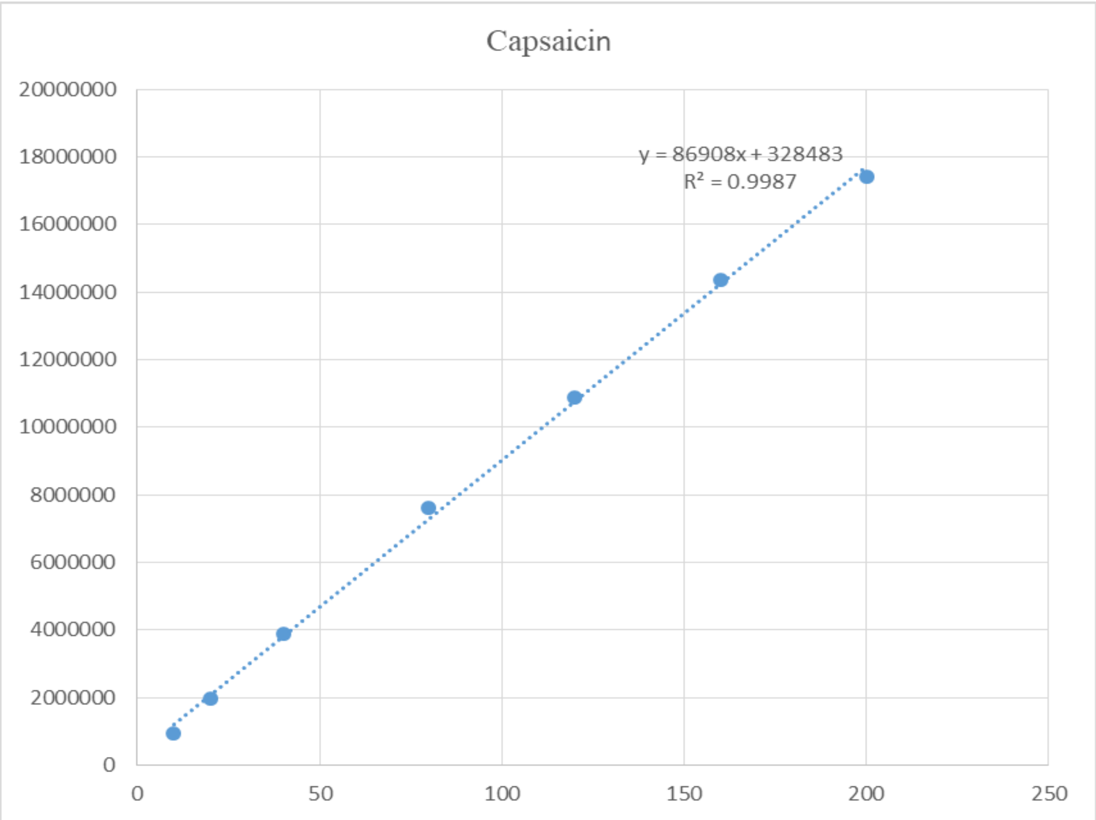
Appendix XCX. Calibration curve for beta cryptoxanthin.



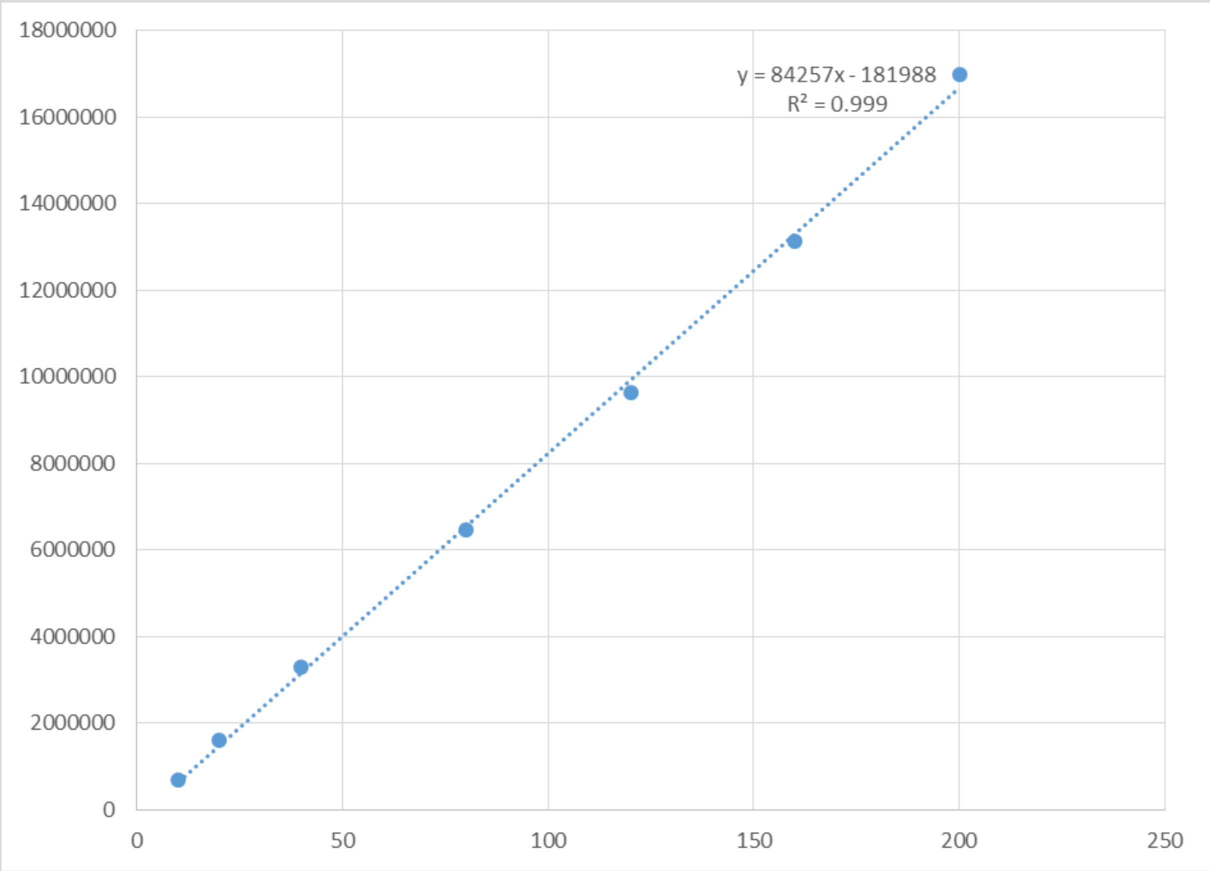
Appendix XCXI. Calibration curve for capsanthin



