Influence of different 1-Methylcyclopropene (1-MCP) concentrations and storage conditions on the physico-chemical properties of (*Solanum lycopersicum* L.) on fruit quality and shelf-life.

Amoateng M. E.[1*], Kumah P.[2], Yaala I.[2], Amoasah B.[2]

[1]*Department of Horticulture, KNUST*

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ABSTRACT

'Power' tomato cultivar was harvested at the mature green stage and studied to determine how different 1-Methylcyclopropene (1-MCP) concentrations and storage conditions may influence its quality and shelf-life. A 3 x 2 factorial arrangement in Completely Randomized Design (CRD) was used and it was replicated three times. The factors were the tomato cultivar: 'Power', three 1-MCP concentration levels: 1 ppm, 2 ppm, untreated was 0 ppm and two storage conditions: ambient and refrigerator conditions. The research was conducted between January and May 2017 at the Department of Horticulture, KNUST in Kumasi, Ghana. The 1-MCP concentration required were obtained by adding 100ml of heated distilled water at 50°C to appropriate amounts of 1-MCP (MaxFresh, 3.3%) powder to obtain the 1 ppm and 2 ppm concentrations. After the 1-MCP powder has completely dissolved, it was then placed in a sealed bottle with a mini fan attached and then placed in the treatment chamber and released in a form of vapour on fruits and sealed immediately to avoid gas loss for a period of 24 hours. They were then stored in the refrigerator and ambient conditions at a temperature of 13°C-15°C and 29.5°C with Relative Humidity of 60-75% and 80-85% respectively. There was a significantly ($P<0.01$) delayed in ripening as characterized by changes in pH, firmness and total titratable acidity. Tomatoes treated with 1 ppm and 2 ppm of 1-MCP concentrations had delayed ripening when stored in the refrigerator and as a result had a longer shelf-life of 74 and 90 days respectively compared to fruits that were not treated and kept at ambient condition which took 60 days. There is confirmation from these results that the use of 1-MCP have saleable outlook for those who grow and trade in a way of delaying the ripening of green tomatoes.

Keywords: 1-MCP, mature green, tomato cultivar and shelf-life

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L) is one of the most important vegetables worldwide [1]. Recent global production of fresh fruit tomato is about 100 million tons cultivated on 3.7 million hectares [2]. The average yield on farm in Ghana is between 7.5-10t/ha [2] which is potentially far below the yield of 45-50Mt/ha. Tomato which is a tropical perennial belongs to the nightshade family Solanaceae [3]. In Ghana, it is almost incapable of being disregarded as an ingredient in the daily meals of people across all regions [4]. Tomato can be used as vegetable served with rice and salads. It is mainly used in Ghana in soups and stews [5]. Also, because Ghana has a relatively high humidity and rainfall, this leads to retard tomato production as a result of high incidence of disease and Pest [6].This may lead to in about 30-40% losses in the production of tomato in Ghana [7]. Fresh produce which is of greater

* E-mail address: amoatengmensah.elvis@yahoo.com

portion is lost worldwide after harvest. Causes of the lost are mainly physiological such as shriveling, wilting, decay due to bacteria and fungi, chilling injury and physical like mechanical injury. An estimated loss is to be 20-40% in developing countries and 10-15% in developed countries. For reduction of losses the main aim of postharvest technologies is to reduce metabolism such as transpiration, ethylene production and respiration of harvested produce. There is a market benefit that is being derived both local and foreign when the shelf life of tomato is extended [8]. Vegetables and fruits play a pertinent role of human diet because of their essential nutrients such as minerals, fibers, vitamins and antioxidants [9]. When vegetables and fruits are regularly consumed, it helps to reduced risk of chronic diseases, stroke, cancer and other cardiovascular diseases [10].1-MCP was found to inhibit ethylene perception by binding aggressively to ethylene receptors and this characterized a major discovery in controlling ethylene responses of horticultural products. According to [11], 1-MCP application retarded softening in tomato. When tomato fruits were treated with 1000ml/l, 1-MCP was about 88% higher than control fruits after 17 days at 20±1°C and 85-95% relative humidity.

