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DEPARTMENT OF BIOCHEMISTRY AND BIOTECHNOLOGY

INFLUENCE OF MATURITY STAGE AND POSTHARVEST CALCIUM CHLORIDE TREATMENT ON THE QUALITY AND STORAGE LIFE OF TOMATOES (*Lycopersicon esculentum*, Mill)

Thesis Submitted as a Partial Fulfillment of the Requirement for the Award of Master of Science Degree in Food Science and Technology

BY

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DECLARATION

I, Eric Arthur hereby declare that this work herein submitted, as dissertation is the results of my own investigation. References made therein are however respectively acknowledged.

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DEDICATION

This work is dedicated to my beloved parents; Mose and Erma Miller for their love and immense financial supports for my life.

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ABSTRACT

The postharvest quality and storage life of tomato fruits harvested at different maturity stages (breaker, pink and light red stage) and dipped in different concentrations of $CaCl_2$ (2 %, 6 % and 0%) for different dip durations (10, 20 and 30 min.) were studied. The experiment was in 3 phases under ambient conditions with average temperature and relative humidity of 26.85^oC and 82.75 % respectively. The first phase was preliminary and was carried out to determine the appropriate dip time to start with. The second phase was carried out to determine the best stage of maturity; which involved treating the 3 stages of maturity with different concentrations of $CaCl_2$ (2 %, 6 % and 0 %). The third phase involved the selection of the best stage of maturity in the second phase and dipping it in different concentrations of $CaCl_2$ for different dip durations. The preliminary study results indicated that, dipping for up to 40 minutes was injurious to the fruits skin. Results from the second phase showed that, fruits harvested at the pink stage recorded significantly ($P < 0.05$) higher amount of titratable acidity and vitamin C after 10 days of storage. All calcium chloride treated fruits showed a significant ($P < 0.05$) delay in the changes of weight loss, firmness, decay titratable acidity and vitamin C as compared to the control (0%). Third phase results indicated that, tomato fruit dipped in 6 % $CaCl_2$ was more effective than in the 2 % $CaCl_2$ and the 0 % in maintaining quality. Both 20 and 30 minutes dip time were significantly ($P < 0.05$) effective in maintaining weight loss, firmness, vitamin C content and also extending storage life as compared to the 10 min dip time. Therefore, tomato fruits harvested at the pink stage and dipped in 6 % $CaCl_2$ for 20 better facilitated the extension of storage life and the preservation of quality.

Key word: Maturity stages, fruit, tomato, dip time, storage life, postharvest

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CHAPTER ONE

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill) is one of the most important vegetables in the world. It is known to belong to the Solanaceae family (Peralta and Spooner, 2007). The crop has been reported to be widely cultivated in Africa and the world at large (Norman, 1992; FAO, 2001). Tomato is also consumed in larger quantities compared to other vegetables in the world and in Ghana for instance; tomato is regarded as an obligatory ingredient in the daily meal of the majority of the people (Ellis *et al*., 1998).

The use of tomato is seen in both local and continental dishes; it can be consumed fresh as in salad or cooked as in sauces and soups, fresh tomatoes may also be processed into purees, juices and ketchup. Literature suggests that, tomato is one of the important sources of vitamin C, carotenoids and other micronutrients such as iron and phosphorous that are necessary for healthy growth. Tomato fruits do not only constitute a great source of lycopene but also contain carotenoids with a high oxygen-radical scavenging and quenching capacity (Dumas *et al*., 2003; Babalola *et al*., 2010).

These benefits notwithstanding, Mutari and Debbie (2011) reported fresh tomatoes to have a limited storage life, which is usually enhanced by various factor such as physical injuries, high storage temperature, high moisture content and high ethylene production at different stages of ripening. In addition, Ullah (2009) attributed the high postharvest losses of tomato in the developing countries to bumper harvest during the peak seasons, causing the supply of tomato to exceed demand in the peak season and scarcity during the off-season, thus diminishing the

grower's returns. Therefore, postharvest losses have great economic implications which do not only affect the local farmers but rather the economy of the entire nation. Moreover, the perishable nature of tomato and its associated consequences necessitate an exploration into appropriate postharvest technologies to extend the storage life without compromising the quality.

According to Genanew (2013), achieving the maximum possible storage is the main focus of storage studies and therefore the combinations of treatments such as low temperature, waxing, low oxygen and high carbon dioxide storage and ethylene inhibitor such as $CaCl_2$ treatment have been reported to have the potential to extend the storage life of fresh produce such as tomatoes. A study conducted by Gharezi *et al*. (2012) indicated that, harvesting crops at the optimum stage of maturity is one of the initial steps required for successful marketing. In addition, Cliff *et al*. (2009) also reported that, tomato fruits may be harvested at matured green stage in order to reduce physical damage incurred during handling and transportation. On the contrary, Helyes and Pek (2006) reported that, when tomatoes are harvested at the matured green stage, the percentage of immature tomatoes fruit that may be found among them may range from 20-80% depending on the time of harvest. This actually implies that, there is the need to carry further study on the other stages of maturity at harvest.

Another approach to maintaining quality and extending the storage life of tomato is to treat the whole fruit with calcium chloride solution. According to Bhattara and Gautam (2006), calcium in the cell wall serves as a binding agent in the form of calcium pectate. This helps to improve the quality and extend the storage life particularly by delaying ripening and senescence as well as reducing respiration rate and physiological disorder. Study by Senevirathna and Daundasekera (2010) indicated that, fruits treated with $CaCl_2$ exhibited firmer texture. The firmer texture of

$CaCl_2$ treated fruit may be due to the inhibited action of polygalacturonase, which is an enzyme that facilitates the degradation of pectate during ripening. Thus, the prolonged storage life of the $CaCl_2$ treated fruit may mainly be due to the increased firmness and retarded ethylene production.

However, there had been disparities in the recommended concentrations of calcium chloride ($CaCl_2$) appropriate for maintaining quality and prolonging storage life of fruits. Whilst some researchers recommended lower concentration such as 1.5% of $CaCl_2$ (Nirupama *et al.*, 2010), other researchers also recommended higher concentration such as 6% of $CaCl_2$ (Senevirathna and Daundasekera, 2010).

Harvesting tomato fruit at an appropriate maturity stage as well as applying the right concentration of calcium treatment may be an important postharvest tool that can be used to maintain the quality and extend the storage life of tomato. Besides, extending the storage life of tomatoes may enable growers, wholesalers and retailers of tomatoes to have a relatively longer period of time to transport and market their produce before losses occur. Postharvest calcium treatment may also facilitate substantial reduction of postharvest loss, which will promote the availability of the produce all year-round, culminating in higher income returns for growers and the country (Olayemi *et al.*, 2010).

The overall objective of this study was therefore to determine the effect of concentration levels of postharvest calcium chloride and dip time on the quality and storage life of tomato (Power cultivar) fruit harvested at different stages of maturity.

The specific objectives were to;

- determine the effect of stage of maturity at harvest on the quality and storage life of tomato;
- study the influence of different concentrations of calcium chloride and dip time on the quality and storage life of tomato; and
- assess the effect of the interaction between the calcium chloride concentration and its dip time on the quality and storage life of tomato fruits.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BOTANY OF TOMATO

Tomato (*Lycopersicon esculentum* Mill) is a herbaceous, warm season crop which is usually annual in temperate region, but growth may continue in the tropical region (Morgan and Lennard, 2000). The crop was reported to have originated from Peru to Ecuador in the Central to South America. The introduction of tomato to West Africa is believed to be in the 16th and 17th century by the Portuguese and right from that time, the crop has become a very important crop used for many recipes and products (Norman, 1992).

2.2 TOMATO CULTIVARS IN GHANA

MoFAIR Centre (2008) has recommended certain varieties of tomatoes in Ghana. These varieties include Roma VF, Wosowoso, Laurano 70, Pectomech, Cac J and Rio Grande. Adubofour *et al*. (2010), also cited Bolga and Ashanti as varieties of tomato grown in Ghana. Besides, Power Rano is another variety which is widely grown under rain fed condition in Brong Ahafo and Ashanti Regions of Ghana. Ellis *et al.* (1998) also reported power variety to be the predominant variety for cultivation in Ghana. However, Robinson and Kolavalli (2010) recommended Pectomech as a suitable variety for processing and also as one preferred by most consumers, thus achieving a premium price over the local varieties in the market.

Although Power cultivar is widely cultivated by most farmers due to its ability to withstand field crack during heavy rain as compared to other local varieties, the Power cultivar is known to have limited postharvest life. In a study by Nyamah (2011), he reported that cultivar type can

influence fruit decay. According to his study, power cultivar recorded the highest incidence of decay and weight loss as compared to other cultivars such as Royal.

2.3 WORLD PRODUCTION OF TOMATO

Tomato is known to be widely cultivated all over the world. The total cultivated area of tomato in the world is estimated to be more than 5 million hectares with about 129 million tones of production. China is reported to be the leading producer of tomatoes in the world, with other high producers being USA, Turkey and India. However, Egypt, Nigeria, Tunisia and Morocco are the leading producers in Africa (Food and Agriculture Organization, 2010).

2. 4 MATURITY AND STAGE OF HARVEST OF TOMATO

According to Kader (1986), the stage at which tomato fruit is harvested is very essential to its composition and quality. Harvesting at the mature green stage will usually attain desirable flavour at the full-ripe stage as compared with those picked at an immature stage. Generally tomato fruit allowed to ripen on the field have better overall quality than fruit ripen in the room. However, tomato fruit harvested at the full-ripe stage has limited storage life.

Extending the storage life is very essential for successful marketing and the initial step necessary for ensuring successful marketing is to harvest the crop at the optimum stage of maturity. Depending on the distance to the market and the readiness of buyers, tomato may be harvested at full-ripe or matured green stage (Sammi and Masud, 2007). Opiyo and Ying (2005) reported that, tomato fruit may be harvested at different stages of maturity ranging from matured green to red stage. The choice to harvest at a particular stage of ripening is usually dependent on the market and consumers requirement. The length of time that tomato fruit is attached to the vine

has an influence on the taste quality of tomato fruit. However, tomato fruit are harvested at matured green stage in order to reduce the level of mechanical damage during handling and transportation to the market (Helyes and Pek, 2006).

According to Getinet *et al*. (2008), the stage at which tomato fruit was harvested greatly influenced the changes in the quality parameters such as total soluble solids (TSS) and ascorbic acid content. Fruit harvested at the matured green stage had the lowest TSS and ascorbic acid level. But fruit harvested at light red stage had the highest TSS content**.** Ullah (2009) also stated that, the time at which famers harvest tomato fruit is very critical for its quality and postharvest behaviors, since over-ripe tomato is more susceptible to physical injuries.

Even though, fruit harvested at the red stage possess high sensory quality, they are also less resistant to the current handling and marketing system. Tomato fruits harvested at the matured green stage eventually ripen to a quality level that is acceptable to the consumer. However, substantial amount of tomatoes harvested at the green stage may be found immature because, since it is difficult to distinguish mature tomato from immature tomato at the green stage using external appearance. Besides, the immature fruits among the mature ones will usually ripen more slowly than the rest, thus resulting in a lack of uniformity in ripening which affect appearance quality (Sasimon *et al*., 2002).

According to Moneruzzaman *et al*. (2009), harvesting fruit at the proper maturity has a great influence on the nutrient content as well as storage life of any fruit. Tomato as a climacteric fruit may be harvested at different maturity stages. Ranatunga *et al*. (2009) reported that, it is very essential to harvest fruit and vegetable at the right maturity and size, because quality cannot be

improved after harvest but can only be maintained. Immature or over-mature produce may affect the quality or shorten the storage life of the produce. The difficulty in distinguishing the mature green from immature fruit remains the largest challenge encountered with tomato fruit harvested green. Moreover, research has proven that, the quality of immature green fruit in Florida is estimated to range from 20% to 80% of the total fruit harvested.

Helyes and Pek (2006) reported that, harvesting tomato fruit at the later stage of maturity (deep red) makes the fruit much more vulnerable to damage and decay. As a result, the first measure to extend the storage life of tomato is to harvest at the right stage of maturity. Harvesting of tomato fruit must be planned and carried out at the right interval, because tomato fruits that had full bloom at the same day may not ripen at the same time. The first tomato harvest is possible 3 months after transplant. Harvesting may continue for about 5 weeks depending on the cultivar, climate, soil and other environmental conditions. After the first harvest, subsequent harvest can be done in every 4 days. The bad side of harvesting at mature green is that, the nutritional value of the fruit is usually lower, however the good side is that, the green tomato can tolerate damage during transportation and handling (Helyes and Pek, 2006).

Depending on the availability of market, harvesting can be done at different maturity stages. According to Cantwell (2009), there are two main types of maturity; physiological and horticultural maturity. Physiological maturity is the stage of development when a plant part will continue to develop even if detached from the vine (eg matured green tomato). However, horticultural maturity is the stage of development where a plant part possesses the necessary characteristic for use by consumers. Some of the maturity indices include; increase in TSS, flesh

firmness, day from planting to harvest, day from full bloom as well as external and internal color development.

2.5 NUTRITIONAL AND HEALTH BENEFITS

Tomato has also been noted to have variety of nutrients. This nutrient values may change based on the variety and the stage of maturity. The USDA National Nutrient Database (2010) gives the nutritional content of an average 123g of ripe raw tomato as follows;

Nutrient	**Content**	**Nutrient**	**Content**
Alpha carotene	124 mcg	Lycopene	3165 mcg
Beta-carotene	552 mcg	Magnesium	1.4 mg
Beta cryptoxanthin	0.0 mcg	Manganese	0.140 mg
Calcium	1.2 mg	Moisture content	116.26 g
Carbohydrate	4.7 g	Niacin	0.731 mg
Cholesterol	0.0mg 8	Pantothenic acid	0.109mg
Fat	0.2g	Phosphorus	3.0 mg
Folate	18mcg	Potassium	292 mg
Iron	0.33 mg	Protein	1.0 g
IU Vitamin A	1025	RAE Vitamin A	52mgz
IU Vitamin D	0	Riboflavin	0.023 mg
Lutein + zeaxanthin	151 mcg	Selenium	0.0 mcg
Sodium	6 mg	Riboflavin	0.023mg
Thiamin	0.046 mg	Sodium	6mg
Thiamin	0.046mg	Vitamin C	16.9 mg

According to Dumas *et al*. (2003), tomato fruit does not only constitute a great source of lycopene but also have carotenoids with a high oxygen-radical scavenging and quenching capacity. The research proved that, lycopene exhibits antioxidant activities as well as suppressing cell proliferation and interfering with the growth of cancer cells. Besides, tomato is known to be a source of antioxidant such as B-carotene, vitamin C, vitamin E and phenolic compound. Most of these constituents have a great health benefit.

A study by Helyes and Pek (2006) indicated that, polyphenols form the greatest part of the antioxidant content in the soluble solid and tomato fruit is a rich source of these polyphenols. Carotenoids and flavonoids offer protection against some form of cancer, this protection may be due to the antioxidant properties of the lycopene (Opiyo and Ying, 2005). According to Marsic *et al*. (2011), carotenoids and flavonoids are also known to be a group of polyphenols that have essential antioxidant benefit.

2.6 POSTHARVEST TECHNOLOGY

A report by Ullah (2009) indicated that, applying the appropriate postharvest techniques and principles can help reduce the undesirable changes that fresh produce undergo during handling. Storage life extension of tomato has both domestic and export market benefit. Low temperature storage remains one usual means of extending the shelf life of tomato. Genanew (2013) reported that, postharvest technology usually plays an important role by slowing down the rate of deterioration of produce as much as possible from the time of harvest till it gets to the final consumer. This then provides high level of flexibility to producers and traders as to when and where to market their commodity in order to make the maximum profit**.**

The study by Genanew (2013) indicates that, achieving the maximum possible storage is the main focus of storage studies. Combination of treatment such as waxing, low oxygen and high carbon dioxide storage as well as the use of ethylene inhibitor such as $CaCl_2$ treatment has been reported to have the potential to extend the storage life of fresh produce.

2.7 CALCIUM CHLORIDE TREATMENT

According to Nirupama *et al*. (2010), postharvest calcium chloride application has also been proven to be a potential treatment to delay the ripening process, thus minimizing quality loss. Bhattarai and Gautam (2006) reported that, calcium in the cell wall serves as a binding agent in the form of calcium pectate. This helps to improve the quality and extend the storage life particularly by delaying ripening and senescence as well as reducing respiration rate and physiological disorder. This desirable effect may explain why calcium is receiving much attention in recent times.