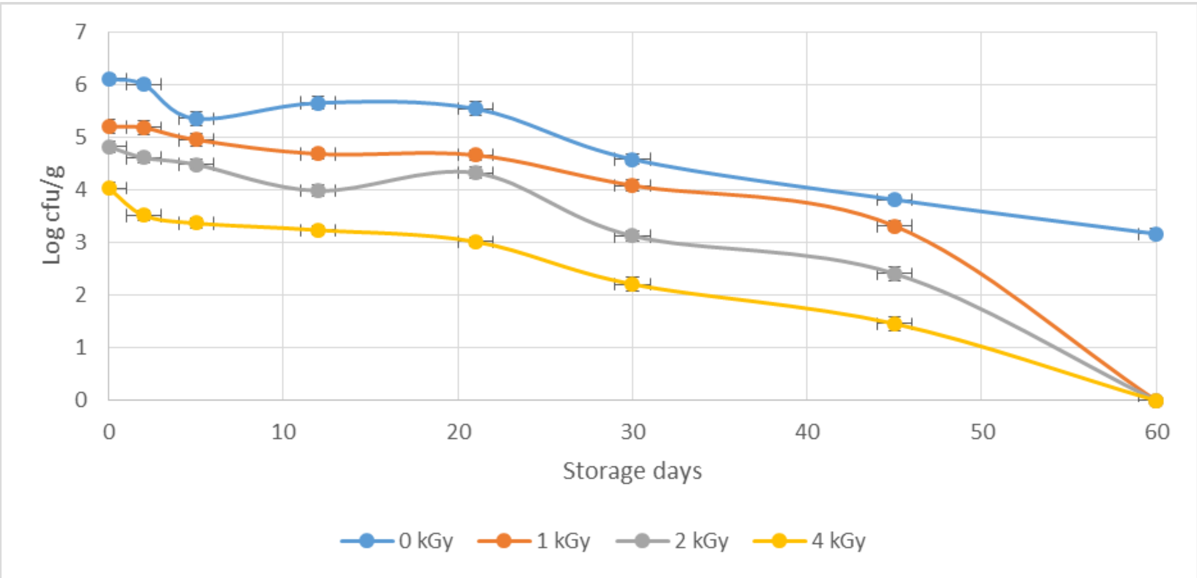
Appendix XCXII. Calibration curve for beta-carotene