Tomato is a very nutritious indigenous fruit vegetable but it is also highly perishable. Its perishability is because of an increased ethylene production and a rise in cellular respiration when ripening [12]. Ripe tomatoes are perishable, therefore they can be damaged easily during harvesting and shipping and this leads to loss of quality and exhibiting a short shelf life [13]. Since there is a great annual loss as a result of spoilage, the delay of ripening by using different 1-MCP concentrations and storage conditions to maintain the quality and extend the shelf-life of the fruit has therefore been of great commercial importance.

2. MATERIAL AND METHODS

2.1 Sources of Material and Experimental Site

Tomato fruits (‘Power’) cultivar was harvested at mature-green stage from a greenhouse at Kwame Nkrumah University of Science and Technology, Department of Horticulture in the Ashanti region of Ghana. The harvesting was done 7 weeks after transplanting. The tomato fruits were sorted and graded to make sure the fruits selected for the research was clearly free from diseases and bruises. The fruits were then packed into wooden boxes with ventilation holes. The research was conducted at January, 2017 after a preliminary trial at December 2016 at the laboratory of the Department of Horticulture at Kwame Nkrumah University of Science and Technology (KNUST), Kumasi.

2.2. Experimental Design

The experiment was conducted in a 2X3 factorial arrangement in a Completely Randomized Design (CRD) with the tomato cultivar “Power” testing 3 different concentrations and two storage conditions.

2.3 Fruit Treatment

The fruits were distributed among the three treatments (90 fruits) respectively in a completely randomized design with three replications. The fruits were treated with 0 (control), 1 and 2 ppm 1-MCP concentrations at 29°C in hermetically sealed rubbers. The 1-MCP concentration required were obtained by adding 100ml of heated distilled water at 50°C to appropriate amounts of 1-MCP (MaxFresh, 3.3%) powder to obtain the 1 ppm and 2 ppm concentrations. After the 1-MCP powder has completely dissolved, it was then placed in a sealed bottle with a mini fan attached and then placed in the treatment chamber and released in a form of vapour on fruits and sealed immediately to avoid gas loss for a period of 24 hours. After treatment, the treated samples (1 ppm and 2 ppm) of the 1-MCP

* E-mail address: amoatengmensah.elvis@yahoo.com

concentrations and the control (0 ppm) were placed at random in replications and stored at well ventilated place (ambient condition) at the laboratory of the Department of Horticulture - KNUST at a temperature of 29°C and the others on cold storage (Refrigerator) in a Plant house at the Department of Horticulture- KNUST with a temperature of 13-15°C with relative humidity of 80-85%.

2.4 PARAMETERS ASSESSED

2.4.1 Electrical Conductivity (EC)

For electrical conductivity determination, the tomato samples (50 grams) was added to 100ml of distilled water, blended and sieved to obtain the juice. The electrical conductivity meter (TDS-3 handheld TDS meter, U.S.A.) was then placed in the juice and the readings or values were recorded.

2.4.2 pH

For pH determination, the tomato samples (50 grams) was added to 100ml of distilled water, blended and sieved to obtain the juice. A pH meter (ELICO) LI 617, was used in determining the pH of the tomato samples. The probe of the pH meter was placed in the juice and the readings recorded.

2.4.3 Total Titratable Acidity (TTA)

10ml of juice from the various samples were titrated with 0.1m NaOH and the results were expressed in percentage citric acid [14].

2.4.4 Vitamin C content

This was determined by titrating 10ml of the sample juice with 0.05 iodine solution using 0.05% starch as an indicator.

2.4.5 Weight loss

The weight (g) of fruits were initially taken for all treatments and subsequently weighed daily for all individual fruits until the individual fruits were considered unmarketable or it starts to rot. The loss in weight differences were calculated as: accumulated weight loss percentage from the initial weight of the fruit [15].

2.4.6 Firmness

Durometer was used to check the firmness of the tomato fruit pulp. The fruit was held on both sides and force was applied to constantly compress the spring on the fruit. The constant pressing allows the anvil to measure the firmness of the fruit.

2.4.7 Moisture content

Weight of the moisture can was initially taken and subsequently a slice of the tomato (2 grams) was then added to the moisture can and weighed together again. The tomato samples were oven dried for 24 hours at a temperature of 60°C and re-weighed again [16].