Anthon *et al*. (2005) also stated that, calcium salt has been used to improve the firmness of diced tomato. The interaction of calcium with pectin in the cell wall is known to be the mechanism for calcium firming role. Generally, the calcium salt binds to block the free carboxylic acid group along the polygalacturonic acid back of the pectin to form cross-link between pectin chains. Therefore, the firmer texture is as a result of increase crose-linking in the middle lamella which leads to a greater adhesion between cells. Thus, the calcium eventually inhibits the activities of polygalacturonase resulting in much firmer texture as compared to fruits with no calcium treatment**.**

Ullah (2009) reported that, extending the storage life of tomato by slowing down the rate of ripening can be achieved to a certain degree when low temperature storage (4-10^{o}C) is combined with $CaCl_2$ treatment. Calcium is needed for both pre and postharvest application of fruit. Some of the desirable effects of calcium application include reduction in respiration, maintaining firmness and delaying of ripening which subsequently prolong the storage life. In the study by Ullah (2009), fruit treated with 4% $CaCl_2$ maintained more of the green life of the fruit as compared to the untreated fruit (control).

According to Manganaris *et al*. (2007), using the right type of salt and concentration, postharvest calcium application can improve calcium content substantially as compared to pre-harvest application. Moreover, Nirupama *et al*. (2010) reported that, calcium application helps maintain membrane integrity, tissue firmness, cell turgor as well as delaying membrane lipid catabolism and extending storage life of fruit. The study by Senevirathna and Daundasekera (2010) showed that, fruit treated with $CaCl_2$ exhibited firmer texture. The higher firmness of $CaCl_2$ treated fruit may be due to the inhibited action of polygalacturonase, which is an enzyme that facilitates the degradation of pectate during ripening. Thus, the prolonged storage life of the $CaCl_2$ treated fruit may mainly be due to the increased firmness and retarded ethylene production.

2.8 RIPENING AND ETHYLENE PRODUCTION OF TOMATO FRUIT

Opiyo *et al*. (2005) reported that, the red colour of fruit is mostly due to lycopene. The research revealed that if one is able to slow down the ripening process significantly, then a tomato fruit could be left on the parent plant for a long enough time to develop a superior taste and still be sold to the final consumer before its storage life is ended. Ethylene plays an active role in the fruit ripening process. The most important characteristic to assess ripeness and postharvest life of

tomato is colour and is of major importance in making purchasing decision. Most often, tomato fruit are consumed at their maximum organoleptic quality which is attained when the fruit reaches the full red stage before excessive softening. The red colour of tomato could be said to appear as a result of chlorophyll degradation as well as lycopene synthesis (Dumas *et al*., 2003). Based on the external colour, six ripening stage which reflect the human ability to differentiate ripening has been established. The USDA (2010) colour classification is widely used for tomato fruit, however if more accurate colour description is needed then colorimeter is used.

Ullah (2009) stated that, colour change remains the most important maturity indices to determine the harvesting time of tomato. The skin colour of tomato has a great influence on consumer acceptability. Genanew (2013) reported that, high level of endogenous ethylene (C_2H_4) has been a challenge for most fruit and vegetable. Therefore, most chemical formulations have been directed towards keeping the ethylene below the threshold level. The use of ethylene absorbent such as $CaCl_2$ together with controlled storage atmosphere has a promising commercial application in future.

Pigment synthesis in tomato is closely associated with the starting and advancement of ripening. Thus, the red colour of the fruit comes about as a result of lycopene accumulation (Helyes and Pek, 2006). According to Manganaris *et al*. (2007), ripening of fruit is generally associated with softening and the softening results from the cell wall disruption. Hurr *et al*. (2005) also mentioned that, there are two types of fruits in relation to respiration rate and ripening. These are climacteric and non-climacteric fruit. The climacterics fruits show a rapid rise and fall in the rate of respiration during ripening, example include tomato and mango. However, the non-climacteric fruits such as pineapple and citrus do not show a sharp rise and fall in respiration rate. Besides,

the ripening process usually influence the level of pigment, sugar, acid and aroma volatile to make the fruit more attractive while at the same time promoting tissue softening (Oms-Olius *et al*., 2011).

2.9 QUALITY OF FRESH TOMATOES

Ullah (2009) reported that, quality may be referred to as the combination of relevant attributes of a product such that those attributes have significance in determining the degree of acceptability of the product to the end user and thus determining its value. Cantwell (2009) also stated that, quality of fresh produce may be explained as the attributes that give the produce value as a food. Quality may mean different things to different players in the food chain, for example the grower may see quality as good appearance, high yield and resistant to damage. However, the consumer may see a good quality as good appearance, firmness and nutritional value. Generally, quality is at maximum when the product is harvested more mature or ripe, however storage life is also extended if the produce is harvested less mature or unripe. Most indices are a compromise between eating quality and storage life (Ullah, 2009).

2.9.1 Mechanical Damage

According to the study by Babarinsa and Ige (2012), tomato fruit as compared to other fruit is much more susceptible to mechanical injuries because it is more tender and perishable. The result from their study showed that, fruit harvested at the advanced stage of ripening were more vulnerable to compression damage. Injuries in the form of cats, compression, split or bruises may destroy the physical integrity of the fruit. Zhiguo *et al*. (2010) reported that, mechanical injuries resulting from harvesting, handling and transportation may eventually affect cell walls causing enzymatic degradation which may be observed as soft spots on the fruits. However, mechanical

injuries do not only result in visible but may also give room for a higher risk of bacterial and fungal infection leading to a shorter storage life of the fruits.

Besides, Mohammadi-Aylar *et al*. (2010) indicated that, tomato is very vulnerable to mechanical injuries and these injuries are usually manifested by water soaked cellular breakdown of the cell wall. Some injuries may not be visible immediately they occur but may become evident during subsequent handling or storage. According to Idah *et al*. (2007), rubbing of harvested produce against each other as well as with the packaging container may promote bruising in fruits and vegetable. Besides, loading and off loading of fruit may also enhance mechanical injuries. Controlling the amount of mechanical injury is one of the ways to increase food safety by lowering the potential for microbial infestation. The study revealed that, the ripe and bigger fruit are usually more vulnerable to impact damage then smaller fruit at the breaker stage.

According to Adah (2012), the amount of tomato fruits that suffer physical injuries during handling and transportation is very significant and it is estimated to range from 50 to 70% in full ripe stage. There has also been a serious problem of mechanical damage such that, it is affecting the trade of fruit and vegetable both locally and internationally. This high level of mechanical damage and its associated diseases are all pointing to the fact that, there is the need to improve the handling of perishable produce such tomato. These physical injuries serve as the entry point to the spoilage organisms. Besides, the opening areas promote the release of moisture from the damage fruit, this eventually accelerate the rate of weight loss, shrinkage and decay.

2.9.2 Weight Loss

Weight loss is mainly due to water loss from the fruit. This implies a loss of saleable weight and volume. Besides, excessive water loss also leads to shrinkage and metabolic stress. Therefore, one can improve the marketability of a produce by putting in measures to minimize weight loss, excessive shrinkage, spoilage and metabolic stress after harvest (Genanew 2013). According to Zhiguo *et al*. (2011), transpiration is the main process that account for weight loss in most fresh produce. In tomato fruit, about 92-97% of the weight loss is attributed to transpiration. However, the weight loss attributed to respiration is usually considered negligible.

Most fresh fruit and vegetable contain up to 70 to 95% water at time of harvesting. Water loss from harvested fruit cannot be replaced and therefore this may result in shrinkage as well as weight loss. High water loss may be controlled by high humidity level. Usually when fresh produce losses up 5-10% of its fresh weight it will begin to wilt, therefore perishable plant should be maintained at relative humidity level of 90-95% (Ullah, 2009). In a study by Bhattara and Gautam (2006) it was shown that, $CaCl_2$ treatment had a significant impact on the weight loss of fruit from day 2 of storage into subsequent days. After the day 2, the fruit without any treatment (control) showed 4.2% weight loss which was significantly higher than fruits treated with $CaCl_2$.

2.9.3 Firmness

Ullah (2009) stated that, firmness is an important index for evaluating fresh produce quality. Generally, firmness decrease with the ripening of the fruit. Therefore, the texture of over ripe fruit will be softer than that of optimum mature fruit. This serves as an important criterion for assessing the quality of the fruit. Usually marketable fruit is required to have firmness value

higher then 1.45N but fruit at the home-use stage must have value higher than 1.28N. However, all fruit eventually softens progressively during storage. Ranatunga *et al*. (2009) reported that, firmness is often used to estimate maturity and also monitor the maturing process. Firmness generally refers to the force required for making a pre-determine piece using a standard probe. The registered force at the penetration of a standard probe up to a certain depth is read as the firmness. When both ripe and unripe fruit are subjected to the same level of damage, usually the ripe tomato is more vulnerable to mark losses in firmness.

According to Ortiz *et al*. (2011), firmness is an important indicator of storage potential. Besides, firmer fruits are known to be more resistant to physical damage during handling and transportation and thus contribute to extending storage life which has economic benefit. As a result of this, most Postharvest strategies are directed towards delaying extensive fruit softening. The softening may be attributed to the disassembly of middle lamella and the primary cell wall, which are made up of rigid cellulose, micro fibril held together by net work of matrix glycan and pectin**.**

Firmness has attracted a lot of research attention such that various researches have been directed towards improving the firmness of tomato during storage. According to Guzman and Barrett (2000), the principle behind maintaining the firmness of fruit can be explained by the complexing of calcium ion with cell wall and middle lamella pectin as well as the stabilization of the cell membrane by the calcium ion. A research by Bhattara and Gautam (2006) indicated that, there is a weakening of middle lamellae during ripening and that explains the softening of fruit during the ripening process. Calcium as an important constituent of the middle lamellae helps to bind the polygalacturonic acid to each other and thus making the membrane strong and rigid.

The fruit cell wall is made up of polysaccharide which are extensively modified during ripening by the action of cell wall-localised protein which result in depolymerization, solubilization and rearrangement which eventually weaken the cell wall and lead to fruit softening (Ortiz *et al*., 2011).

2.9.4 Total Soluble Solids (TSS)

According to the study by Bhattara and Gautam (2006), Calcium treatment did not affect TSS much. In the current study, there was general increase in TSS with storage. This increase may be attributed to water loss during storage which leads to higher concentration of sugar in the fruit. In the study by Genanew (2013), the amount of soluble solid in the fruit was known to increase with maturation due to the conversion of starch to sugar. The results of his study showed that, TSS of the tomato fruit increased in the first week (3.5-5.6) and continues almost constantly in all treatment. However, the differences between and within the treatment were non significant. The result also showed that, the effect of $CaCl_2$ as an ethylene absorbent on TSS of tomato fruit during storage was not significant.

According to Helyes *et al*. (2006), the range for TSS was from 4 to 9 ^{o}Brix. However malic and citric acid were the main organic acid in the tomato fruit and the range was between 0.3-0.6%. The interaction of the TSS and the acid are very important component of sweetness, sourness and flavour intensity in tomato**.** Carbohydrates constitute about 65% of the soluble solid of ripe tomato fruit. High carbohydrate and acid are required for best flavour. Results from the study by Helyes *et al*. (2006) indicated that, the first 5 stage of maturity showed no significant difference in soluble solid. However, the deep red stage showed a significantly higher ($P < 0.05$) Brix value (12 ^{o}Brix) as compared to the previous maturity stages.

Moneruzzaman *et al*. (2008) reported that, sugar content varies with the stage of harvesting because sugar content increase with maturation from the green mature to the red stage. Hurr *et al*. (2005) also mentioned that, the development of taste, aroma and flavour of the fruit is as a result of the accumulation of sugars and organic acids in the vacuoles and the production of complex volatiles.

2.9.5 Titratable Acidity

A study by Bhattara and Gautam (2006) indicated that, the effect of $CaCl_2$ treatment on titratable acidity content of the fruit juice was not significant, although, there was a general decrease in Titratable acidity with storage. During storage, the fruit might have utilized the acid through metabolic activities. Therefore the depletion of total Titratable acidity during storage may also be attributed to metabolic activities of living tissues which causes a decrease in organic acid in the fruits. In the study by Genanew (2013), the depletion of titratable acidity during ripening may be attributed to oxidation of organic acid to sugar. A rapid decrease in the content of acidity may also reduce desirable quality of the fruit. According to the report from Moneruzzaman *et al*. (2008), immature fruit has lower content of acids as compared to the matured fruit. Moreover, the acid content is usually highest at the stage when color start to appear. This is followed by a rapid decrease during fruit ripening. The pink stage is found to be the stage of tomato fruit with the maximum acidity but it falls subsequently.

2.9.6 Vitamin C

According to Lee and Kader (2000), Vitamin C is the most important vitamin among the vitamins in fruits and vegetables. These two crops supply more than 90% of the vitamin C in human diet. Vitamin C is necessary for prevention of certain diseases and maintaining the skin,

gums and blood vessel. Vitamin C is also known to be an antioxidant which reduces the risk of cardiovascular diseases and other form of cancer. The study by Lee and Kader (2000) showed that, tomato fruit harvested green and ripens at 20^{o}C turned to contain less ascorbic acid as compared to those harvested at full ripe stage. The analysis of tomato harvested at breaker stage and ripened off plant contained about 69% of the potential ascorbic acid of fruit ripened on the vine. Therefore fruit ripen on the vine generally contain more vitamin C than those ripen in storage.

Dumas *et al*. (2003) reported that, tomato is a great source of vitamin C, the mean value of vitamin C recorded range from 15 to 23mg/100g raw edible part of the tomato. However the actual range is from 8.4 to 59mg/100g. This wide variation may be due to the depletion of nutrients during storage. According to Moneruzzaman *et al*. (2008), as the tomato fruit ripens the ascorbic acid content decreases and this showed that, half ripe tomatoes generally contain the highest amount of ascorbic acid (20.05mg/100g) while the matured green recorded the lowest quality of ascorbic acid (8.58mg/100g). Moreover, with the advancement of storage time, half ripe fruit indicated a sharp decline in ascorbic acid content.

2.10 PHYSIOLOGICAL CHANGES

Ullah (2009) reported that, fresh produce are alive and still carry out transpiration, respiration, ripening and other biochemical process which shorten the storage life of the fruit. These biochemical processes and changes that occur in fresh tomato cannot be eliminated but rather reduced to certain limit by applying the appropriate postharvest technology. After harvest, the life processes still continues but there is no longer the transfer of food material and water to the fruit, therefore it has to depend on its stored food reserves for survival. Eventually the reserves

are depleted, thus the produce undergo an aging processing resulting in breakdown due to natural decay. Respiration and transpiration are the two main physiological processes that lead to deterioration. The respiration process makes use of the stored starch as long as they are available, in this process carbohydrate are broken down through oxidation resulting in the production of CO_2, water and heat.

According to Wang *et al*. (2005), the change in colour, flavour and aroma as well as the texture cell wall modification associate with fruit ripening is attributed to complex developmental process that fruit goes through during ripening and softening. Moreover, polygalacturonase is a notable enzyme that is well associated with ripening and softening of ripe fruit. The reduction in the activity of polygalacturonase enzyme has a positive correlation with enhance structural integrity of tomato fruit especially during postharvest storage.

2.11 POSTHARVEST LOSSES

Sammi and Masud (2007) reported that, the application of $CaCl_2$ has the potential to reduce postharvest decay as well as improving the quality of tomato fruit. Opiyo and Ying (2005) stated that, tomato fruit is known to have a limited postharvest life; therefore many processes that affect quality take place during storage. There has been a report on high postharvest losses annually due to spoilage. This suggests that, a method that will prolong storage life would be of great economic relevance. This implies that, a prolonged physiological process would allow the farmers and whole sellers much time to market the produce before the quality is degraded.

Fruits and vegetable require much care in handling and storage because they are extremely perishable. These horticultural crops naturally have limited shelf life due to their high moisture

content which makes them more susceptible to deterioration (Ullah, 2009). The estimated postharvest losses of tomatoes range from 40 to 60% in the developing countries which at the long round contribute to higher market price. Therefore, reduction of postharvest losses is very essential in recovering the growers cost of production as well as improving the livelihood of those in tomato business (Delina and Mahandran, 2009). Moneruzzaman *et al*. (2009) reported that, postharvest losses do not only occur in physical quantity but may also occur in the essential nutrient such as the vitamins and minerals.

2.12 STORAGE LIFE

The storage life of tomato can be described as the period of time from the harvest of the crop up to the start of rotting of the fruit and tomato fruit can be kept at ambient temperature for a period up to 5 days (Mondal, 2000). According to Bhattara and Gautam (2006), the storage life of fruit increased with the increasing concentration of $CaCl_2$. Results from this study reveal that, the maximum storage life recorded by 1% $CaCl_2$ treated fruits were significantly higher than the fruits that were not given any treatment. Therefore, tomato fruits treated with 1% $CaCl_2$ could extend the storage life and as well minimize the physiological weight.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 SOURCE OF MATERIAL

Tomato fruits (Power cultivar) were harvested at different stages of maturity (breaker, pink and light red), with calyx attached, from a tomato field at Kumawu in the Ashanti Region of Ghana. The harvesting was done 7 weeks after transplanting. The stages of maturity were determined based on the colour of the pericarp as indicated in Table 3.1.