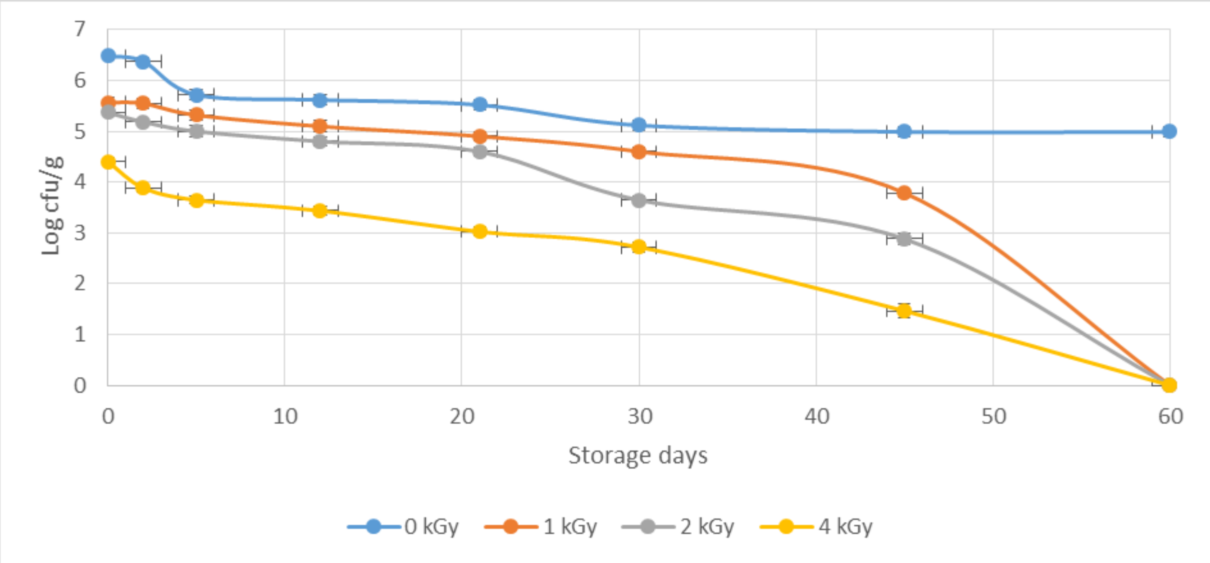
Appendix XCXIII. Calibration curve for capsaicin



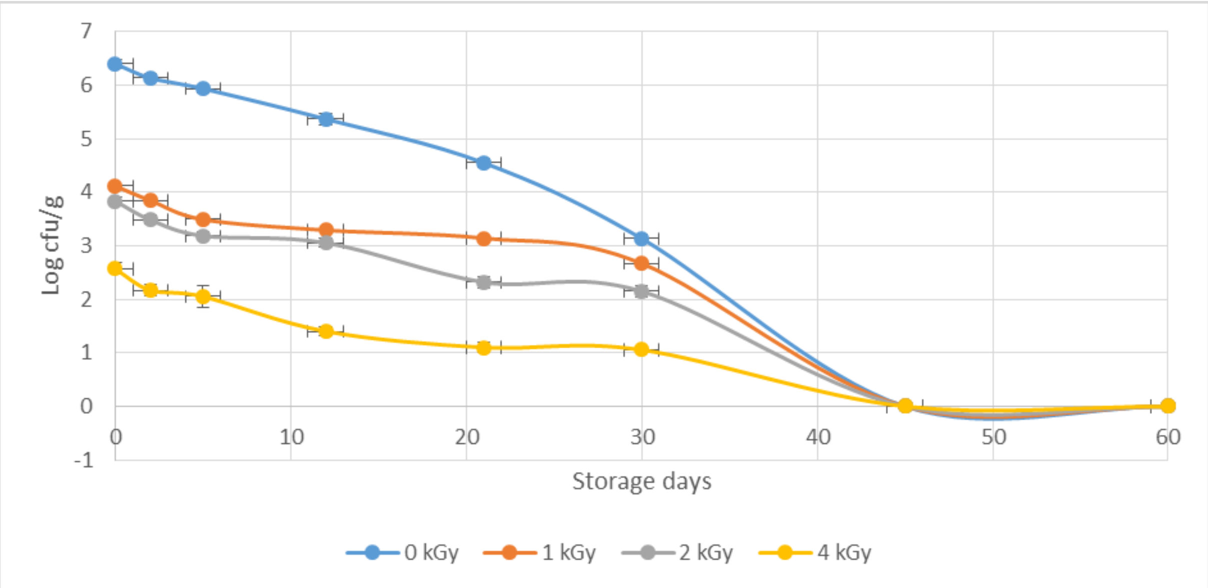
Appendix XCXIV. Calibration curve for dihydrocapsaicin



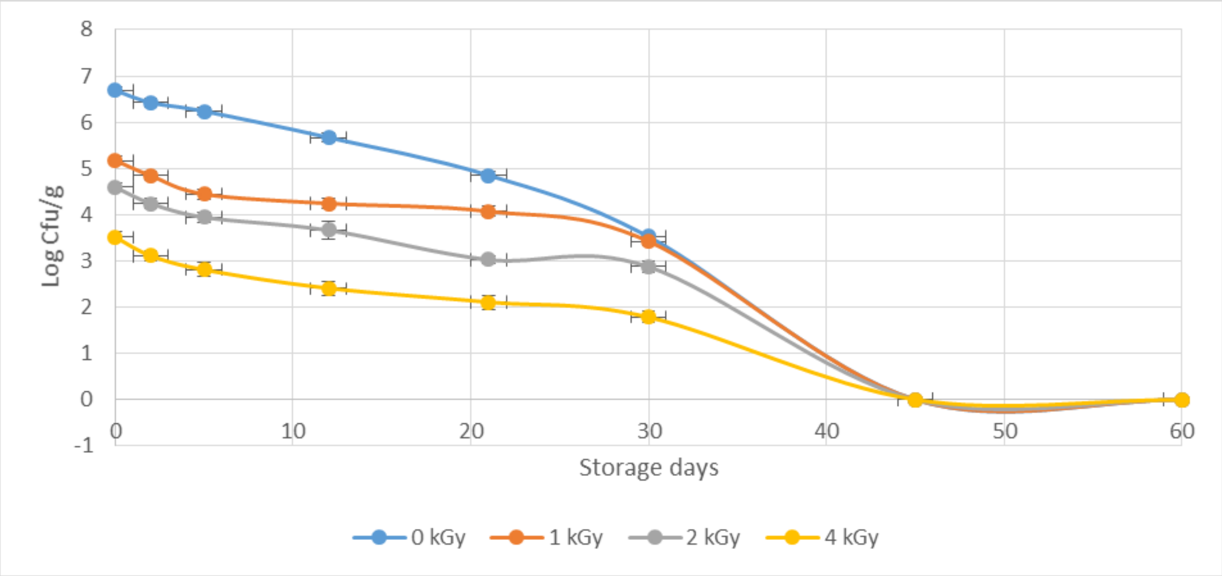
Appendix XCXV: Effect of gamma irradiation and storage time (days) on the inactivation of *S.* Typhimurium at 4 ºC.