2.4.8 Shelf-life

* E-mail address: amoatengmensah.elvis@yahoo.com

The shelf-life of the tomatoes was assessed from the time they were harvested to the time they became unmarketable that is; shows signs of rotting [17].

2.5 Statistical Analysis

The data generated were statistically analyzed using statistix software version 9. The data was subjected to Analysis of Variance (ANOVA) using the Tukeys Honesty Significant Difference (HSD) test at 1% (P <0.01). The results were presented in tables.

3.0 RESULTS AND DISCUSSION

3.1: Electrical Conductivity of tomato treated with different concentrations of 1-MCP and stored under different storage conditions

Between the 1-MCP concentrations, tomato fruits untreated had a significantly higher (P<0.01) EC (795.50 ppm) whilst those treated with 2 ppm of the 1-MCP concentrations recorded the least EC (641.50 ppm).

With reference to the storage conditions, significant higher (P<0.01) EC was observed by tomatoes stored in the refrigerator (730.67 ppm) as compared to tomatoes stored at ambient condition (692.00 ppm).

Again with regards to the storage conditions and 1-MCP concentration interactions, significantly higher (P<0.01) EC was recorded by tomatoes untreated and stored in the refrigerator (866 ppm) whilst the least EC was recorded by tomatoes treated with 2 ppm of 1-MCP concentration and stored in the refrigerator (632 ppm).

Table 1: Electrical Conductivity (ppm) of tomato treated with different concentrations of 1-MCP and stored under different storage conditions

	Electrical Conductivity			
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	866.00a	694.00bcd	632.00d	730.67a
Refrigerator	725.00b	700.00b	651.00cd	692.00b
Mean	795.50a	697.00b	641.50c	

HSD (1%) Storage conditions=35.279,1-MCP Concentrations=44.461, Storage condition X 1-MCP Concentration=67.915

* E-mail address: amoatengmensah.elvis@yahoo.com

3.2 pH of tomato treated with different concentrations of 1-MCP and kept under different storage conditions.

Between the storage conditions, tomato fruits stored under ambient condition recorded a significantly higher (P<0.01) pH (4.78) and the lowest pH was recorded by tomato fruits stored in the refrigerator (4.28).

Again, amongst the 1-MCP concentrations, tomato fruits untreated had a significantly higher (P<0.01) pH (4.73) and the lowest pH was recorded by tomatoes treated with 2ppm of 1-MCP concentration (4.40).
With regards to the storage conditions and 1-MCP interaction, significantly higher (P<0.01) pH was recorded by tomatoes treated with 2 ppm of 1-MCP concentrations and stored under ambient condition whilst the least pH was recorded by tomatoes treated with 1 ppm of 1-MCP concentrations and stored in the refrigerator.

Table 2: pH of tomato treated with different concentrations of 1-MCP and kept under different storage conditions.

	pH			
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	4.65b	4.84a	4.85a	4.78a
Refrigerator	4.15c	4.07c	4.62b	4.28b
Mean	4.73a	4.46bc	4.40c	

HSD (1%) Storage conditions=0.04,1-MCP Concentrations=0.05, Storage condition X 1-MCP Concentration=0.08

* E-mail address: amoatengmensah.elvis@yahoo.com

3.3: Total Titratable Acidity (%) of tomatoes treated with different 1-MCP concentrations and stored under different storage conditions.

There was significant difference between the means. Tomato fruits stored in the refrigerator had a significantly ($P<0.01$) higher TTA (0.41%) as compared to those stored under ambient condition (0.19%).
Again with respect to the 1-MCP concentrations, tomato fruits treated with 2 ppm of 1-MCP concentrations had a significantly ($P<0.01$) higher TTA (0.42%) whilst the least TTA was recorded by untreated tomato fruits (0.17%).
With regards to the 1-MCP concentration and storage condition interaction, tomato fruits treated with 2 ppm of 1-MCP concentration and stored in the refrigerator recorded the highest TTA (0.62%) whilst the least TTA was recorded by untreated tomato fruits stored under ambient conditions (0.13%).