Table 3.1: Descriptions of the stages of maturity of the sample

		
BREAKER: There is a definite break of colour from green to tannish-yellow, pink or red or 10% or less of the tomato surface.	**PINK:** Pink or red color shows on over 30% but not more than 90% of the tomato surface.	**LIGHT RED:** Pinkish-red or red color shows on over 60% but red color covers not more than 90% of the tomato surface

Source: http://postharvest.ucdavis.edu

Sorting and grading were done to ensure that only fruits that were visibly free from diseases and defect were selected for the experiment. Fruits from each of the three stages of maturity were packed into separate wooden boxes with ventilation holes. The tomato fruits were then transported within 3 hours to the laboratory of the Department of Horticulture, KNUST. Kumasi-Ghana.

3.2 EXPERIMENTAL SITE:

This study was carried out during the period of July and August, 2013 after a preliminary experiment in June 2013 at the laboratory of the Department of Horticulture in Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. The temperature range for the study was between 24 and 28 ^{o}C with an average relative humidity of 82%.

3.3 SETUP OF THE EXPERIMENT

3.3.1 First Phase:

This was a preliminary stage which involved dipping whole tomato fruits in 2% and 6% $CaCl_2$ aqueous for 30, 40 and 60 min. The fruits were monitored for skin injuries. The results indicated that, 40 and 60 min dip time showed signs of skin injuries. Therefore, the 30 min dip time was selected for the next stage of the study.

3.3.2 Second Phase

This phase involved 2 factors: Maturity stage (breaker, pink and light-red stage) and concentration of calcium chloride (2%, 6%, and 0%). After the arrival of the tomatoes fruits at the laboratory, fruits were sorted again for the presence of mechanical injuries. All the fruits were washed with water to remove dirt. Fruits at each stage of maturity were then dipped in different concentrations of $CaCl_2$ for 30 minutes. The 30 minutes dip time was chosen based on the recommendation from the preliminary experiment. Samples were allowed to air-dry under ambient conditions.

The treated samples and the control (0% $CaCl_2$) were all stored in a well-ventilated storage box in the laboratory as shown in plates below:

Plate 3.1 Display of treated samples

Plate 3.2 Treatments in the storage box

Plate 3.3 Top view of storage box

Plate3.4 Section of the storage room

3.3.3 Third Phase:

In the third phase, only tomato fruits harvested at the pink stage were studied. The fruits were dipped in different concentrations of calcium chloride (0%, 2% and 6%) at different dip times (10, 20 and 30 minutes).

3.4.0 PARAMETERS MONITORED IN THE EXPERIMENT:

3.4.1 Mechanical Damage

Tomato fruits from each stage of maturity were assessed for the presence of cut, bruises and compression damage. The value was expressed in percentage of the total number of fruit in that stage of maturity. The weight loss and decay were determined according to the method by Nirupama *et al*. (2010) and the results expressed in percentage.

3.4.2 Weight Loss

Fruits were weighed daily and the differences in weight loss were expressed as a cumulated percentage of weight loss from the initial weight of the fruit.

3.4.3 Decay

The decay was determined by visual observation. Decay was expressed as accumulated percentage of the total fruit decay divided by the initial fruit number stored.

3.4.4 Total soluble solids (TSS)

The TSS was determined by the use of digital refractometer (Reed MT-032 Brix Refractometer, Taiwan) and the value reported as Degree Brix (Nirupama *et al*., 2010).

3.4.5 Firmness

Firmness was determined by measuring the force required for making a pre-determine piece using a standard probe. The registered force at the penetration of a standard probe up to a certain depth is read as the firmness. The firmness of fruits was measured by the use of penetrometer (FT 327, Effegi, *Italy)* and the value was expressed in Newton (Kumah *et al*., 2011).

3.4.6 Titratable Acidity (TA)

In the TA measurement, 10ml of juice from the various samples were titrated with 0.1M NaOH and the result are expressed in percentage citric acid (Mohammadi-Aylar *et al.*, 2010).

3.4.7 Vitamin C

This was determined by using the 2, 6-Dichloroindophenol Titrimetric method and the results reported as mg/100g of tomato fruit (AOAC, 2006).

3.4.8 Storage Life

The storage life was determined from the start of harvest and extended up to the start of rotting of fruits (Mondal, 2000). Therefore, the storage life was determined by monitoring the number of days taken for 20% of the fruits to show symptoms of decay.

3.5 EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

Both the second and the third phases were arranged in 3x3 factorial Complete Randomized Design (CRD) with 3 replicate. The data generated were subjected to analysis of variance (ANOVA) using GenStat statistical software version 12. Significant differences were assessed at 5% ($p \leq 0.05$).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 MECHANICAL DAMAGE

Power cultivar of tomato fruits harvested at 3 different stages of maturity (Breaker, Pink and Light red stage) were evaluated for mechanical injuries after the fruits were transported to the laboratory. The analysis of variance indicated significant differences ($P < 0.05$) among the stages of maturity (Table 4:1). Fruits harvested at the breaker stage recorded the lowest percentage of physical injuries (7.25 %) followed by fruits harvested at pink stage (9.04%) and light red (17.56%) as indicated in Table 4.1. The level of mechanical injuries recorded by the light red stage was significantly more ($P < 0.05$) than fruits harvested at pink and breaker stage. However, there was no significant difference ($P \geq 0.05$) between fruits harvested in breaker and pink of maturity.

Table 4.1: Means of mechanical damage (%) of tomato fruit from three stages of maturity after arrival from the field

Stage of maturity	**Mechanical Damage (%)**
Breaker	7.25±1.56b
Pink	9.04±0.50b
Light-red	17.56±1.16a

**values followed by the same letters are not significantly different at 5%*

Physical injuries serve as the entry point to the spoilage organisms and also promote the release of moisture from the fruit, accelerating the rate of weight loss and shrinkage (Adah, 2012). The higher level of mechanical damage recorded in the fruits harvested at the light red stage could be attributed to the softening of tomato skin which is associated with the ripening of tomato fruit. Mohammadi-Aylar *et al*. (2010) reported that, there is a positive correlation between percentage of physical injury and the development of ripening stage, which means that as the fruit ripens, its susceptibility to physical injuries also increases. The results from the study by Babarinsa and Ige (2012) also showed that, fruit harvested at the advanced stage of ripening were more vulnerable to compression damage.

Therefore, harvesting tomato fruit at the breaker and the pink stage has the potential to reduce mechanical injuries compared to light red stage. The study conducted by Idah e*t al*. (2007) also revealed that the ripe and bigger fruit are usually more vulnerable to impact damage then smaller fruit at the green stage. Injuries in the form of cuts, compression, split or bruises may destroy the physical integrity of the fruit. Zhiguo *et al*. (2010) reported that, mechanical injuries resulting

from harvesting, handling and transportation of tomato may eventually affect cell walls, causing enzymatic degradation which may be observed as soft spots on the fruits. Ullah (2009) also indicated that, the time at which famers harvest tomato fruit is critical for its quality and postharvest behaviors, thus harvesting produce at the proper stage of maturity is the most basic factor affecting quality.

According to Atherton *et al*. (1986), the skin of a fruit which is made up of cuticle and thick-walled epidermal and sub-epidermal cell usually serves as a barrier to the invasion of microorganisms. If this skin barrier is broken through physical injuries, then the fruit compromises its physical protection which makes the fruit more susceptible to decay.

Therefore, controlling the amount of mechanical injury is one of the ways to increase food safety by lowering the potential for microbial infestation.

4.2 WEIGHT LOSS

4.2.1 Second Phase Results and Discussion on Weight Loss

Tomato fruits harvested at the 3 stages of maturity (Breaker, Pink and Light red stage) and dipped in different concentrations of $CaCl_2$ (2%, 6% and 0%) for 30 min. were evaluated for postharvest weight loss from day 1 to day 10. The analysis of variance indicated significant differences ($P < 0.05$) among the stages of maturity in fruit weight loss. Tomato fruits harvested at the light red stage recorded significantly ($P < 0.05$) higher weight loss (6.0%) than fruit harvested at the breaker (5.0%) and pink (5.14%) stage in day 6 as indicated in Figure 4.1 .

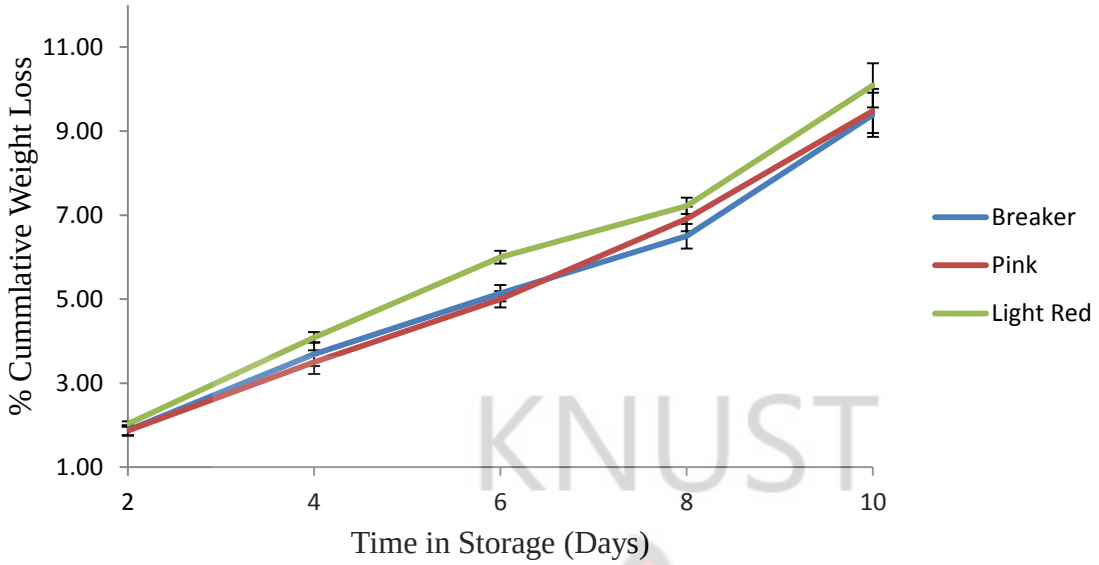

Figure 4.1: Means of cumulative weight loss of tomato fruits harvested at different maturity stages and stored at room conditions.

However, there was no significant ($P < 0.05$) difference in weight loss between fruit harvested at breaker stage and pink stage throughout the storage period, as shown in Figure 4.1. The results also indicated consistent increase in fruit weight loss in the all stages of maturity from day 1 to day 10 (Figure 4.1).

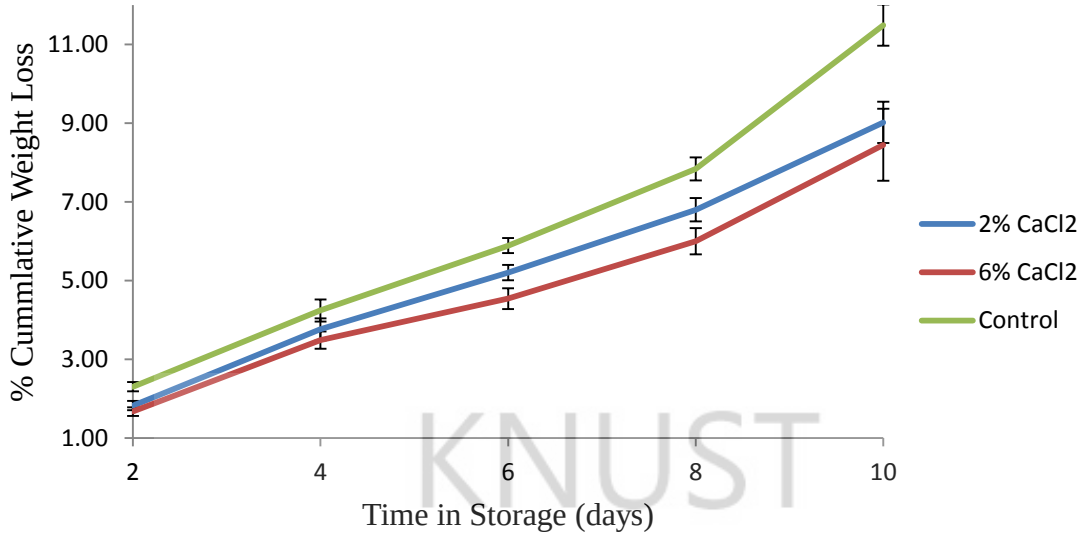

Figure 4.2: Means of cumulative weight loss of tomato fruits treated with different concentrations of $CaCl_2$ at 30 minutes dip time.

The analysis of variance indicated significant differences ($P < 0.05$) among the levels of calcium chloride treatment in fruit weight loss. The significantly ($P < 0.05$) higher weight loss recorded by the control (11.49%) as compared to fruits treated with 2% $CaCl_2$ (9.02%) and 6% $CaCl_2$ (8.45%) at day 10 (Figure 4.2) could be attributed to the network formation of calcium with the pectin in the fruit cell wall to restrict moisture loss as reported by (Genanew, 2013). The calcium might have also reduced physiological processes in the treated samples which retarded the rate of moisture loss. According to Genanew (2013), weight loss is mainly due to water lost from the fruit. Weight loss also implies a loss of saleable weight and volume.

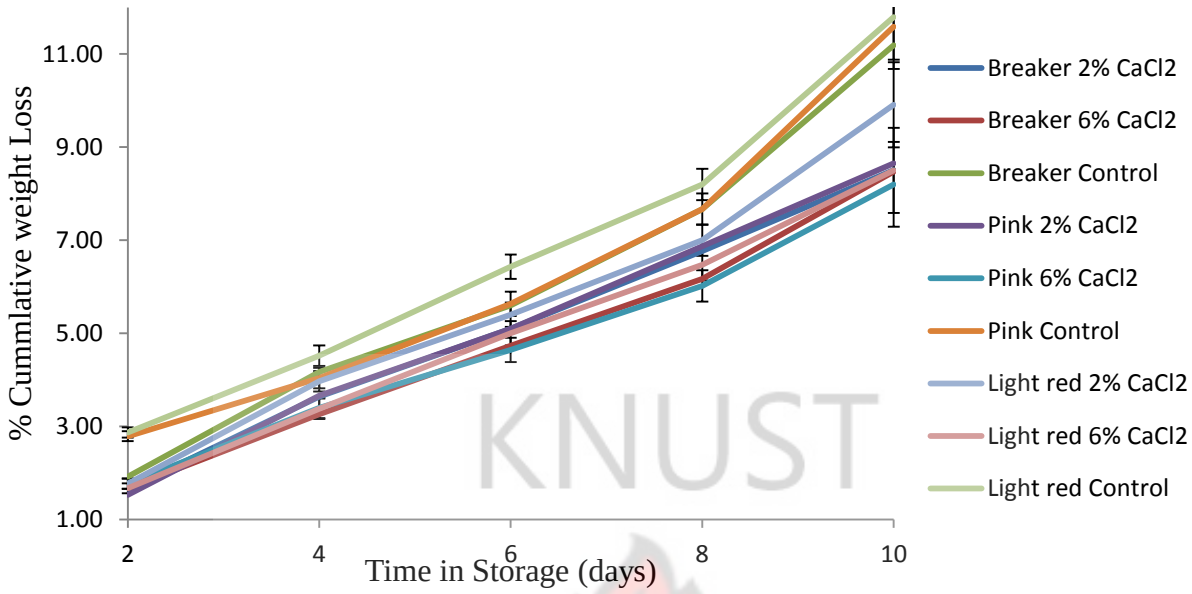

Figure 4.3: Means of cumulative weight loss of tomato fruits from the interaction between the $CaCl_2$ concentration and stage of maturity at the 30 minutes dip time.

Although there were no significant ($P > 0.05$) interaction between the maturity stage and the level of $CaCl_2$ concentration, fruits harvested at the pink stage and dipped in 6% $CaCl_2$ recorded significantly ($P < 0.05$) lower (8.45%) weight loss as compared to fruit harvested at the light red stage with no $CaCl_2$ treatment (11.49) as shown in Figure 4.3. Zhiguo *et al*. (2011) reported that, transpiration is the main process that account for weight loss in most fresh produce. In tomato fruit, about 92-97% of the weight loss is attributed to transpiration. Therefore, the significantly ($P < 0.05$) lower weight loss in the calcium treated samples may be due to the reduced transpiration rate which leads to less water loss. The higher weight loss in the control samples may lead to shrinkage, metabolic stress and eventually decay which reduces the storage of the tomato fruit.

4.2.2 Third Phase Results and Discussion on Weight Loss

Tomato fruits harvested at only pink stage were treated with different concentration of calcium chloride (0%, 2% and 6%) solution for different durations (30, 20 and 10 min.). The analysis of variance indicated significant differences ($P < 0.05$) among concentrations of $CaCl_2$ treatment in fruit weight loss. Tomato fruits treated with 6% $CaCl_2$ recorded significantly lower ($P < 0.05$) weight loss (8.97%) than fruits treated with 2% $CaCl_2$ (9.82%) and the control (12.19%) at day 10 as indicated in Figure 4.4.