Appendix XCXVI: Effect of gamma irradiation and storage time (days) on the inactivation of *S.* Typhimurium at 28±2 °C.

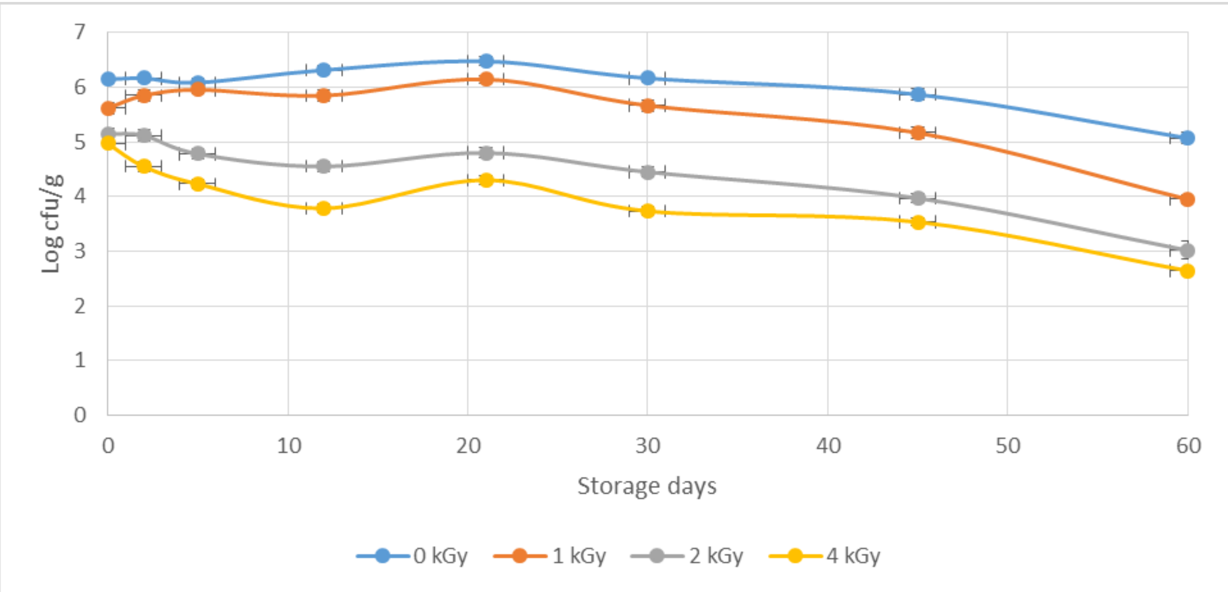


Appendix XCXVII: Effect of gamma irradiation and storage time (days) on the inactivation of *E. coli* at 4 °C.