Table 3: Total Titratable Acidity (%) of tomatoes treated with different 1-MCP concentrations and stored under different storage conditions

	TTA			
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	0.13c	0.24c	0.21c	0.19b
Refrigerator	0.21c	0.39b	0.62a	0.41a
Mean	0.17c	0.32b	0.42a	

HSD (1%) Storage conditions=0.0344,1-MCP Concentrations=0.0486, Storage condition X 1-MCP Concentration=0.0809

* E-mail address: amoatengmensah.elvis@yahoo.com

3.4: Vitamin C (mg/100mg) of tomatoes treated with different concentrations of 1-MCP and stored under different storage conditions.

Significantly higher (P<0.01) vitamin C content (6.93mg/100mg) was recorded by tomato fruits stored in the refrigerator whilst the least (4.87 mg/100mg) was recorded by fruits stored under ambient conditions between the storage conditions.

Also amongst the 1-MCP concentrations, significantly higher (P<0.01) vitamin C content was recorded by untreated tomato fruits (7.87 mg/100mg) whilst the least was recorded by tomato fruits treated with 2 ppm of 1-MCP concentration (4.37 mg/100mg).

With regards to the storage conditions and 1-MCP concentrations interactions, tomato fruits untreated and stored in the refrigerator had the highest vitamin C (8.65 mg/100mg) and the least vitamin C (3.54 mg/100mg) was by fruits treated with 2 ppm of 1-MCP concentration.

Table 4: Vitamin C (mg/100mg) of tomatoes treated with different concentrations of 1-MCP and stored under different storage conditions.

	Vitamin C			
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	7.09b	3.99d	3.54d	4.87b
Refrigerator	8.65a	6.93b	5.20c	6.93a
Mean	7.87a	5.46b	4.37c	

HSD (1%) Storage conditions=0.28,1-MCP Concentrations=0.39, Storage condition X 1-MCP Concentration=0.65

3.5: Percentage weight loss (%) of tomatoes treated with different concentrations of 1-MCP and kept under different storage conditions

Between the storage conditions, tomato fruits stored under ambient condition recorded a significantly higher (P<0.01) percentage weight loss whilst the least was recorded by fruits in the refrigerator.

Amongst the 1-MCP concentrations, untreated tomato fruits had a significantly higher (P<0.01) percentage weight loss which was similar to tomato fruits treated with 1 ppm of 1-MCP concentration and the least was recorded by tomato fruits treated with 2 ppm of 1-MCP concentration.

* E-mail address: amoatengmensah.elvis@yahoo.com

With reference to 1-MCP concentrations and storage condition interaction, tomato fruits untreated and kept under ambient condition had a significantly higher (P<0.01) percentage weight loss which was similar to tomato fruits treated with 1 ppm and 2 ppm when stored under ambient condition and the least was recorded by tomato fruits treated with 2 ppm of 1-MCP concentration and stored in the refrigerator which was also similar to untreated tomato fruits which stored in the refrigerator.

Table 5: Percentage weight loss (%) of tomatoes treated with different concentrations of 1-MCP and kept under different storage conditions.

	Percentage Weight Loss			
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	0.75a	0.63ab	0.58ab	0.65a
Refrigerator	0.59ab	0.72a	0.46b	0.59a
Mean	0.67a	0.67a	0.52b	

HSD (1%) Storage conditions=0.0552,1-MCP Concentrations=0.0781, Storage condition X 1-MCP Concentration=0.1300

3.6: Firmness (N) of tomatoes treated with different concentrations of 1-MCP and stored under different storage conditions.

Significantly higher (P<0.01) firmer fruits was recorded by tomato fruits stored in the refrigerator whilst firm fruits was recorded by tomato fruits kept under ambient conditions between the storage conditions.

Amongst the 1-MCP concentrations, tomato fruits treated with 2 ppm of 1-MCP concentration had a significantly firmer (P<0.01) fruits which was similar to tomato fruits treated with 1 ppm of 1-MCP concentration whilst firm fruits was recorded by untreated tomato fruits.

Interactively, tomato fruits treated with 2 ppm of 1-MCP concentration and stored in the refrigerator was significantly firmer (P<0.01) whilst firm fruits was recorded by untreated tomato fruits kept in the refrigerator.

Table 6: Firmness (N) of tomatoes treated with different concentrations of 1-MCP and stored under different storage conditions.