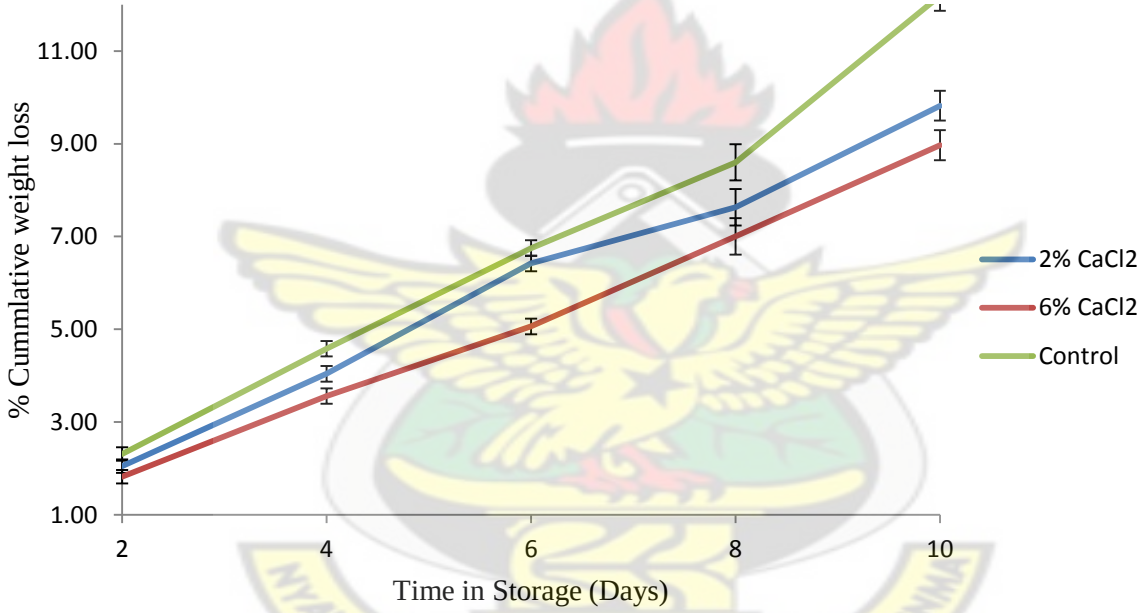

Figure 4.4: Means of cumulative weight loss of tomato fruits harvested at the pink stage and treated with different concentrations of $CaCl_2$.

The analysis of variance also showed significant differences ($P < 0.05$) in weight loss among the 3 dip times (30, 20 and 10 minutes) at day 10 (Figure 4.5). There was a general increase in weight loss during storage. However, fruits dipped for 10 minutes recorded a significantly higher

(P < 0.05) weight loss (11.20%) than fruits treated for 30 and 20 minutes (9.83% and 9.95% respectively). The differences in weight loss between fruits treated for 30 and 20 minutes were not significant (P > 0.05).

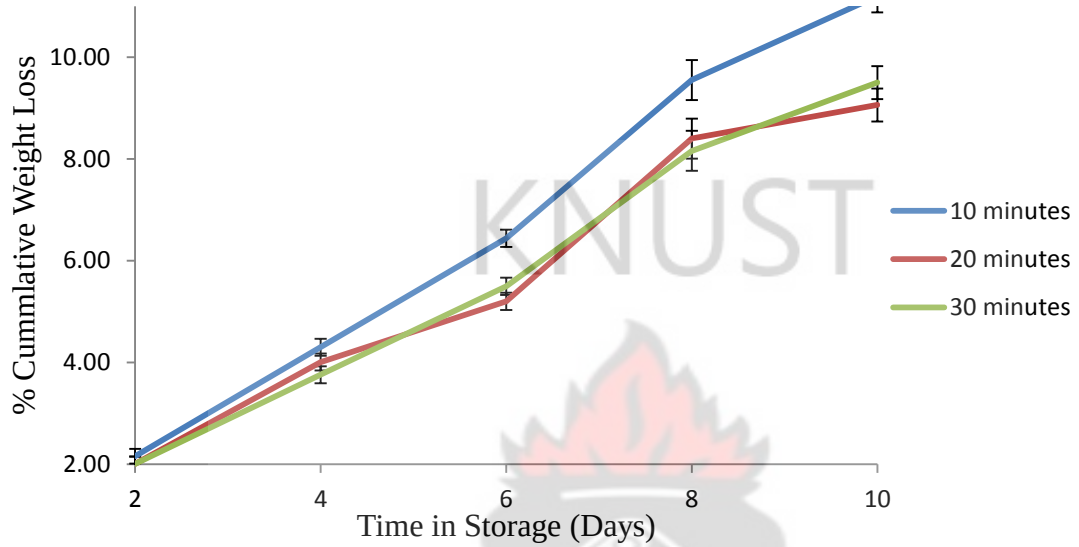

Figure 4.5: Means of cumulative weight loss (%) of tomato fruits harvested at the pink stage and dipped in $CaCl_2$ at different dip time.

Therefore tomato fruits dipped for 20 and 30 minutes adequately allowed for effective cross linking between the Ca ion and the pectin which effectively slowed down respiration and transpiration rate which are known to be the major cause of weight loss (Zhiguo *et al.*, 2011). Weight loss in tomato fruit negatively affects the appearance of the fruit therefore there is the need to control rapid weight loss. In addition, significantly (P < 0.05) lower weight loss recorded by tomato fruits treated with $CaCl_2$ for 30 and 20 minutes as shown in Figure 4.5, may be attributed to the fact that, the $CaCl_2$ had enough time to penetrate into the fruit to retard physiological processes such as respiration. In other words, significantly (P < 0.05) higher

weight loss recorded by fruits treated for 10 minutes may be attributed to inadequate time for the calcium to form complex with the pectin in the fruit cell wall to control weight loss.

Results from the interaction showed that, significantly ($P < 0.05$) lower weight loss was recorded in fruits dipped in 6% $CaCl_2$ for 20 (8.43%) or 30 (8.17%) minutes. However, the highest weight loss was recorded by the control (with no $CaCl_2$ treatment) as shown in Figure 4.6.

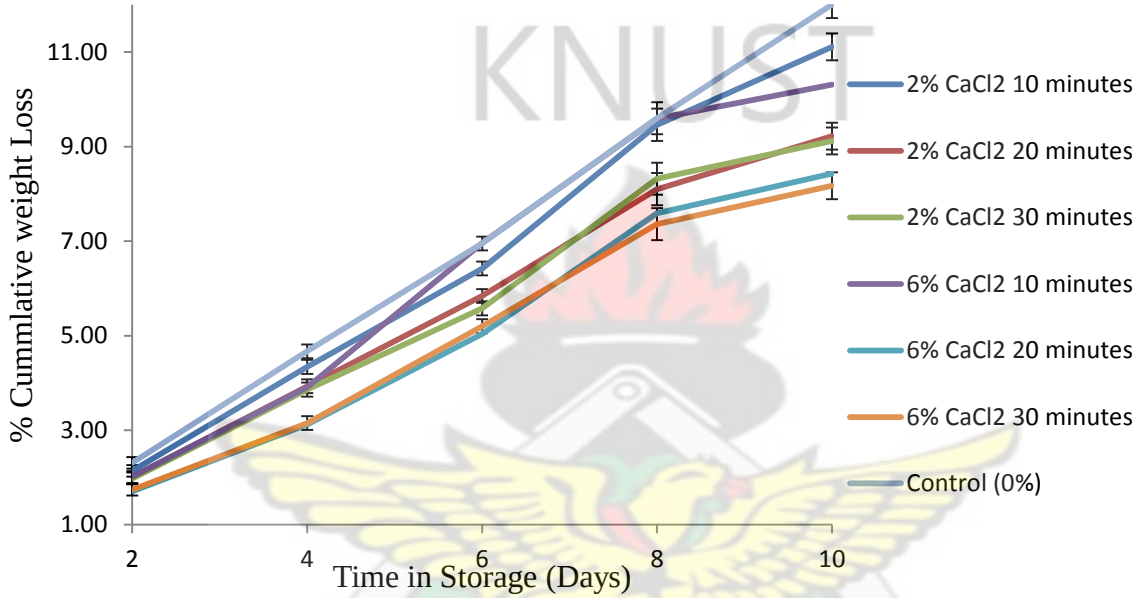

Figure 4.6: Means of cumulative weight loss of tomato fruits from the interaction between the CaCl2 concentration and dip time.

The significantly higher weight loss recorded by the control was undesirable because, when fresh produce losses up to 5%-10% of its fresh weight it begins to wilt which also affect its marketability (Gautam, 2006). Therefore, one can actually improve the marketability of a produce by putting in measures such as calcium treatment to minimize weight loss, excessive shrinkage, spoilage and metabolic stress after harvest.

4.3.0 FIRMNESS

4.3.1 Second Phase Results and Discussion on Firmness

The analysis of variance for fruit firmness showed significant differences ($P < 0.05$) among the stages of maturity (Breaker, Pink and light red stage) as indicated in Figure 4.7.

Tomato fruits harvested at the light red stage recorded significantly ($P < 0.05$) lower firmness than fruit harvested at the breaker and pink stage in day 3, 6 and 12. However, there was no significant ($P < 0.05$) difference in firmness between fruit harvested at breaker stage and pink stage, as shown in Figure 4.7. The results also indicated consistent decrease in fruit firmness in the all stages of maturity from day 1 to day 12 (Figure 4.7).

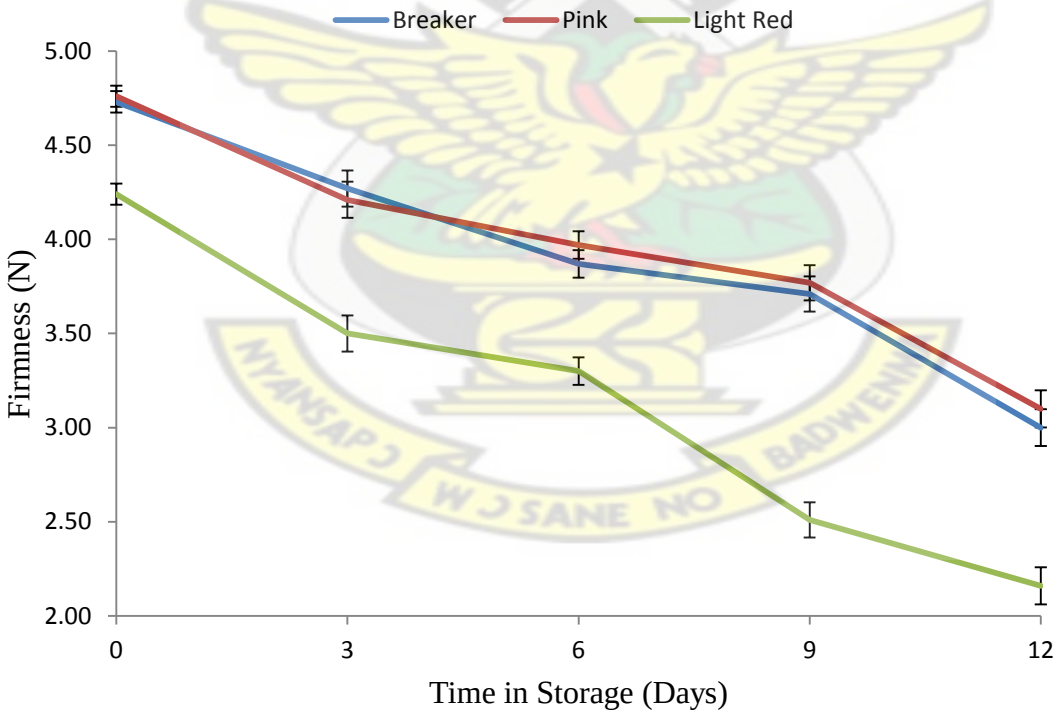

Figure 4.7: Means of firmness of tomato fruits harvested at different maturity stages and stored at room conditions

Fruits harvested at the breaker and the pink stage lost firmness at a much slower rate compared to fruits harvested at the light red stage. This may be attributed to the difference in their cell wall strength. Generally, as fruit ripens it becomes soft and fruit cell wall is firmer or stronger in the breaker and the pink stage than in the light red stage. According to Ranatunga *et al*. (2009), when both ripe and unripe fruit are subjected to the same level of damage, usually the ripe tomato is more vulnerable to mark losses in firmness. This implies that, ripe tomato fruit may soften more quickly as compared to the less ripe tomato.

The analysis of variance for fruit firmness (N) at day 6, 9 and 12 also indicated significant differences ($P < 0.05$) among the levels of calcium chloride treatment. The firmness of fruit treated with 6% $CaCl_2$ was significantly ($P < 0.05$) higher than fruits treated 2% $CaCl_2$ and the control (0%) throughout the storage period as shown in Figure 4.8. Although, there was a general decrease in firmness in all the treatments, the control lost firmness at a faster rate as indicated in Figure 4.8. This may be attributed to the faster rate of metabolic processes in the fruits that were not treated as compared to the fruits treated with $CaCl_2$. According to Nirupama *et al*. (2010), the decrease in firmness of fruit may be as a result of cell wall carbohydrate metabolism during storage which further increases the susceptibility of the fruit to decay.

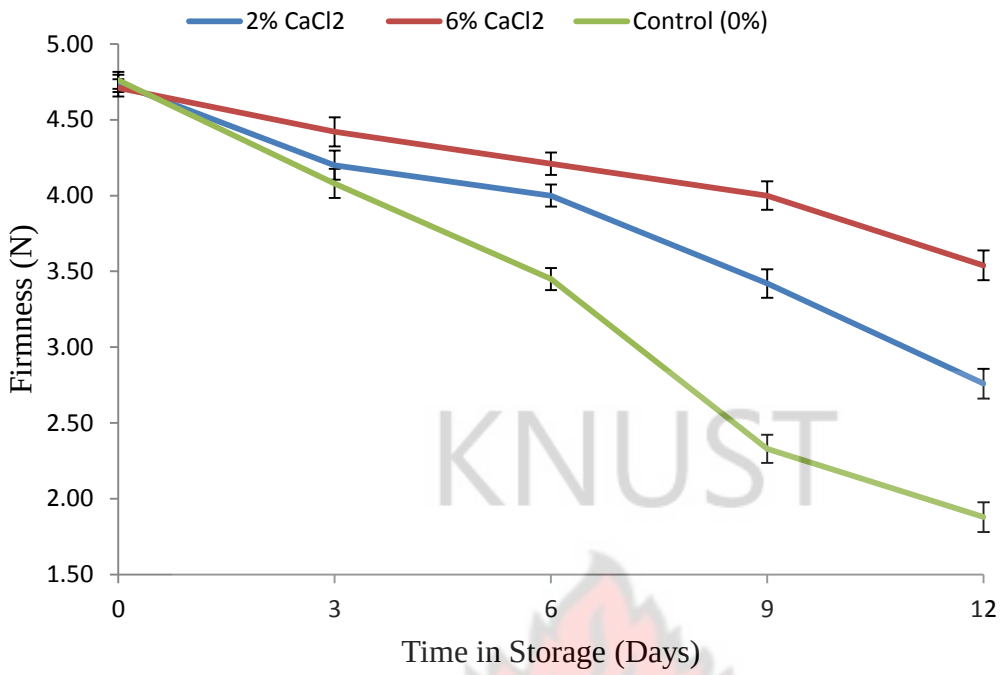

Figure 4.8: Means of firmness of tomato fruits treated with different concentrations of $CaCl_2$ at 30 minutes dip time.

Anthon *et al.* (2005) reported that, the calcium salt binds to block the free carboxylic acid group along the polygalacturonic acid back of the pectin to form cross-link between pectin chains. Therefore, the firmer texture of the $CaCl_2$ treated fruits may be as a result of increase cross-linking in the middle lamella which leads to a greater adhesion between cells. Thus, the calcium eventually inhibits the activities of polygalacturonase resulting in much firmer texture as compared to tomato that received no calcium treatment.