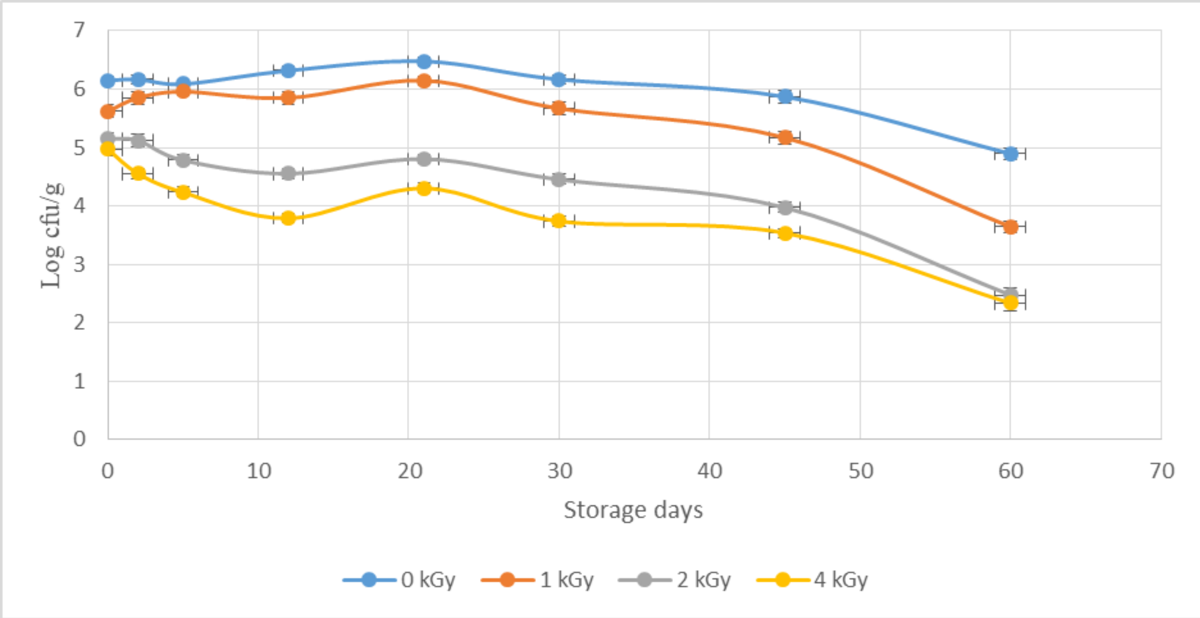


Appendix XCXVIII: Effect of gamma irradiation and storage time (days) on the inactivation of *E. coli* at.

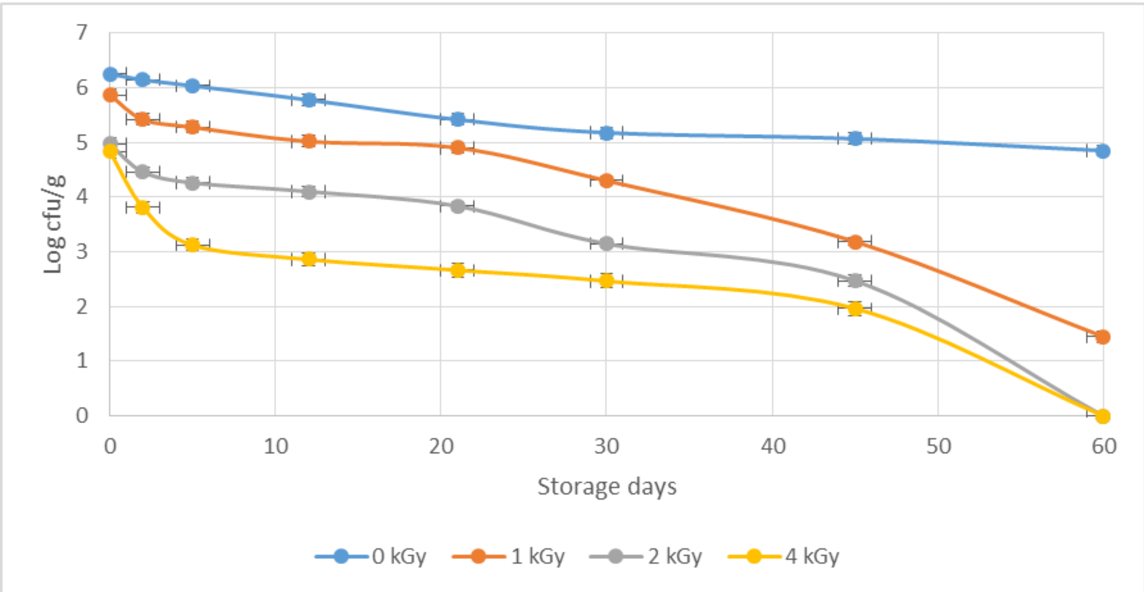
28±2 ^{o}C.



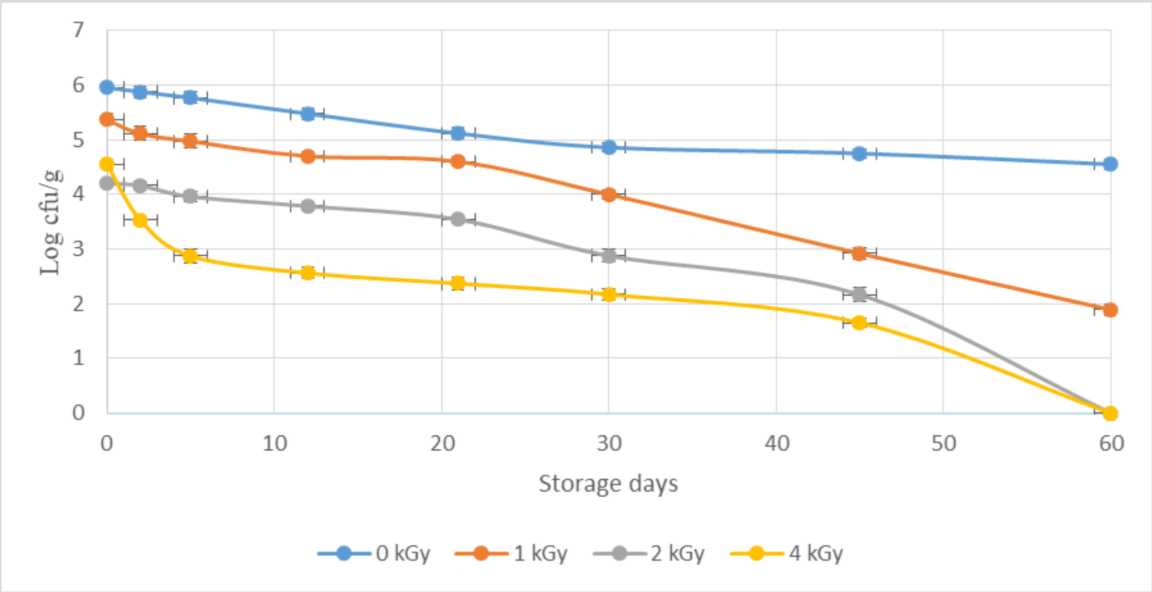
Appendix XCXIX: Effect of gamma irradiation and storage time (days) on the inactivation of *B. cereus* at 4 ^{o}C.