* E-mail address: amoatengmensah.elvis@yahoo.com

	Firmness			
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	48.5bc	53.6ab	48.6bc	50.2a
Refrigerator	43.7c	50.9abc	58.3a	50.9a
Mean	46.1b	52.2a	53.5a	
HSD (1%) Storage conditions=3.7088,1-MCP Concentrations=5.2441, Storage condition X 1-MCP Concentration=8.7283				

3.7: Moisture content (%) tomatoes treated with different concentrations of 1-MCP and kept under different storage conditions.

Between the storage conditions, there was no significant (P>0.01) in moisture content even though tomato fruits stored under ambient condition had a significantly higher moisture content.

Amongst the 1-MCP concentrations, there was no significant difference (P>0.01) between the various levels of 1-MCP concentrations.

Interactively, there was again no significant difference (P>0.01) between the untreated fruits and treated fruits when they were stored at both ambient and refrigerator conditions.

Table 7: Moisture content (%) tomatoes treated with different concentrations of 1-MCP and kept under different storage conditions.

* E-mail address: amoatengmensah.elvis@yahoo.com

	Moisture Content			
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	93.3a	93.2a	91.9a	92.8a
Refrigerator	92.4a	91.9a	92.4a	92.2a
Mean	92.9a	92.6a	92.2a	

HSD (1%) Storage conditions=0.9811,1-MCP Concentrations=1.3872, Storage condition X 1-MCP Concentration=2.3088

3.8: Shelf-life (days) of tomatoes treated with different concentrations of 1-MCP and stored under different storage conditions.

Between the storage conditions, tomato fruits kept in the refrigerator recorded significantly longer (P<0.01) shelf-life of 78 days and a shorter shelf-life of 69 days was recorded by tomato fruits kept under ambient condition.

With reference to storage conditions and 1-MCP concentration interaction, tomato fruits treated with 2 ppm of 1-MCP concentration and stored in the refrigerator had a significantly longer (P<0.01) shelf-life of 90 days and a shorter shelf-life of 60 days was recorded by untreated tomato fruits kept under ambient condition which was similar to tomato fruits treated with 1 ppm of 1-MCP concentration and stored under ambient condition.

Amongst the 1-MCP concentrations, tomato fruits treated with 2 ppm of the 1-MCP concentration had a significantly (P<0.01) longer shelf-life of 85 days whilst a shorter shelf-life was recorded by fruits untreated with 1-MCP concentration which was similar to fruits treated with 1 ppm of 1-MCP concentration.

Table 8: Shelf-life (days) of tomatoes treated with different concentrations of 1-MCP and stored under different storage conditions.

* E-mail address: amoatengmensah.elvis@yahoo.com

Shelf Life				
	1-MCP concentrations			
Storage conditions	0 ppm	1 ppm	2 ppm	Mean
Ambient	60c	68bc	80ab	69b
Refrigerator	70b	74b	90a	78a
Mean	65b	71b	85a	

HSD (1%) Storage conditions=2.82,1-MCP Concentrations=3.99, Storage condition X 1-MCP Concentration=6.644

4.0 DISCUSSION

4.1 Electrical Conductivity (EC)

The reason for higher EC recorded by the untreated fruits amongst the 1-MCP concentrations could be attributed to the gradual loss of cell membrane integrity in the course of ripening. It was reported by [18] that, after harvest, the EC of a fruit increased steadily and this indicates a gradual loss of cell membrane. The increase in EC was stimulated during ripening process. It could be that in the absence of ethylene inhibitor, fruits ripening were initiated at a faster rate. As fruits ripens, ion concentration increases thereby leading to an increase in EC.

The lowest EC recorded by fruits to which 2 ppm of 1-MCP treatment was applied could be that, the 1-MCP concentration applied inhibited the ethylene effects and as a result the cell membrane integrity was also intact in the fruits thereby delaying its ripening. As ripening is delayed the ion concentrations in the fruits also decreases.

The highest EC recorded by fruits stored at ambient condition at a temperature of 29°C might be as a result of high temperature at the ambient condition. Fruits stored at higher temperatures increases respiration rate as well as metabolic processes and thus ripening is also faster. Since a lot of ions are produced as fruits starts to ripen, there is the tendency of high EC that would be produced as well. It was reported by [19] that, the enzymatic catalysis that leads to biochemical breakdown of compounds in fruits and vegetables is as a result of an increase in temperature.