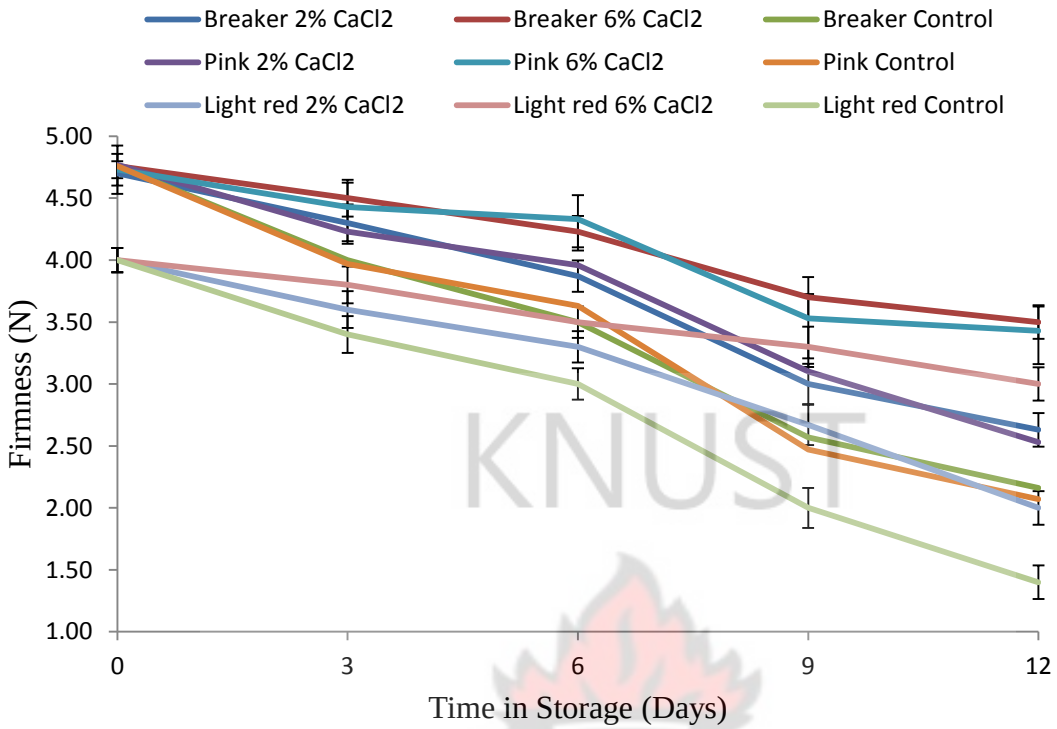

Figure 4.9: Means of Firmness (N) of tomato fruits from the interaction between the $CaCl_2$ concentration and stage of maturity at the 30 minutes dip time.

There was a significant interaction between the $CaCl_2$ concentration and stage of maturity. This was demonstrated when tomato fruit harvested at the light red stage and treated with 6% $CaCl_2$ recorded significantly ($P < 0.05$) higher firmness (3.0N) than fruits harvested at the breaker without $CaCl_2$ treatment (2.16N) at day 12 (Figure 4.9).

4.3.2 Third Phase Results and Discussions on Firmness

Tomato fruits harvested at the pink stage were treated with different concentration of $CaCl_2$ solution at different dip times (30, 20 and 10 minutes). The analysis of variance for fruit firmness during storage indicated significant differences ($P < 0.05$) between levels of $CaCl_2$ treatment at

day 6, 9 and 12 (Figure 4.10). Fruits treated with 6% $CaCl_2$ recorded a significantly ($P < 0.05$) higher firmness (3.53N) than fruits treated with 2% $CaCl_2$ (2.94N) at day 9. Moreover, both fruits treated with 6% and 2% $CaCl_2$ recorded significantly ($P < 0.05$) higher fruit firmness than the control (0%).

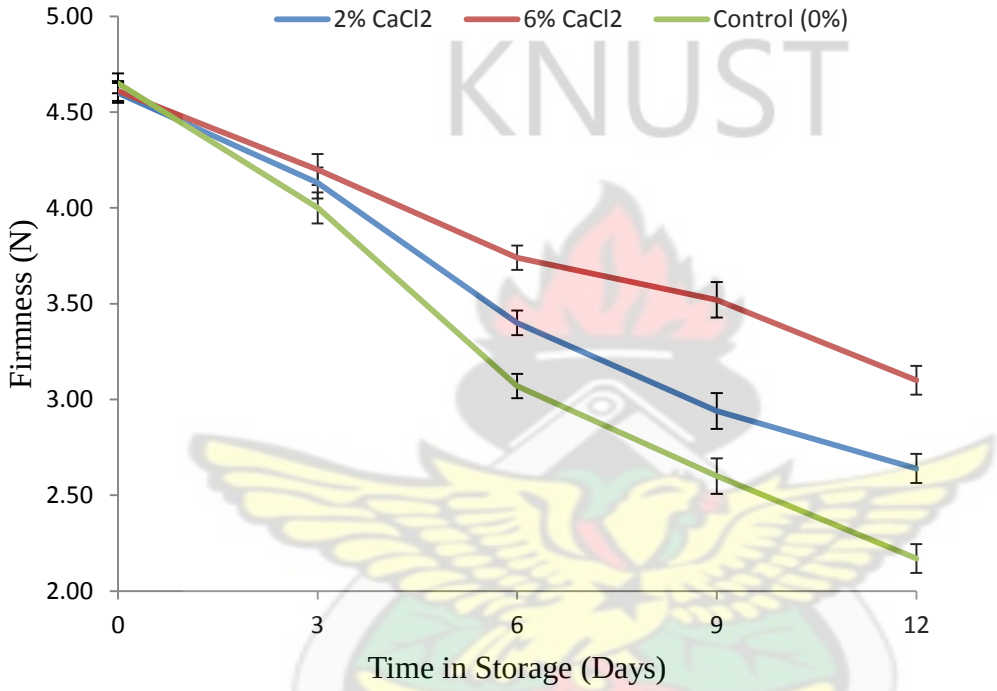

Figure 4.10: Means of firmness (N) of tomato fruits harvested at the pink stage and treated with different concentrations of $CaCl_2$.

The analysis of variance for fruit firmness (N) also showed significant differences ($P < 0.05$) between the dip times of $CaCl_2$. Both tomato fruits dipped for 30 and 20 minutes recorded significantly ($P < 0.05$) higher values of fruit firmness than the fruits dipped for 10 minutes at day 6, 9 and 12. However, there was no significant difference in fruit firmness between fruits dipped for 30 minutes and those dipped for 20 minutes as indicated in Figure 4.11. The

significantly ($P < 0.05$) higher firmness recorded by tomato fruit dipped for 30 and 20 minutes as compared to the 10 minutes, may be attributed to the adequate time for effective interaction between the calcium and the pectin in the cell wall of the tomato fruit. Anthon *et al* (2005) also reported that the interaction of calcium with pectin is known to be the mechanism for calcium firming role.

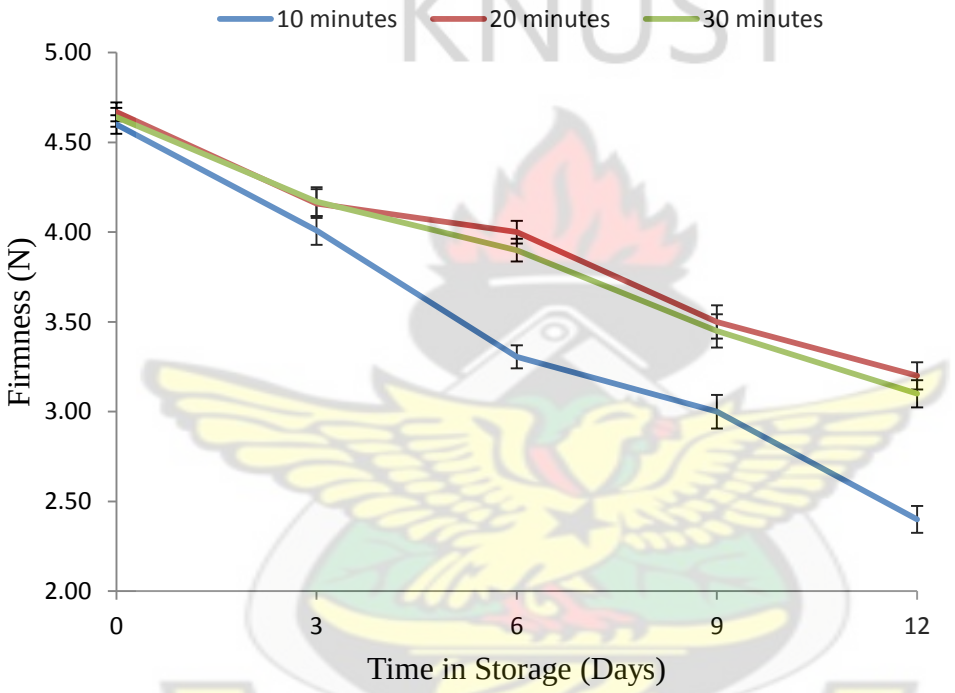

Figure 4.11: Means of firmness (N) of tomato fruits harvested at the pink stage and dipped in $CaCl_2$ at different dip times.

The analysis of variance indicated significant ($P < 0.05$) differences in the interactions between the dip times and the concentration of $CaCl_2$ treatment. Even though, the mean fruit firmness for fruits treated with 6% $CaCl_2$ (4.0N) is significantly higher ($p < 0.05$) than fruits treated with 2% $CaCl_2$ (3.42N). Yet, fruits treated with 2% $CaCl_2$ for 30 minutes recorded significantly ($P < 0.05$)

higher (3.50N) fruit firmness than fruit treated with 6% $CaCl_2$ for 10 minutes (3.23N), as indicated in Figure 4.12. This is as a result of the interaction between the $CaCl_2$ concentration and the dip time.

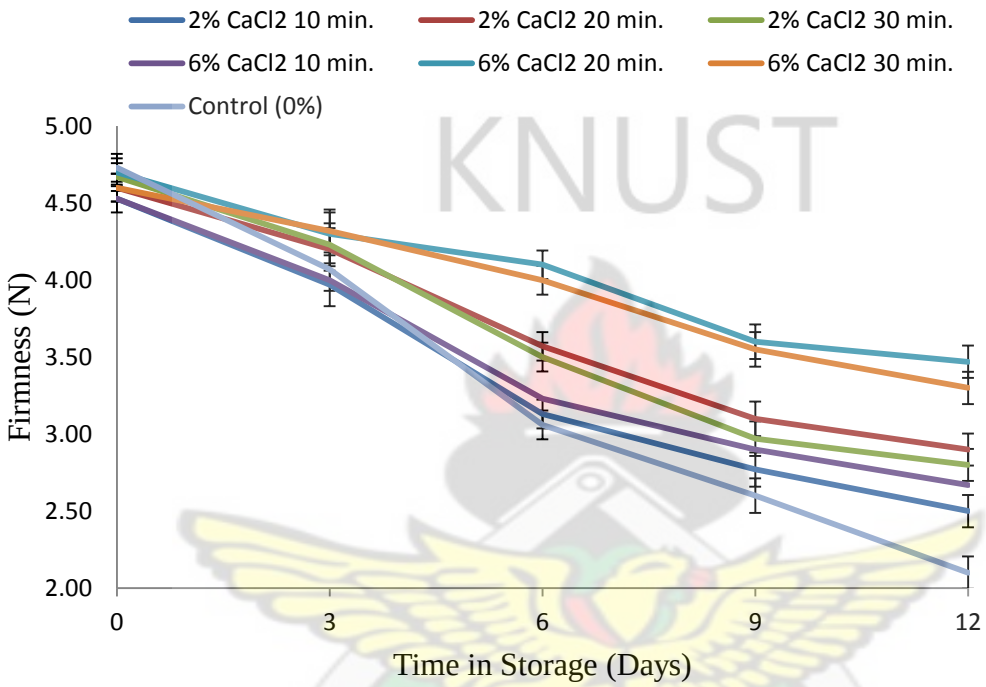

Figure 4.12: Means of firmness (N) of pink stage fruits from the interaction between the $CaCl_2$ concentration and the dip time.

The significant interaction recorded between the concentration of $CaCl_2$ and the dip time suggests that, for effective firming role, one needed to apply the right concentration over the right time period. Even though 6% $CaCl_2$ recorded the highest mean of fruit firmness (3.10N), tomato fruits dipped in 6% $CaCl_2$ for 10 minutes, recorded significantly ($P < 0.05$) lower firmness (2.67N) than fruits dipped in 2% $CaCl_2$ for 20 min. (2.90N) at day 12. This may be attributed to the inadequate time period for the calcium to complex with the pectin to perform its

firming role on the fruit.

At the pink stage of maturity, low firmness values recorded by the control and fruits dipped for 10 minutes may be attributed to the faster weakening of their cell wall. A research conducted by Bhattara and Gautam (2006) indicated that, there is a weakening of middle lamellae during ripening and that may explain the softening of fruit during the ripening process. Calcium as an important constituent of the middle lamellae helps to bind the polygalacturonic acid to each other and thus making the membrane strong and rigid, therefore the presence of calcium in the treated samples may account for their firmer pericarp.

Firmness is an important indicator of storage potential. Besides, firmer fruits are known to be more resistant to physical damage during handling and transportation and thus contribute to extending storage life which has economic benefit. As a result of this, most Postharvest strategies are directed towards delaying extensive fruit softening (Ortiz *et al*., 2011). Maintaining higher firmness of tomato fruit will go a long way to control decay, hence increased the storage life of the fruit.

4.4 DECAY

4.4.1 Second Phase Results and Discussions on Decay

The stage of maturity and the level of calcium chloride treatment had a significant ($P < 0.05$) difference on fruit decay when the tomato fruits were evaluated for the presence of decay during storage. The analysis of variance indicated significant ($P < 0.05$) differences in percentage decay levels among the 3 stages of maturity (Breaker, pink and light red stage). The fruits harvested at

the light red stage recorded a significantly ($P < 0.05$) higher level of decay (46.10%) during storage as compared to fruit harvested at the breaker (41.67%) and pink stage (41.33%) at day 10. However, there was no significant difference ($P > 0.05$) in decay levels between the breaker (41.67%) and the pink stage (41.33%) as shown in Table 4.2.

Table 4.2: Means of Decay (%) of tomato fruit from the interaction between the stage of maturity and $CaCl_2$ concentrations at 30 min. dip time after 10 days of storage.

	Maturity Stage			
$CaCl_2$ Concentrations	**Breaker**	**Pink**	**Light Red**	**Mean**
6%	32.00±6.11c	32.00±4.60c	40.00±4.00bc	34.67±4.10b
2%	37.30±4.10c	37.30±2.31c	49.30±3.10b	41.00±3.00b
Control (0%)	56.00±4.10	54.70±4.11b	69.00±6.10a	59.90±610a
Mean	41.67±3.10b	41.33±4.00b	46.10±4.10a	

**values followed by the same letters are not significantly different at 5%*

The significantly (($P < 0.05$) higher rate of decay recorded by the fruits harvested at the light red stage may be due to the softer skin tissue which makes the red fruits more susceptible to decay. Helyes and Pek (2006) reported that, harvesting tomato fruit at the later stage of maturity (deep red) makes the fruit much more vulnerable to damage and decay. As a result, the first measure to extend the storage life of tomato is to harvest at the right stage of maturity. According to Genanew (2013), delaying in the harvest may lead to higher tendency of increasing the susceptibility to decay which results in poor quality and low market value. Since the fruit

harvested in the breaker and pink stage were firmer than those in the light red stage, they were less susceptible to decay.

The analysis of variance also indicated significant differences ($P < 0.05$) among the levels of calcium chloride treatment in fruit decay (%). The fruits treated with 6% $CaCl_2$ recorded the lowest level of decay (34.67 %) followed by 2% $CaCl_2$ (41.00%) and 0% (59.90%). The level of decay was significantly ($P < 0.05$) higher in the control (59.90%) than in the treated sample (34.67 and 41%). However, there were no significant difference in the level of decay between the 6% $CaCl_2$ (34.67%) and 2% $CaCl_2$ (41%) as indicated in Table 4.2. The significantly ($P < 0.05$) lower levels of decay recorded by the calcium treated fruits may be attributed to the reduced respiration and transpiration rate which have been reported to be the two main physiological processes that lead to deterioration. According to Ullah (2009), the respiration process makes use of the stored starch as long as they are available, in this process carbohydrate are broken down through oxidation resulting in the production of CO_2, water and heat.

The higher level of decay recorded in the control (0%) could be attributed to the faster rate of softening facilitated by the action of polygalacturonase. A study by Wang *et al*. (2005) also indicated that, polygalacturonase is a notable enzyme that is well associated with ripening and softening of ripe fruit. The reduction in the activity of polygalacturonase enzyme has a positive correlation with enhance structural integrity of tomato fruit especially during postharvest storage. Calcium has been reported by Anthon e*t al*. (2005) to inhibit the activities of polygalacturonase resulting in much firmer texture and delayed rotting as compared to tomato fruit that received no calcium treatment.

4.4.2 Third Phase Results and Discussions on Decay

The analysis of variance of the third phase also indicated significant differences ($P < 0.05$) between the levels of calcium chloride treatment in fruit decay (%). Tomato fruits treated with $CaCl_2$ (6% and 2% $CaCl_2$) recorded a significantly ($P < 0.05$) lower level of fruit decay as compared to the control set (0%). However, there was no significant difference ($P > 0.05$) in fruit decay between the 6% (44.77%) and the 2% $CaCl_2$ (50.23%) treatment as shown in Table 4.3.

Table 4.3: Means of Decay (%) of pink stage tomato fruit from the interaction between the $CaCl_2$ concentrations and the dip time after 10 days storage.