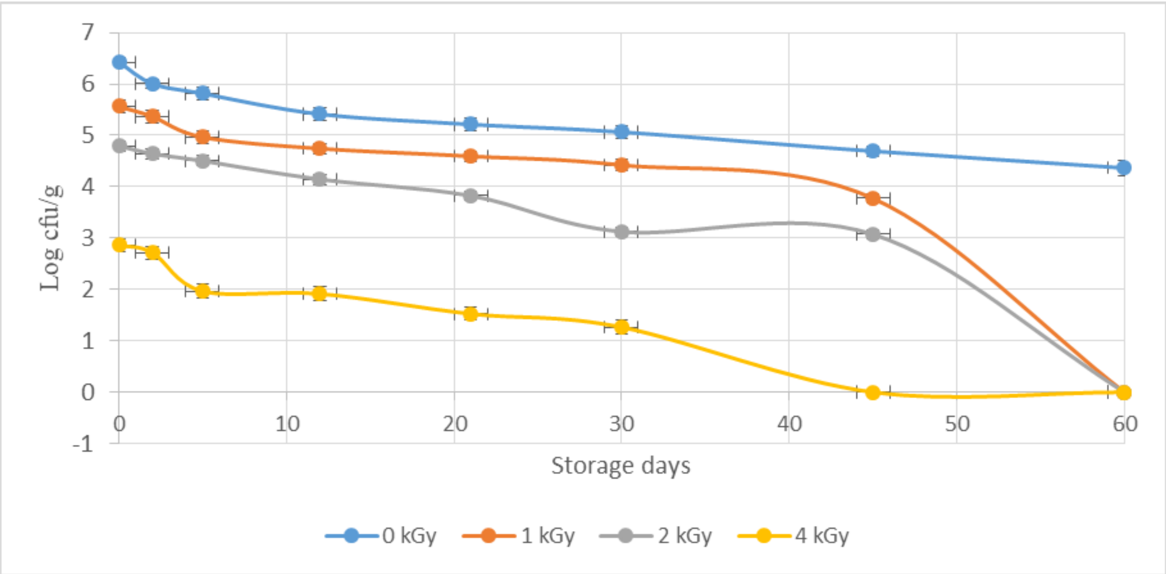
Appendix C: Effect of gamma irradiation and storage time (days) on the inactivation of *B. cereus* at 28±2 °C.



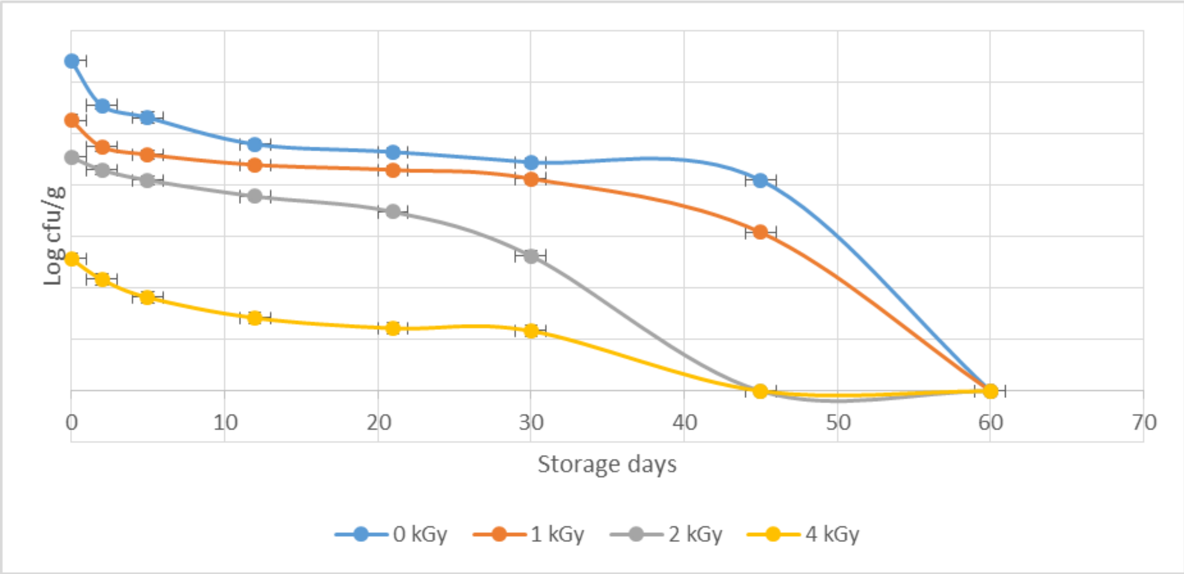
Appendix CI: Effect of gamma irradiation and storage time (days) on the inactivation of *L. monocytogenes* at 4 °C.