The lowest EC recorded by fruits stored in the refrigerator at a temperature of 13°C with regards to storage condition interaction could be as a result of the lower temperature at the

* E-mail address: amoatengmensah.elvis@yahoo.com

refrigerator. At low temperatures, ethylene absorption is drastically removed thus delaying ripening.

It was reported by [20] that, the best effective means to maintain quality of most vegetables and fruits are by preserving them below relatively low temperature as a result of its response of minimizing respiration rate, ethylene production and ripening, transpiration, rot development and senescence.

4.2 pH

With regards to the storage conditions, a higher pH which indicates a decrease in acid by fruits kept at ambient condition at a temperature of 29°C could be as a result of the high temperature at the ambient condition as reported by [21]. The authors reported that at higher temperatures, there was an increase in pH values of pepper with an increased storage period.

When there is high temperature the rate of cellular respiration is also higher and the enzymes in the fruits break down easily as well thereby leading to faster rate of ripening which intends leads to higher pH in the fruits.

Also the lower the temperature the slower the rate of cellular respiration. Low temperatures reduce respiratory activities and degradation of some enzymes and as a result the conversion of sugars to acids in the course of ripening is also delayed thus leading to a low pH which is an indication of an increase in acid in the fruit. So this also could have accounted for the decrease in pH by fruits in the refrigerator at a temperature of 13°C.
A decrease in pH recorded by fruits at 2 ppm of 1-MCP concentration could be as a result of the impact the 1-MCP concentration had on the fruit. The 1-MCP concentrations applied blocked the ethylene receptors which elicit its physiological action to cause the early ripening in the fruits. The 1-MCP concentration applied was able to reduce the rate of respiration and as a result ripening was delayed.
The highest pH recorded by untreated fruits with reference to the 1-MCP treatments could be attributed to the fact that, because no 1-MCP concentration was applied to the fruit and there was no blockage of ethylene receptors, the fruits had enough ethylene to ripen and as fruits starts to ripen, there is an increase in sugars and a decrease in acidity thus an increase in pH of the fruits.

4.2 Weight loss

The highest weight loss recorded at ambient at a temperature of 29°C could be attributed to the higher temperature at the ambient condition. In a report by [22] the authors indicated that the major cause of higher weight loss could be as a result of higher transpiration rate in the tomato fruits when preserved at higher temperatures as compared to tomato fruits preserved at low temperatures. It could therefore be deduced that at high temperatures, the biochemical processes are also high thereby leading to higher weight loss as compared to low temperatures (13°C).

In addition, it was discussed by [23] that, when there is high temperature, the variations in the vapour pressure between the fruits and its environs also increases and this variation could be one of the factors that promote quicker moisture transfer from the tomato fruit to the surrounding air.

The highest weight loss recorded by 0 ppm (control) with regards to the 1-MCP treatments could be due to an increased respiration and transpiration rate which in turn led to water loss in the fruit.

* E-mail address: amoatengmensah.elvis@yahoo.com

It was mentioned by [24] that, the major means that result in weight loss in most fresh produce is transpiration. And in tomato fruit about 92-97% of the weight loss is due to transpiration.

The lowest weight loss recorded by 2 ppm of 1-MCP concentration might be attributed to the effect the 1-MCP concentration applied had on the fruit. It could be that the 1-MCP concentration applied was able to penetrate into the fruits to retard the physiological and respiratory processes that promote water loss in fruits.
These observations are in agreement with the findings of [25]; [26] who reported that 1-MCP reduced fruit weight loss in plum.

4.3 Firmness

With regards to the storage conditions, the firmer fruits at a temperature of 13°C could be attributed to the lower temperature of the storage condition. At low temperatures the rate of respiration, ethylene production, ripening as well as senescence is low than at high temperatures of 29°C such as ambient.
The 2 ppm of 1-MCP concentration which resulted in firmer fruits might be as a result of the effect the 1-MCP concentration applied had on the fruits. It could be that it was able to block the ethylene receptors which aids in ripening.