$CaCl_2$ concentration	Dip Time (Minutes)			Mean
	30	20	10	
6%	33.33±4.11d	37.00±4.00cd	58.00±2.00b	44.77±3.11b
2%	46.00±4.11c	44.00±2.00c	60.70±6.33b	50.23±4.00b
Control (0%)	72.70±2.10a	72.70±2.10a	72.70±2..10a	72.70±2.10a
Mean	50.68±4.00b	51.23±4.11b	63.56±3.00a	

**values followed by the same letters are not significantly different at 5%*

The analysis of variance for fruit decay also indicated significant differences ($P < 0.05$) between the dip times of the $CaCl_2$ treatment. There was however no significant difference ($p > 0.05$) in decay levels (%) between fruits dipped for 30 minutes (50.68%) and 20 minutes (51.23%) but they however recorded significantly ($P < 0.05$) lower decay levels than the fruits dipped for 10 min (63.56%), as indicated in Table 4.3. The significantly ($P < 0.05$) lower decay levels recorded by tomato fruits dipped for 30 and 20 minutes may be attributed to the fact that, the $CaCl_2$ had a

sufficient time to penetrate into the fruit to retard physiological processes which also delayed the incidence of decay.

The analysis of variance for the interactions between the dip times and the concentration of calcium chloride treatment in fruit decay also indicated significant differences ($P < 0.05$) in the decay levels. The interaction results indicated that, fruits dipped in 2% $CaCl_2$ for 30 minutes recorded significantly lower level (66.7%) of decay than fruit dipped in 6% $CaCl_2$ for 10 minutes (80%). Meanwhile, the mean decay level of fruit treated with 2% $CaCl_2$ (50.23%) is higher than the mean decay level of fruit treated with 6% $CaCl_2$ (44.77%) as shown in Table 4.3. This is as a result of the interaction between the $CaCl_2$ concentration and the dip time. This meant that, for effective control of decay, one needed to dip the tomato fruit in the right concentration of the $CaCl_2$ (6%) over the right duration (20 or 30 min.). The 20 and 30 minutes dip time enhanced better network between the calcium and the pectin in the fruit, thus delayed the rate of decay.

Nirupama *et al*. (2010) reported that, calcium application helps maintain membrane integrity, tissue firmness, cell turgor as well as delaying membrane lipid catabolism and extending storage life of fruit**.**

4.5.0 TOTAL SOLUBLE SOLIDS (TSS)

4.5.1 Second Phase Results and Discussion on TSS

The stage of maturity (Breaker, Pink and Light red stage) and the level of $CaCl_2$ treatment (6% $CaCl_2$, 2% $CaCl_2$ and the control (0%)) did not have significant influence on the fruit's total soluble solids. The analysis of variance indicated no significant differences ($P > 0.05$) among the

levels of $CaCl_2$ treatment in fruit TSS. The TSS of the fruits treated with 6% $CaCl_2$, 2% $CaCl_2$ and the control (0%) was not significant at 5% significant level (P >0.05) as shown in Table 4.4.

Table 4.4: Means of TSS (^oBrix) of tomato fruit from the interaction between the stage of maturity and $CaCl_2$ concentrations at 30 minutes dip time after 10 days storage.

	Maturity Stage			
$CaCl_2$ Concentrations	**Breaker**	**Pink**	**Light Red**	**Mean**
6%	4.00±0.02a	4.00±0.02a	4.06±0.15a	4.02±0.02a
2%	4.00±0.02a	4.00±0.02a	4.06±0.15a	4.02±0.03a
Control (0%)	4.10±0.15a	4.10±0.03a	4.13±0.11a	4.11±0.02a
Mean	4.03±0.02a	4.03±0.01a	4.08±0.02a	

**values followed by the same letters are not significantly different at 5%*

There was a general increase in total soluble solids in all the treatments during storage. Although the control (0%) recorded higher TSS (4.11 ^oBrix) than the calcium treated fruits (4.02 ^oBrix), the difference between them were not significant. This result was comparable to the study by Bhattara and Gautam (2006) which reported that, calcium treatment did not affect TSS. Thus, there was general increase in TSS with storage. This increase in TSS may be attributed to the conversion of starch to sugar during ripening of the fruit and also water loss during storage which leads to higher concentration of sugar in the fruit.

The analysis of variance showed no significance difference (P >0.05) in TSS among the stages of maturity (Breaker, Pink and Light red) at day 10 of the storage period. Moreover, there was no

significant difference in the interaction between the stage of maturity and the level of calcium chloride treatment in total soluble solids as indicated in Table 4.4. The results from the study indicated a general increase in TSS in all the stages of maturity during storage. This result is in line with the study by Helyes *et al*. (2006), which showed that, the amount of soluble solid in the fruit was known to increase with maturation. This could be attributed to the conversion of starch to sugar during ripening. According to Getinet *et al*. (2008), fruit harvested at the matured green stage had the lowest TSS and ascorbic acid level. But fruit harvested at light red stage had the highest TSS content.

4.5.2 Third Phase Results and Discussions on TSS

In the third phase, the analysis of variance indicated no significant differences ($P > 0.05$) between the levels of $CaCl_2$ treatment in fruit TSS. However, the TSS of the fruits treated with 6% and 2% $CaCl_2$ recorded a lower TSS than the control (0%). There was also no significant difference in TSS between the 2 levels of $CaCl_2$ (2% and 6%) treatment as shown in Table 4.5.

The analysis of variance for fruit TSS showed significant differences ($P < 0.05$) in fruit dip time of $CaCl_2$. Fruits dipped for 20 and 30 minutes ((4.13^{o}Birx) recorded significantly ($P < 0.05$) lower TSS than fruits dipped for 10 minutes (4.23^{o}Birx). However, there was no significant difference ($P > 0.05$) in TSS between fruits dipped for 30 (4.24 ^{o}Brix) minutes and fruits dipped for 20 minutes (4.22^{o}Brix), as shown in Table 4.5. There was also no significant ($P < 0.05$) difference in the interaction between the dip time and the level of $CaCl_2$ treatment in total soluble solids.

Table 4.5: Means of TSS (^{o}Brix) of tomato fruit harvested at pink stage from the interaction between the $CaCl_2$ concentrations and dip times after 10 days storage.

$CaCl_2$ Concentrations	Dip Time (Minutes)			Mean
	30	20	10	
6%	4.13±0.12b	4.13±0.12b	4.23±0.15a	4.16±0.12a
2%	4.23±0.12ab	4.16±0.06ba	4.30±0.10a	4.23±0.15a
Control (0%)	4.37±0.02a	4.37±0.02a	4.37±0.02a	4.37±0.12a
Mean	4.24±0.02a	4.22±0.12a	4.30±0.02a	

**values followed by the same letters are not significantly different at 5%*

According to Helyes *et al*. (2006), malic and citric acid were the main organic acid in the tomato fruit and the range was between 0.3-0.6%. The interaction of the TSS and the acid are important component of sweetness, sourness and flavour intensity in tomato. Carbohydrates constitute about 65% of the soluble solid of ripe tomato fruit. Beside high carbohydrate and acid are required for best flavour. Hurr *et al*. (2005) also mentioned that, the development of taste, aroma and flavour of the fruit is attributed to the accumulation of sugars and organic acids in the vacuoles and the production of complex volatiles.

4.6.0 VITAMIN C CONTENT

4.6.1 Second Phase Results and Discussions on Vitamin C

Tomato fruits harvested at different stages of maturity (Breaker, Pink and Light red stage) and treated with different levels of calcium chloride (6% $CaCl_2$, 2% $CaCl_2$ and control) were evaluated for vitamin C content at day 10.

Table 4.6: Means of Vitamin C (mg/100g) of tomato fruit from the interaction between the stage of maturity and the concentration of $CaCl_2$ at 30 minutes dip time after 10 days storage.

$CaCl_2$ Concentrations	Maturity Stage			Mean
	Breaker	Pink	Light Red	
6%	16.00±0.13a	16.26±0.05a	14.51±0.05b	15.59±0.02a
2%	15.02±0.13ab	15.50±0.05a	13.33±0.05c	14.62±0.13b
Control (0%)	13.12±0.33c	13.29±0.33c	13.29±0.33c	13.23±0.02c
Mean	15.02±0.05a	15.12±0.33a	13.71±0.05b	

**values followed by the same letters are not significantly different at 5%*

The analysis of variance indicated significant differences ($P < 0.05$) between the levels of $CaCl_2$ treatment in vitamin C content. Tomato fruits treated with 6% $CaCl_2$ recorded the highest level of vitamin C (15.59mg/100g) which was significantly ($P < 0.05$) higher than fruits treated with 2% $CaCl_2$ (14.62mg/100g) and the control (13.23mg/100g) as shown in Table 4.6.

The analysis of variance also showed a significant difference ($P < 0.05$) in vitamin C content among the 3 stages of maturity (Breaker, pink and light red stage). Tomato fruit harvested at the breaker (15.02mg/100g) and the pink (15.12mg/100g) stage recorded significantly higher ($P < 0.05$) vitamin C content (than fruits harvested at the light red stage (13.71mg/100g) as indicated in Table 4.6. This suggests that, the vitamin C content of tomato juice generally increase with ripening of the fruit until a peak stage is reached after which it started to decline. In the current study, there was a significant difference ($P < 0.05$) in the interaction between the stage of

maturity and the level of calcium chloride treatment in vitamin C content of tomato fruits as indicated in Table 4.6. Therefore, tomato fruits harvested at the breaker and pink stages and dipped in 6% $CaCl_2$ had the highest amount of vitamin C. Moneruzzaman *et al*. (2008) reported that, as the tomato fruit at the deep red stage has lower ascorbic acid content, thus harvesting fruit at the proper maturity has a great influence on the nutrient content as well as storage life of any fruit.

4.6.2 Third Phase Results And Discussions On Vitamin C

The analysis of variance in the third phase also indicated significant differences ($P < 0.05$) among the levels of $CaCl_2$ treatment in vitamin C content. Fruits treated with 6% $CaCl_2$ recorded a significantly higher ($P < 0.05$) vitamin C (16.08mg/100g) than fruits treated with 2% $CaCl_2$ (14.58mg/100g) and the control (12.63mg/100g), besides, both fruits treated with 6% and 2% $CaCl_2$ recorded a significantly higher vitamin C content than the control as shown in Table 4.7.

The analysis of variance for vitamin C content indicated significant differences ($P < 0.05$) among the dip times of $CaCl_2$. However, there was no significant difference ($p > 0.05$) in vitamin C content between fruits dipped for 30 minutes (14.86mg/100g) and fruits dipped for 20 minutes (14.76mg/100g). Besides, both fruits dipped for 20 and 30 minutes recorded a significantly higher ($P < 0.05$) vitamin C content than the fruits dipped for 10 minutes (13.68mg/100g), as shown in Table 4.7.

Table 4.7: Means of vitamin C (mg/100g) of tomato fruit at pink stage from the interaction between the $CaCl_2$ concentrations and the dip time after 10 days storage.

	Dip Time (Minutes)			
$CaCl_2$ concentration	**30**	**20**	**10**	**Mean**
6%	16.56±0.05a	16.42±0.05a	15.26±0.10b	16.08±0.05a
2%	15.38±0.20b	15.21±0.10b	13.13±0.10c	14.58±0.10b
Control (0%)	12.64±0.20d	12.64±0.33d	12.64±0.33d	12.63±0.10c
Mean	14.86±0.10a	14.76±0.05a	13.68±0.10b	

**values followed by the same letters are not significantly different at 5%*

There was a significant ($P < 0.05$) difference in the interaction between the dip time and the level of $CaCl_2$ treatment in vitamin C content of the fruits as shown in Table 4.7. From the study, the vitamin C content of all the treatments showed a general decrease. However, Tomato fruits treated with 6% $CaCl_2$ recorded the highest level of vitamin C (16.08mg/100g) which was significantly ($P < 0.05$) higher than 2% $CaCl_2$ (14.58mg/100g) and the control (12.63mg/100g) at day 10. (Table 4.7). Besides, the fruits dipped for 30 and 20 minutes retained significantly ($P < 0.05$) higher vitamin C content (14.86 and 14.76mg/100g respectively) as compared to those dipped for 10 minutes (13.68mg/100g). These results suggest that, $CaCl_2$ treatment at the right concentration (6%) and dip time (20 min) was able to retard the degradation of ascorbic acid content of the tomato fruit during storage.

According to Nirupama *et al*. (2010), the retention of ascorbic acid of the treated samples may be attributed to the lowering of respiration rate of the fruits by the $CaCl_2$. Dumas *et al*. (2003)

reported that, tomato fruit is a great source of vitamin C, some of the factors that determine the vitamin content of tomato may include the storage coditions, the nutrient in the soil and climate. From their study, the mean value of vitamin C recorded range from 15 to 23mg/100g raw edible part of the tomato. However, the actual range is from 8.4 to 59mg/100g.

The decrease in vitamin C content of tomato fruit during storage may be attributed to the biochemical processes that the fruit undergo before and after harvest. Ullah (2009) reported that, respiration and transpiration are the two main physiological processes that lead depletion of nutrients and deterioration. Besides, harvested fruits still continue their life processes meanwhile there is no longer the transfer of food material and water to the fruit, therefore it has to depend on its stored food reserves for survival. Eventually the reserves are depleted, including vitamin C, thus the produce undergo an aging processing resulting in breakdown due to natural decay.

4.7 TITRATABLE ACIDITY

4.7.1 Second Phase Results and Discussions on Titratable Acidity

The stages of maturity (Breaker, Pink and Light red stage) of the tomato and the levels of $CaCl_2$ treatment (6% $CaCl_2$, 2% $CaCl_2$ and control) were evaluated for Titratable acidity at day 10. The analysis of variance indicated significant differences ($P < 0.05$) between the levels of $CaCl_2$ treatment in Titratable acidity (%). Tomato fruits treated with 6% $CaCl_2$ recorded the highest Titratable acidity (0.60%) which was significantly ($P < 0.05$) higher than fruits treated with 2% $CaCl_2$ (0.55%) and the control (0.46%). There was also a significant difference ($P < 0.05$)

between the Titratable acidity of fruits treated with 2% $CaCl_2$ and the control (0%) as shown in Table 4.8.

Table 4.8: Means of Titratable Acidity (%) of tomato fruit from the interaction between the stage of maturity and $CaCl_2$ concentrations at 30 min. dip time after 10 days storage.

	Maturity Stage			
$CaCl_2$ Concentrations	**Breaker**	**Pink**	**Light Red**	**Mean**
6%	0.60±0.02a	0.63±0.02a	0.57±0.02a	0.60±0.02a
2%	0.52±0.02b	0.55±0.04b	0.57±0.04a	0.55±0.04a
Control (0%)	0.44±0.03c	0.49±0.05c	0.46±0.02c	0.46±0.02b
Mean	0.52±0.03a	0.56±0.05a	0.53±0.03a	

**values followed by the same letters are not significantly different at 5%*

There was a general decrease in titratable acidity in all the treatments during storage. However, the significantly higher titratable acidity recorded by tomato fruits treated with 6% $CaCl_2$ (0.60%) as compared to fruits treated with 2% $CaCl_2$ (0.55%) and the control (0%) (0.46%) may be attributed to metabolic activities that take place during storage. A general decrease in fruits Titratable acidity with storage was reported by Bhattara and Gautam (2006), thus the tomato fruit might have utilized the acid through metabolic activities. Therefore the depletion of total Titratable acidity during storage may also be attributed to metabolic activities of living tissues which causes a decrease in organic acid in the fruits.

There was no significant difference ($P > 0.05$) in fruit TA between fruit harvested at the breaker stage (0.52%) and fruit harvested at light red stage (0.53%) as indicated in Table 4.8. The Titratable acidity of tomato fruits harvested at the pink stage (0.56%) recorded the highest Titratable acidity followed by the light red stage (0.53%) and the breaker stage (0.52%). The TA of tomato fruits harvested at the pink stage was significantly ($P < 0.05$) higher than the TA of fruits harvested at the breaker stage. A study conducted by Moneruzzaman *et al*. (2008) revealed that, immature fruit has lower content of acids as compared to the matured fruit. Moreover, the acid content is usually highest at the stage when color start to appear. This is followed by a rapid decrease during fruit ripening.

There was a general decrease in titratable acidity in all the treatments during storage. The pink stage was found to be the stage of tomato fruit with the maximum acidity but it fell subsequently during storage. The result indicated that, pink stage tomato recorded the highest quantity of total Titratable acidity This implied that, the Titratable acidity content of tomato juice actually increased with ripening of fruit due to accumulation of nutrients (maturation) until a peak stage is reached after which it started to decline as organic acids were oxidized to sugar (Genanew, 2013).

4.7.2 Third Phase Results and Discussions on Titratable Acidity

The analysis of variance showed significant differences ($P < 0.05$) among the levels of $CaCl_2$ treatment in titratable acidity (%) at day 10. Tomato fruits treated with both levels (6% and 2%) of $CaCl_2$ recorded a significantly ($P < 0.05$) higher titratable acidity (0.59% and 0.51% respectively) than the control (0.41%) as indicated in Table 4.9. There was also a significant

difference ($P < 0.05$) in titratable acidity between fruits treated with 6% and 2% $CaCl_2$ as indicated in Table 4.9.