Appendix CII: Effect of gamma irradiation and storage time (days) on the inactivation of *L. monocytogenes* at 28±2 ºC.



Appendix CIII: Effect of gamma irradiation and storage time (days) on the inactivation of *S. aureus* 4 ºC.



Appendix CIV: Effect of gamma irradiation and storage time (days) on the inactivation of *S. aureus* at 28±2 °C.

Appendix CV. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *S.* Typhimurium at 4 °C.

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	123.5615	17.65164	2651.17	<.001*
Doses (B)	4	418.141	104.5353	15700.57	<.001*
AB	28	60.69558	2.167699	325.58	<.001*
Residual	79	0.525986	0.006658		
Total	**118**	**602.9241**			

Values designated as * are significant (p<0.05)

Appendix CVI. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *S.* Typhimurium at 28±2 °C.

Source of variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	137.967	19.70958	2323.2	<.001*
Doses (B)	4	354.2124	88.5531	10437.91	<.001*
AB	28	45.0775	1.609911	189.76	<.001*
Residual	80	0.678704	0.008484		
Total	**119**	**537.9356**			

Values designated as * are significant (p<0.05)

Appendix CVII. ANOVA summary table for the effect of gamma irradiation, temperature and storage time (days) on the inactivation of *S.* Typhimurium

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Storage days (A)	7	2.66E+02	3.80E+01	5017.56	<.001*
Temperature (B)	1	4.83E+00	4.83E+00	638.13	<.001*
Doses (C)	4	7.77E+02	1.94E+02	25661.91	<.001*
AB	7	6.92E-01	9.89E-02	13.07	<.001*
AC	28	1.01E+02	3.62E+00	477.95	<.001*
BC	4	1.66E+00	4.14E-01	54.7	<.001*
ABC	28	4.20E+00	1.50E-01	19.84	<.001*
Residual	160	1.21E+00	7.57E-03		
Storage days (A)	239	1.16E+03			
Total	**239**	**1.16E+03**			

Values designated as * are significant ($p<0.05$)

Appendix CVIII. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *E. coli* at 4 °C.

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	178.3944	25.48492	282.82	<.001
Doses (B)	4	198.9963	49.74906	552.09	<.001
AB	28	80.92326	2.89012	32.07	<.001
Residual	79	7.11878	0.09011		
Total	**118**	**465.4327**			

Values designated as * are significant ($p<0.05$)

Appendix CIX. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *E. coli* 28±2 °C.

Source of variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	181.6851	25.95501	4113.22	<.001*
Doses (B)	4	198.4249	49.60623	7861.35	<.001*
AB	28	79.05667	2.823453	447.45	<.001*
Residual	80	0.504811	0.00631		
Total	119	459.6715			

Values designated as * are significant ($p<0.05$)

Appendix CX. ANOVA summary table for the effect of gamma irradiation, temperature and storage time (days) on the inactivation of *E. coli*

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Storage days (A)	7	369.77332	52.82476	1108.18	<.001*
Temperature (B)	1	0.12732	0.12732	2.67	0.104*
Doses (C)	4	405.86058	101.46515	2128.57	<.001*
AB	7	0.10083	0.0144	0.3	0.952**
AC	28	160.60926	5.73604	120.33	<.001*
BC	4	0.41564	0.10391	2.18	0.074**
ABC	28	0.57381	0.02049	0.43	0.995**
Residual	160	7.62691	0.04767		
Storage days (A)	239				
Total	**239**				

Values designated as * are significant ($p<0.05$)

Appendix CXI. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *B. cereus* at 4 °C.

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	23.4511	3.350157	495.62	<.001*
Doses (B)	4	542.1026	135.5257	20049.51	<.001*
AB	28	10.56801	0.377429	55.84	<.001*
Residual	79	0.534004	0.00676		
Total	**118**	**576.6557**			

Values designated as * are significant ($p<0.05$)

Appendix CXII. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *B. cereus* at 28±2 °C.