4.4 Vitamin C content

With reference to storage conditions, a higher vitamin C content by fruits refrigerated at a temperature of 13°C as compare to fruits stored at ambient at a temperature of 29°C might be as a result of the temperature changes at the various storage conditions.

Vitamin C is heat sensitive so as the temperature rises there is a fall in vitamin C content. It was reported by [27] that low temperature storage is crucial in order to ensure low ascorbic acid retention.
High levels of Vitamin C content by untreated fruits compared to the treated amongst the 1-MCP treatments could be attributed to the faster rate of maturity of the control fruit than the treated ones. As fruits starts to ripen, the rate of respiration as well as ethylene production is high and this therefore leads to faster rate of maturity and thus a higher vitamin C content as previously indicated by [28] and [29]. The authors attributed higher vitamin C content in untreated fruits to the faster maturity rates as compared to the treated fruits.
These results are in agreement with previous reports by [30], that 1-MCP decreases or delays loss of ascorbic acid in tomato.

Similar findings were also reported by [31] for Pineapple.

4.5 Total Titratable Acidity (TTA)

The highest TTA level by fruits refrigerated at a temperature of 13°C compared to lower at ambient conditions might be that at low temperatures, the biochemical processes in fruits are lowered and therefore ripening is also delayed as compared to higher temperatures of 29°C.

According to [32] mature green tomato can be stored for relatively longer period at a temperature of 13-15°C.
The highest TTA recorded by 2 ppm of 1-MCP concentration could be that, citric acid which is a major contributor to TTA was blocked by the ethylene inhibitor (1-MCP) concentration that was applied. According to [33], citric acid is the most abundant acid in tomatoes and the largest contributor to TTA. Since there was a delay in ripening as a result of the 1-MCP application, the rate of conversion of sugars to acids was also delayed thereby leading to a higher TTA in the tomato fruit.

* E-mail address: amoatengmensah.elvis@yahoo.com

4.7 Moisture Content

With reference to the storage conditions there was no significant difference on fruits stored at ambient and those stored in the refrigerator conditions respectively.

Also amongst the 1-MCP concentrations applied, there was no significant difference between the treated and non-treated tomato fruits.

4.8 Shelf-life

The longer shelf-life fruits refrigerated at a temperature of 13°C could be due to the storage temperature at the refrigerator. At low temperatures, the rate of respiration, ethylene production as well as ripening is low and as a result the shelf-life of the fruits stored would be longer as compare to high temperatures such as ambient at a temperature of 29°C.

The longer shelf-life by fruits stored at 2 ppm of 1-MCP treatment could be due to the fact that, the highest dose of 1-MCP concentration applied were able to retard the physiological processes in the fruit and greatly reduced the respiratory rate and delayed the onset of the climacteric peak during the storage period.

The shorter shelf-life by the untreated fruits could be attributed to the fact that, in prolong periods of storage, fruit tissues synthesize more ethylene receptors which in turn increases the respiratory rate at the end of storage as previously indicated by [34].

5.0 CONCLUSION

It can be concluded that, fruits treated with 1-MCP concentrations delayed ripening with regards to changes in firmness, total titratable acidity, pH and shelf-life compared to untreated fruits.

With reference to the storage conditions, it can be concluded that fruits stored in the refrigerator at a temperature of 13-15°C with relative humidity of 80-85% delayed ripening, maintain the quality and extended the shelf-life compared to fruits stored at ambient conditions at a temperature of 29°C with relative humidity of 65-70%.

Also the untreated fruits (0 ppm) recorded higher weight loss, vitamin C and a shorter shelf-life.

These results propose that 1-MCP application could be manipulated to give a precise shelf-life expectation by controlling temperature to alter the reaction to 1-MCP, accepting that shelf life expectations must be significantly reduced at higher temperatures.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author AME designed the study. Author IY performed the statistical analysis and Author AME and AB wrote the protocol as well as the first draft of the manuscript. Authors IY also managed the analyses of the study. Authors AME and KP read and approved the final manuscript.

* E-mail address: amoatengmensah.elvis@yahoo.com

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* E-mail address: amoatengmensah.elvis@yahoo.com

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* E-mail address: amoatengmensah.elvis@yahoo.com