Table 4.9: Means of Titratable Acidity (%) of tomato fruit at pink stage from the interaction between the $CaCl_2$ concentrations and the dip time after 10 days storage

$CaCl_2$ concentration	Dip Time (Minutes)			Mean
	30	20	10	
6%	0.65±0.03a	0.64±0.03a	0.47±0.04c	0.59±0.03a
2%	0.56±0.05b	0.53±0.04b	0.44±0.03cd	0.51±0.03b
Control (0%)	0.41±0.03d	0.41±0.04d	0.41±0.04d	0.41±0.05c
Mean	0.53±0.05a	0.53±0.04a	0.44±0.04b	

**values followed by the same letters are not significantly different at 5%*

The analysis of variance for titratable acidity (%) in the third phase also indicated significant differences ($P<0.05$) between the dip times of $CaCl_2$. There was no significant difference ($p > 0.05$) in titratable acidity (%) between fruits dipped for 30 minutes and fruits dipped for 20 minutes. However, both fruits dipped for 30 and 20 minutes recorded a significantly higher ($p < 0.05$) titratable acidity than the fruits dipped for 10 minutes, as shown in Table 4.9. This may be attributed to the effective penetration of the $CaCl_2$ at 20 and 30 minute dip time. Thus, the 30 and the 20 minutes allowed sufficient dip time for $CaCl_2$ to effectively retard metabolic processes which help retain the titratable acidity and other nutrients.

There is the need to minimize the rapid loss of acid in tomato fruit because a rapid decrease in the content of acidity may also reduce desirable quality of the fruit. In the third phase, the analysis of variance indicated significant differences ($P < 0.05$) in the interactions between the dip time and the concentration of calcium chloride treatment in titratable acidity (%). Although, the mean titratable acidity (%) of fruits treated with 6% $CaCl_2$ (0.59%) is significantly higher ($p < 0.05$) than fruits treated with 2% $CaCl_2$ (0.51%) as shown in Table 4.9. The fruits treated with 2% $CaCl_2$ for 30 minutes recorded significantly higher titratable acidity (0.56%) than fruit treated with 6% $CaCl_2$ for 10 minutes (0.47%). This means, there is an interaction between the $CaCl_2$ concentration and the dip time. Moreover, fruit dipped in 6% $CaCl_2$ for 20 and 30 minutes better facilitated in the retaining of titratable acidity.

According to Helyes *et al*. (2006), a rapid decrease in the content of acidity may reduce desirable quality of the fruit. A study by Genanew (2013) reported that, this rapid depletion of titratable acidity during ripening may be attributed to oxidation of organic acid to sugar. Therefore, there is the need to control rapid decrease in titratable acidity, since the interaction of the TSS and the acid in the fruit are very important component of sweetness, sourness and flavour intensity in tomato fruit which also affect the acceptability of the fruit.

4.8.0 STORAGE LIFE

4.8.1 Second Phase Results and Discussions on Storage life

The analysis of variance indicated significant differences ($P < 0.05$) between the levels of $CaCl_2$ treatment in fruit storage life (days). Tomato fruits treated with 6% $CaCl_2$ recorded the highest storage life (9.29 days) which was significantly ($P < 0.05$) higher than fruits treated with 2% $CaCl_2$ (7.11 days) and the control (5.86 days). Besides, the storage life of fruit treated with 2% $CaCl_2$ was significantly ($P < 0.05$) higher than the control (0%), as indicated in Table 4.10.

Table 4.10: Means of Storage Life (Days) of tomato fruit from the interaction between the stage of maturity and $CaCl_2$ concentrations at 30 minutes dip time after 10 days storage.

	Maturity Stage			
$CaCl_2$ Concentrations	**Breaker**	**Pink**	**Light Red**	**Mean**
6%	10.00±0.58a	10.13±0.58a	7.73±0.58b	9.29±0.58a
2%	7.33±1.16b	7.33±0.02b	6.67±1.00b	7.11±1.16b
Control (0%)	6.15±1.16c	6.00±1.53c	5.44±1.00c	5.86±0.58c
Mean	7.83±0.58a	7.82±0.02a	6.61±0.58b	

**values followed by the same letters are not significantly different at 5%*

The differences observed in fruits storage life between the levels of calcium treatment as shown in Table 4.10 may be attributed to the ability of the calcium to minimise respiration rate, weight (water) loss and other factors which affect fruits storage life negatively. According to Bhattara and Gautam (2006), the storage life of fruit increased with the increasing concentration of $CaCl_2$. Therefore, the maximum storage life (9.29 days) recorded by 6% $CaCl_2$ treated fruits was

significantly ($P < 0.05$) higher than the control (5.86 days). Therefore, tomato fruits treated with 6% $CaCl_2$ extended the storage life by delaying the incidence of decay as compared to the lower concentrations.

The analysis of variance for storage life of the fruits also showed significant differences ($P < 0.05$) between the stages of maturity (Breaker, Pink and light red stage). The storage life of fruits harvested at the breaker (7.83 days) and the pink stage (7.82 days) were significantly ($P < 0.05$) higher than fruits harvested at the light red stage (6.61days), but there was no significant difference ($P > 0.05$) between the storage life of fruits harvested at the breaker stage and the fruits harvested at pink stage of maturity, as shown in Table 4.10.

The relatively longer storage life recorded by fruits harvested at the breaker (7.83 days) and the pink stage (7.82 days) as compared to the control (6.61 days) may be attributed to their firmer fruit skin which mininised physical injury, weight loss and fruit decay. This suggests that, it took more days for tomato fruits harvested in breaker and pink stage to start rotting. Moreover, tomato fruits harvested at the pink stage and dipped in 6% $CaCl_2$ recorded a longer storage life (10.13 days) which was almost twice (5.44 days) as that of fruits harvested at the light red stage with no $CaCl_2$ treatment (Table 4.10) According to Nyamah (2011), the storage life of tomato can be described as the period of time from the harvest of the crop up to the start of rotting of the fruit. Some of the major factors that limit the storage life of fruits include decay and external damage incurred during harvest and handling.

The higher level of decay recorded in the fruit harvested at the light red stage may be attributed to its high level of mechanical injuries which is facilitated by its soft skin. Some of the injuries cannot be seen, yet served as a gate way for microorganism to destroy the fruit.

According to Sergeant *et al*. (1998), the principal cause of fruit decay is the opportunistic pathogens which are ubiquitous in the natural surroundings. Physical injuries such as bruises, cuts and punctures serve as the entry point for the decay causing pathogens to enter the fruit to initiate the decay. Therefore, the initiation of decay by the microorganism shortens the storage life of tomato fruits. In the current study, the analysis of variance for fruit's storage life indicated no significant differences ($P > 0.05$) in the interaction of between the stage of maturity and the level of calcium chloride treatment.

4.8.2 Third Phase Results and Discussions on Storage life

As shown in the second phase, the analysis of variance in the third phase also indicated significant differences ($P<0.05$) among the levels of $CaCl_2$ treatment in fruit storage life (days). Tomato fruits treated with 6% $CaCl_2$ recorded a significantly ($P < 0.05$) higher storage life (9.23 days) than fruits treated with 2% $CaCl_2$ (8.77 days) and the 0% (6.33 days). The storage life of the fruits treated with 2% $CaCl_2$ was significantly ($P < 0.05$) higher than the control (0%) as shown in Table 4.11.

Moreover, the analysis of variance for storage life also showed significant differences ($P <0.05$) among the dip times of $CaCl_2$. There was no significant difference ($P > 0.05$) in storage life between fruits dipped for 30 minutes and fruits dipped for 20 minutes. However, both fruits

dipped for 30 and 20 minutes recorded a significantly higher ($P < 0.05$) storage life (8.77 and 8.78 days respectively) than the fruits dipped for 10 minutes (6.78 days), as indicated in Table 4.11.

Table 4.11: Means of Storage Life (Days) of tomato fruit at pink stage from the interaction between the $CaCl_2$ concentrations and the dip time after 10 days storage.

$CaCl_2$ concentration	Dip Time (Minutes)			Mean
	30	20	10	
6%	10.67±1.16a	10.33±0.01a	8.67±0.57c	9.89±1.16a
2%	9.30±0.57b	9.67±0.58b	7.33±0.50c	8.77±0.57b
Control (0%)	6.33±0.57c	6.33±0.57c	6.33±0.57c	6.33±0.57c
Mean	8.77±0.57a	8.78±0.57a	6.78±0.57b	

**values followed by the same letters are not significantly different at 5%*

The analysis of variance indicated significant differences ($P < 0.05$) in the interactions between the dip time and the concentration of calcium chloride in fruits storage life as shown in Table 4.11. Fruits dipped in 6% $CaCl_2$ for 20 minutes recorded significantly ($P < 0.05$) higher storage life (10.33 days) than the control (6.33 days). The significant interaction is demonstrated when fruit dipped in 2% $CaCl_2$ for 20 minutes (9.67 days) recorded longer storage life than fruit dipped in 6% $CaCl_2$ for 10 minutes (6.67days). The longer storage life recorded by fruits dipped for 30 and 20 minutes than fruit dipped for 10 minutes (Table 4.11) may be attributed to sufficient time allowed for the calcium to complex with the pectin to maintain firmness and retard other physiological processes that shorten the storage life (Genanew, 2013).

4.9 CORRELATIONS OF QUALITY TRAITS

The correlation among parameters of tomato fruits stored at 26 ºC and 82.75% RH were examined to determine their significant associations. The relationship indicated both positive and negative association among the various quality parameters studied.

Table 4.12: Correlation values and P values between postharvest quality traits of tomato fruits harvested at different maturity stages and dipped in different concentrations of $CaCl_2$ for 30 min.

	FD	**WL**	**FF**	**SL**	**TSS**	**TA**	**VC**
Fruit Decay (FD)	-						
Weight Loss (WL)	0.55**	-					
Fruit Firmness (FF)	-0.84**	-0.63**	-				
Storage life (SL)	-0.78**	-0.56**	0.87**	-			
Total Soluble Solids (TSS)	0.45*	0.31NS	-0.49**	-0.54**	-		
Titratable Acidity (TA)	-0.65**	0.71**	0.71**	0.59**	-0.45*	-	
Vitamin C (VC)	-0.79**	-0.39*	0.86**	0.77**	-0.51**	0.47*	

= P < 0.05, ** = P<0.01 *NS = not significant*

There was a significant (P < 0.05) positive correlation among fruit decay, weight loss and total soluble solid. Thus, fruit decay increased with increasing weight loss and total soluble solid. However, there was a significantly (P < 0.05) higher negative correlations between fruit decay and fruit firmness and also between fruit decay and fruit storage life. This meant that, higher level of decay resulted in lower fruit firmness and shorter storage life. From Table 4.12, higher weight loss resulted in lower fruit firmness, shorter storage life and higher fruit decay.

Fruit decay also indicated a significantly ($P < 0.05$) higher negative correlation with fruit Titratable acidity (-0.65) and vitamin C (-0.79). Thus, increased in fruit decay implied a decreased in titratable acidity and vitamin C content. Vitamin C content showed a significant ($P < 0.01$) and positive correlation with fruit firmness (0.86), storage life (0.77) and titratable acidity (0.47). This also meant that, the higher vitamin C content was directly proportional to higher firmness and longer storage life. There was also a significantly ($P < 0.05$) negative correlation (-0.51) between vitamin and total soluble solids. However, no significant correlations ($P > 0.01$) were observed between fruit weight loss and total soluble solids as indicated in Table 4.12.

The significant negative correlation of weight loss with fruit firmness (-0.63), storage life (-0.56) and vitamin C (0.39) inferred that, when fruit weight loss was increased, fruit firmness, storage life and vitamin C also decreased. Fruit firmness had a significant ($P < 0.01$) and positive correlation with storage life (0.87), titratable acidity (0.71) and vitamin C (0.86). This implied that, when fruit firmness was maintained, the titratable acidity and vitamin C were also maintained and the storage life was extended. Therefore, results from the correlation analysis are of great importance in assessing the relationship between the postharvest qualities of tomato fruits during storage.

CHAPTER FIVE

5.1 CONCLUSION

Tomato fruits harvested at the breaker and the pink stage "suffered" minimal levels of mechanical injuries than light red fruits during handling and transportation. The firmer pericarp of the breaker and the pink stage fruits made them resistant to the mechanical injuries. The reduced mechanical injuries of the fruit harvested at the breaker and the pink stage also minimised decay and extended storage life. The pink stage fruits retained significantly ($P < 0.05$) higher amount of titratable acidity (0.56%) and vitamin C (15mg/100g) after 10 days of storage, as compared to fruit harvested at the breaker and light red stage. There was no significant difference in storage life between tomato fruit harvested at the breaker stage (7.83 day) and pink stage (7.82 days).

Dipping tomato fruit in 6% $CaCl_2$ was more effective than in 2% $CaCl_2$ and the control (0%) in reducing weight loss and decay as well as maintaining firmness, titratable acidity and vitamin C. There was no significant ($P < 0.05$) difference between fruits dipped for 20 and 30 min with respect to reducing weight loss and decay as well as maintaining firmness and extending storage life of the fruit. Tomato fruit dipped in 6% $CaCl_2$ for 20 minutes recorded significantly ($P < 0.05$) lower weight loss (8.43%) and higher firmness (3.47N) compared to fruits dipped for 10 minutes which recorded higher weight loss (10.37%) and lower firmness (2.83N).

There were significant ($P < 0.05$) interactions between $CaCl_2$ concentration and dip time. This was shown when fruits dipped in 2% $CaCl_2$ for 20 minutes recorded significantly ($P < 0.05$) higher firmness (3.10N) than fruits treated with 6% $CaCl_2$ for 10 minutes (2.83N), even though

the mean firmness for 6% $CaCl_2$ (3.28N) was higher than that of 2% $CaCl_2$ (3.09N). Therefore, the effectiveness of $CaCl_2$ treatment on tomato fruit was much dependent on both the $CaCl_2$ concentration and its dip time. Therefore, tomato fruits harvested at the pink stage and dipped in 6 % $CaCl_2$ for 20 better facilitated the extension of storage life and the preservation of quality.

The correlation analysis of these quality traits indicated a positive correlation between weight loss and decay and also between firmness, storage life and vitamin C. This suggests that, when weight loss is increased, decay may increase whilst firmness, storage life and vitamin C is also decreased and vice versa.

5.2 RECOMMENDATIONS

- Economic analysis of the use of $CaCl_2$ should be conducted to assess the profitability of its use.
- Further research should be done to compare the effect of postharvest $CaCl_2$ treatment on other local cultivars of tomato in Ghana.

REFERENCES

1. **Adah,** P.A., Yisa M. G., Chukwu, O. and Morenikeji O. O. (2012). Simulated transport damage study on fresh tomato (*Lycopersicon esculentum*) fruit. Agricultural. Engineering. International. CIGR Journal 14 (2); Manuscript No. 2035

2. **Adubofuo**r, J. E., Amankwah, A., Arthur, B. S. and Appiah, F. (2010). Comparative study related to physico-chemical properties and sensory qualities of tomato juice and cocktail juice produced from oranges, tomatoes and carrots. African Journal of Food Science Vol. 4(7), pp. 427 – 433.

3. **Anthon**, G. E., Blot, L. and Barrett, D. M. (2005). Improved Firmness in calcified diced tomatoes by temperature activation of pectin Methylesterase. Journal of Food Science Vol. 70: 5

4. **AOAC** (2006). Official Methods of Analysis, Ascorbic Acid in Vitamin Preparation and Juices. 2, 6-Dichloroindophenol Titrimetric Method. Vitamins and Other Nutrients Chapter 45, p. 19.

5. **Artherton**, J. G. and Rudich, J. (1986). The Tomato Crop. Chapman and Hall press pp. 260-273.