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	26.56107	3.794439	443.25	<.001*
Doses (B)	4	508.1883	127.0471	14840.98	<.001*
AB	28	14.34506	0.512324	59.85	<.001*
Residual	80	0.684845	0.008561		
Total	**119**	**549.7793**			

Values designated as * are significant ($p<0.05$)

Appendix CXIII. ANOVA summary table for the effect of gamma irradiation, temperature and storage time (days) on the inactivation of *B. cereus*

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Storage days (A)	7	5.10E+01	7.28E+00	947.54	<.001*
Temperature (B)	1	2.91E+00	2.91E+00	379.06	<.001*
Doses (C)	4	1.05E+03	2.63E+02	34243.14	<.001*
AB	7	2.87E-01	4.10E-02	5.33	<.001*
AC	28	2.39E+01	8.54E-01	111.21	<.001*
BC	4	1.10E+00	2.76E-01	35.92	<.001*
ABC	28	8.49E-01	3.03E-02	3.95	<.001*
Residual	160	1.23E+00	7.68E-03		
Total	**239**	**1.13E+03**			

Values designated as * are significant ($p<0.05$)

Appendix CXVI. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *S. aureus* 4 °C.

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	157.1885	22.4555	2547.36	<.001*
Doses (B)	4	376.4077	94.10193	10674.96	<.001*
AB	28	64.84396	2.315856	262.71	<.001*
Residual	79	0.696401	0.008815		
Total	**118**	**599.1366**			

Values designated as * are significant ($p<0.05$)

Appendix CXVII. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *S. aureus* 28±2 °C.

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Days (A)	7	155.308	22.18685	3896.01	<.001*
Doses (B)	4	317.4543	79.36357	13936.24	<.001*
AB	28	71.39257	2.549735	447.73	<.001*
Residual	80	0.455581	0.005695		
Total	119	544.6104			

Values designated as * are significant ($p<0.05$)

Appendix CXVIII. ANOVA summary table for the effect of gamma irradiation, temperature and storage time (days) on the inactivation of *S. aureus*

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Storage days (A)	7	3.16E+02	4.51E+01	6221.86	<.001*
Temperature (B)	1	6.65E+00	6.65E+00	916.32	<.001*
Doses (C)	4	6.98E+02	1.75E+02	24063.12	<.001*
AB	7	3.28E+00	4.68E-01	64.55	<.001*
AC	28	1.28E+02	4.56E+00	628.75	<.001*
BC	4	2.78E+00	6.96E-01	95.97	<.001*
ABC	28	8.64E+00	3.09E-01	42.53	<.001*
Residual	160	1.16E+00	7.25E-03		
Total	**239**	**1.16E+03**			

Values designated as * are significant ($p<0.05$)

Appendix CXIX. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *L. monocytogenes* 4 °C.

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	85.70755	12.24394	1599.23	<.001*
Doses (B)	4	427.6144	106.9036	13963.15	<.001*
AB	28	41.2907	1.474668	192.61	<.001*
Residual	79	0.604834	0.007656		
Total	**118**	**555.2175**			

Values designated as * are significant ($p<0.05$)

Appendix CXX. ANOVA summary table for the effect of gamma irradiation, doses and days on the inactivation of inactivation of *L. monocytogenes* at 28±2 °C.

Source of variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Days (A)	7	81.31138	11.61591	1542.26	<.001*
Doses (B)	4	384.1245	96.03113	12750.22	<.001*
AB	28	36.04856	1.287448	170.94	<.001*
Residual	80	0.602538	0.007532		
Total	**119**	**502.087**			

Values designated as * are significant ($p<0.05$)

Appendix CXXI. ANOVA summary table for the effect of gamma irradiation, temperature and storage time (days) on the inactivation of *L. monocytogenes*

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Storage days (A)	7	1.72E+02	2.46E+01	3246.17	<.001*
Temperature (B)	1	3.42E+00	3.42E+00	451.34	<.001*
Doses (C)	4	8.15E+02	2.04E+02	26871.05	<.001*
AB	7	2.27E-01	3.25E-02	4.28	<.001*
AC	28	7.68E+01	2.74E+00	361.58	<.001*
BC	4	8.98E-01	2.24E-01	29.6	<.001*
ABC	28	4.04E-01	1.44E-02	1.9	<0.007*
Residual	160	1.21E+00	7.58E-03		
Storage days (A)	239	1.07E+03			
Total	**239**	**1.07E+03**			

Values designated as * are significant (p<0.05)

Appendix CXXII. ANOVA summary table for the effect of gamma irradiation, temperature and the type of organism on the log cfu/g in pepper powder

Source of variation	D.F.	S.S.	M.S.	F PR.
Microorganisms (A)	4	477.5767	119.3942	<.001*
Storage temperature (B)	1	15.09803	15.09803	<.001*
Storage days (C)	7	1043.47	149.0671	<.001*
Doses (D)	4	3584.89	896.2224	<.001*
AB	4	2.83753	0.70938	<.001*
AC	28	131.1655	4.68448	<.001*
BC	7	1.30289	0.18613	<.001*
AD	16	163.0295	10.18934	<.001*
BD	4	4.60666	1.15166	<.001*
CD	28	298.3691	10.65604	<.001*
ABC	28	3.28127	0.11719	<.001*
ABD	16	2.25005	0.14063	<.001*
ACD	112	191.8624	1.71306	<.001*
BCD	28	2.8387	0.10138	<.001*
ABCD	112	11.8287	0.10561	<.001*
Residual	800	12.44034	0.01555	
Total	**1199**	**5946.847**		

Values designated as * are significant (p<0.05).