6. **Babalola** D. A., Makinde Y. O., Omonona B.T and Oyekanmi M. O. (2010) Determinant of Postharvest losses in tomato production: a case study of Imeko-Afon local government area of Ogun State. Acta SATECH 3 (2): 14-18

7. **Babarinsa** F. A. and Ige M. (2012). Strength parameters of packaged Roma tomatoes at break point under compressive loading. International Journal Scientific and Engineering Research Vol. 3

8. **Bhattarai**, D. R. and Gautam, D. M. (2006). Effect of harvesting Method and calcium on postharvest physiology of tomato. Nepal Agricultural Resource Journal Volume 7 pp. 23-26
9. **Cantwell**, M. (2009). Maturation and Maturity indices. Postharvest. Technology short course. http://postharvest.ucdavis.edu
10. **Cliff**, M., Lok, S., Lu, C. and Toivonen, P. M. A. (2009). Effect of I-methly cyclopropene on the sensory visual and analytical quality of green house tomatoes. Postharvest biology and technology 53:11-15
11. **Delina** E. F. and T. Mahandran (2009). Physic chemical properties of mature green tomatoes (Lycopersicon esculentum Mill) coated with pectin during storage and ripening. Tropical Agricultural Research and Extension 12 (2)
12. **Dumas**, Y., Dadomo, M., Lucca, G. D. and Grolier, P. (2003). Effect of environmental factors and agricultural technologies on antioxidant content of tomatoes. Journal of the Science of Food and Agriculture. 83: 369-383.
13. **Ellis**, W.O., Olympio, N.S., Mensah, E. P., Adu-Amankwa, A. and Tetteh,Y. (1998). Postharvest problems of tomato production in Ghana - Field studies of some selected major growing areas in Ghana. Journal of the Ghana science association volume 1 number 1, July (1998) pp. 55-59. ISSN: 0855-3823
14. **FAO**, (2001). FAO Bulletin of Statistics. Food and Agriculture Organization of the United Nations (FAO), 2: 85.
15. **Food and Agriculture Organization** (2010). FAOSTAT. http://faostat.fao.org.
16. **Genanew,** T. (2013). Effect of postharvest treatment on storage behavior and quality of tomato of fruit. World Journal of Agricultural Science 9(1) : 29-37

17. **Getinet**, H., Seyoum, T. and Woldetsadik, K. (2008). The effect of cultivar. Maturity stage and storage environment on quality of tomatoes. Journal of Food Engineering 87: 467-478

18. **Gharezi**, M., Joshi, N. and Sadeghian, E. (2012). Effect of postharvest treatment on stored cherry tomato, J. Nutrition and Food Science 2:8

19. **Guzman**, I. L. and Barrett, D. M. (2000). Comparison of Calcium Chloride and Calcium Lactate effectiveness in maintaining shelf stability and quality of fresh-cut Cantaloupes. Postharvest Biology and Technology. 19: 61-72

20. **Helyes**, L. and Pek, Z. (2006b). Tomato fruit quality and content depend on stage of maturity. Hort. Science 41 (6): 1400-1401

21. **Helyes**, L., Dimeny, J., Pek, Z. and Lugasi, A. (2006). Effect of maturity stage on content, color and quality of tomato (*Lycopersicon esculentum* L. Karsten) fruit. International Journal of Horticultural Science 12 (1): 41-44

22. **Hurr**, B. M., Huber, D. J. and Lee, J. H. (2005). Differential Responses in colour changes and softening of "Florida 47" Tomato fruit treated at green and advanced ripening stage with the ethylene antagonist 1-methylcyclopropene. HortTechnology 15(3) : 617-622

23. **Ida**, P. A., Ajisegiri, E. S. A. and Yisa, M. G. (2007). An assessment of impact damage to fresh tomato fruit. AU. Journal of Technology 10 (4): 271-275

24. **Kader** A. A. (1986). Effect of postharvest handling procedures on tomato quality. Acta Horticulture. 190

25. **Kumah**, P, Olympio, N. S., Tayviah, C. S. (2011). Sensitivity of three tomato (*Lycopersicon esculentum*) cultivars - Akoma, Pectomech and power- to chilling

injury. Agriculture and biology journal of North America ISSN Print: 2151-7517, ISSN Online: 2151-7525

26. **Lee**, S. K. and Kader, A. A. (2000). Pre-harvest and postharvest factors influence vitamin C content of horticulture crop. Postharvest Biology and Technology 20: 207-220
27. **Manganaris**, A., Vasilakakis, M., Diamantidis, G., and Mignani, I. (2007). The effect of postharvest calcium application on tissue calcium concentration, quality attribute, incidence of flesh browning and cell wall physicochemical aspect of peach fruit. Food Chemistry 100: 1385-1392
28. **Marsic**, N. K., Gasperlin, L., Abram, V. and Maja Budic, K. V. (2011). Quality parameters and total phenolic content in tomato fruit regarding cultivar and micro climate conditions. Turk Journal. Agriculture. 35: 185-194
29. **MoFAIR** Centre, (2008). Production Guide for Tomato. Ministry of Food and Agriculture Information Resource Centre, Accra-Ghana. (Online) http://www.mofaircentre.info/production-guide-for-tomato Accessed"19th May 2011. 10:23pm GMT.
30. **Mohammadi-Aylar**, S., Somarin, S. J. and Azimi J. (2010). Effect of stage of ripening on Mechanical damage in tomato fruits. American-Eurasian Journal Agriculture & Environmental Science. 9 (3): 297-302.
31. **Monda**l, M. F. (2000). Production and Storage of Fruits (in Bangla). Published by Afia Mondal. BAU Campus, Mymensingh-2202. Pp-312.

32. **Moneruzzaman**, R.M., Hossain, A. B. M. S., Sani, W. and Saifuddin, M. (2008) Effect of stage of maturity and ripening condition on the biochemical characteristics of tomato. American Journal of Biochemistry and Biotechnology 4 (4): 336-344

33. **Moneruzzaman**, R.M., Hossain, A. B. M. S., Sani, W., Saifuddin, M. and Alenazi, M. (2009). Effect of harvesting and storage condition on the postharvest quality of tomato (Lycopersicon esculentum Mill) cv. Roma VF. Australian Journal of Crop Science. 3(2): 113-121

34. **Morgan**, L and Lennard, S. (2000). Hydroponic Capsium Production. A Comprehensive Practical and Scientific Guide to Commercial Hydroponic Capsicum production, Casper Publications Pty Ltd. Narabeen, Australia. Pp 403-409

35. **Mutari**, A. and Debbie, R. (2011). The Effect of Postharvest handling and storage temperature on the quality and storage life of tomatoes. African Journal of food science Vol: 5(7) pp: 446-452

36. **Nirupama** P., Neeta B. Gol and T.V. Ramana Rao, (2010). Effect of Postharvest Treatments on Physicochemical Characteristics and Storage life of Tomato (*Lycopersicon esculentum* Mill.) Fruits during Storage. American-Eurasian Journal Agricultural. & Environmental. Science., 9 (5): 470-479

37. **Norman**, J. C. (1992). Tropical Vegetable Production. Macmillan press pp 52-67.

38. Nyamah E. Y. (2011). Influence of different soil amendments and cultivar types on postharvest performance of three (3) commercial tomatoes (Lycopersicon esculentum, Mill). A thesis submitted to the school of graduate studies, Kwame Nkrumah University of Science and Technology, Kumasi in partial fulfillment of the

requirements for the award of a Master of Science degree in postharvest technology. Pp. 3-50

39. **Olayemi** F. F., Adegbola J. A, Bamishaiye E. I and Daura A. M. (2010). Assessment of postharvest challenges of small scale farm holders of tomatoes, bell and hot pepper in some local government area of Kano State. Pp. 23-29
40. **Oms-Oliu**, G., Hertog, M. L. A. T. M., Van de Poel, B., Ampofo-Asiama J., Geeraerd, A. H. and Nicolai, B. M. (2011). Metabolic characterization of tomato fruit during pre-harvest development ripening and postharvest storage life. Postharvest Biology and Technology, 62: 7-16.
41. **Opiyo**, M. A. and Ying, T (2005). The effect of 1-methylcyclopropene treatment on the shelf life and quality of cherry tomato fruit. International Journal of Food Science and Technology 40:665-673
42. **Ortiz** A., Graell J. and lara I. (2011). Cell wall modifying enzymes and firmness loss in ripening Golden Reinders apple, a comparison between calcium dip and ULO storage. Food Chemistry 128: 1072-1079
43. **Peralta**, I. E. and Spooner, D. M. (2007). History, Origin and Early Cultivation of Tomato (*Solanaceae*). In: Razdan, M. K. And Mattoo, A. K. Editors. Genetic Improvement of Solanaceous Crops, Vol. 2. Enfi eld, USA: Science Publishers. P. 1-27.
44. **Ranatunga**, C. L., Jayaneera, H. H. E., Suraweera, S. K. K. and Ariyaratne T. R. (2009). Effect of measurement of non-destructive firmness on tomato quality and comparison with destructive methods. Proceedings of the technical session 25: 29-35

45. **Robinson**, J. Z. E. and Kolavalli, S. L. (2010). The Case of Tomato in Ghana – Marketing. (International Food Policy Research Institute - IFPRI). (Online) http://www.ifpri.org/publication/case-tomato-ghana-marketing

46. **Samm**i, S. and Masud, T. (2007). Effect of different packaging system on storage life and quality of tomato during different ripening stages. Internet Journal of food safety Vol. 9, P 37-44

47. **Sasimon**, C., Assi, N.M. El, Sargent, S. A. and Brencht, J. K. (2002). Fruit maturity and timing of ethylene treatment affecting storage performance of green tomatoes at chilling and non chilling temperature. Research Report. Horticulture. Technology vol. 12 pp.1-5

48. **Senevirathna** P.A.W.A.N.K. and Daundasekera, W.A.M. (2010). Effect of postharvest calcium chloride vacuum infiltration on shelf life and quality of tomato (cv. Thilina). Cey. Journal. Science. (Biological. Science) 39 (1):35-44

49. **Sergeant**, S.A., Maul, F., Sims, C.A. (1998). Implementing the Florida premium quality tomato program – Florida Tomato Institute University of Florida/Citrus and Vegetables. Magazine. Pp.49-54.

50. **Ullah**, J. (2009). Storage of fresh tomatoes to determine the level of calcium chloride coating and optimum temperature for extending shelf life. A post Doctorate Fellowship Report submitted to Professor Athapol Athapol Noomhorm.

51. **USDA** National Nutrient Database for Standard Reference (2010). SR23 - Reports by Single Nutrients.. US Department of Agriculture. Research Service. Release # 23. Pp 1-26

52. **Wang**, T. W., Wu, C. G. Z. W., Nowack, L. M., Madey, E. and Thompson, J. E. (2005). Antisense suppression of Deoxyhypusine synthase in tomato Delays fruit softening and alters growth and development. Plant physiology, 138: 1372-1382

53. **Zhigno** Li, Pingping Li and Jizhan Liu (2011). Effect of mechanical damage on mass loss and water content in tomato fruits. International Agrophys. 25: 77-83

54. **Zhiguo** Li, Pingping Li and Jizhan, Lius (2010). Effect of tomato internal structure on its mechanical properties and degree of mechanical damage. African Journal of Biotechnology Vol. 9 (12): 1816-182.

APPENDICES

1.0 TABLES OF ANALYSIS OF VARIANCE

Table 1.1 Mechanical Damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	181.920	90.960	12.29	0.008
Residual	6	44.389	7.398		
Total	8	226.310			

Grand mean = 11.28

Table 1.2 Weight Loss

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	2.351	1.176	1.04	0.375
Conc. of $CaCl_2$	2	60.593	30.297	26.74	<.001
Maturity stage x Conc. of $CaCl_2$	4	0.418	0.105	0.09	0.984
Residual	18	20.393	1.133		
Total	26	83.755			

Grand mean = 9.51

Table 1.3 Weight Loss

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Conc. of $CaCl_2$	2	11.5707	5.7853	18.13	<.001
Trt. duration	2	6.6108	3.3054	10.36	0.001
Conc. of $CaCl_2$ x Trt. duration	4	3.4445	0.8611	2.70	0.064
Residual	18	5.7433	0.3191		
Total	26	27.3693			

Grand mean = 9.06

Table 1.4 Fruit Firmness

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	1.99056	0.99528	27.92	<.001
Conc. of $CaCl_2$	2	4.70167	2.35083	65.95	<.001
Maturity stage x Conc. of $CaCl_2$	4	0.02778	0.00694	0.19	0.938
Residual	18	0.64167	0.03565		
Total	26	7.36167			

Grand mean = 2.894

Table 1.5 Fruit Firmness

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Conc. of $CaCl_2$	2	1.99790	0.99895	47.90	<.001
Trt. duration	2	0.97570	0.48785	23.39	<.001
Conc. of $CaCl_2$ x Trt. duration	4	0.49695	0.12424	5.96	0.003
Residual	18	0.37540	0.02086		
Total	26	3.84594			

Grand mean = 3.001

Table 1.6 Fruit Decay

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	1259.85	629.93	22.15	<.001
Conc. of $CaCl_2$	2	2696.30	1348.15	47.40	<.001
Maturity stage x Conc. of $CaCl_2$	4	23.70	5.93	0.21	0.930
Residual	18	512.00	28.44		
Total	26	4491.85			

Grand mean = 45.9

Table 1.7 Fruit Decay

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Conc. of $CaCl_2$	2	3844.74	1922.37	60.07	<.001
Trt. duration	2	904.30	452.15	14.13	<.001
Conc. of $CaCl_2$ x Trt. duration	4	617.48	154.37	4.82	0.008
Residual	18	576.00	32.00		
Total	26	5942.52			

Grand mean = 75.4

Table 1.8 Total soluble solids

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	0.026667	0.013333	1.80	0.194
Conc. of $CaCl_2$	2	0.026667	0.013333	1.80	0.194
Maturity stage x Conc. of $CaCl_2$	4	0.000000	0.000000	0.00	1.000
Residual	18	0.133333	0.007407		

Grand mean = 4.044

Table 1.9 Total soluble solids

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Conc. of $CaCl_2$	2	0.165185	0.082593	11.15	<.001
Trt. duration	2	0.036296	0.018148	2.45	0.115
Conc. of $CaCl_2$ x Trt. duration	4	0.012593	0.003148	0.42	0.789
Residual	18	0.133333	0.007407		
Total	26	0.347407			

Grand mean = 4.252

Table 1.10 Vitamin C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	35.349046	17.674523	5623.26	<.001
Conc. of $CaCl_2$	2	10.934371	5.467185	1739.42	<.001
Maturity stage x Conc. of $CaCl_2$	4	4.728626	1.182156	376.11	<.001
Residual	18	0.056576	0.003143		
Total	26	51.068619			

Grand mean = 14.695

Table 1.11 Vitamin C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Conc. of $CaCl_2$	2	53.67056	26.83528	691.63	<.001
Trt. duration	2	7.70842	3.85421	99.34	<.001
Conc. of $CaCl_2$ x Trt. duration	4	4.73209	1.18302	30.49	<.001
Residual	18	0.69840	0.03880		
Total	26	66.80947			

Grand mean = 14.431

Table 1.12 Titratable Acidity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	0.0140074	0.0070037	7.39	0.005
Conc. of $CaCl_2$	2	0.0641407	0.0320704	33.82	<.001
Maturity stage x Conc. of $CaCl_2$	4	0.0021481	0.0005370	0.57	0.690
Residual	18	0.0170667	0.0009481		
Total	26	0.0973630			

Grand mean = 0.5270

Table 1.13 Titratable Acidity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Conc. of $CaCl_2$	2	0.1409852	0.0704926	221.31	<.001
Trt. duration	2	0.0496519	0.0248259	77.94	<.001
Conc. of $CaCl_2$ x Trt. duration	4	0.0297037	0.0074259	23.31	<.001
Residual	18	0.0057333	0.0003185		
Total	26	0.2260741			

Grand mean 0.5048

Table 1.14 Storage life

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Maturity stage	2	20.2222	10.1111	13.65	<.001
Conc. of $CaCl_2$	2	38.2222	19.1111	25.80	<.001
Maturity stage x Conc. of $CaCl_2$	4	2.2222	0.5556	0.75	0.571
Residual	18	13.3333	0.7407		
Total	26	74.0000			

Grand mean 6.67

Table 1.15 Storage life

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Conc. of $CaCl_2$	2	64.296	32.148	19.73	<.001
Trt. duration	2	44.519	22.259	13.66	<.001
Conc. of $CaCl_2$ x Trt. duration	4	40.370	10.093	6.19	0.003
Residual	18	29.333	1.630		
Total	26	178.519			

Grand mean 8.59

4.0 TABLE OF RESULTS

Table 4.15 Means of firmness (N) of tomato fruit from three stages of maturity after 10 days storage at 26.85ºC and 82.75% RH

Stage of maturity	**Firmness (N)**
Breaker	3.12a
Pink	3.07a
Light-red	2.50b

**values followed by the same letters are not significantly different at 5%*

Table 4.16 Means of firmness (N) of tomato fruit treated with different concentration of $CaCl_2$ after 10 days storage at 26.85ºC and 82.75% RH

Calcium Chloride concentration (% $CaCl_2$)	**Firmness (N)**
6% $CaCl_2$	3.33a
2 % $CaCl_2$	3.02b
Control (0%)	2.33c

**values followed by the same letters are not significantly different at 5%*

Table 4.17 Means of firmness (N) of tomato fruits treated with different concentrations of $CaCl_2$ after 10 days storage at 26.85ºC and 82.75% RH

Calcium Chloride concentration (% $CaCl_2$)	**Firmness (N)**
6% $CaCl_2$	3.28a
2**% $CaCl_2$**	3.09b
Control (0%)	2.63c

**values followed by the same letters are not significantly different at 5%*

Table 4.18 Means of firmness (N) of tomato fruit under different dip time after 10 days storage at 26.85ºC and 82.75% RH

Dip time (minutes)	**Firmness (N)**
30	3.12a
20	3.15a
10	2.73b

**values followed by the same letters are not significantly different at 5%*