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Effect of 1-methylecyclopropane and Low-Temperature Storage on Postharvest Longevity of Banana cv 'Ambul'

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ABSTRACT

Purpose: *The experiment was conducted to investigate the efficacy of low-temperature storage conditions on the local banana cultivar 'Ambul' postharvest longevity after 1-methylecyclopropane (1-MCP) application.*

Research Method: *Banana fruits were treated with two dosages of 1-MCP; 1 mg·L^{-1} for 12 hours and 1 mg·L^{-1} for 18 hours at room temperature (29±3^{o}C). 1-MCP treated banana fruits were stored at ambient conditions (28 ±5o C and 70 ±6% of RH) and cool room conditions (14 ±1^{o}C and 85 ±4% of RH). Physico-chemical quality parameters, including ripening index, peel colour as L^*, a^*, b^* values, physiological weight loss, pulp firmness, chlorophyll content, total soluble solids, respiration rate, ethylene production, pulp-to-peel ratio, sucrose, fructose and glucose contents, titratable acidity and pH of the fruits were measured before treatment and during the storage period.*

Findings: *Banana fruits stored at ambient conditions reached yellow earlier within 18 and 21 days whereas fruits stored at cool room conditions maintained an extended green life up to 24 and 30 days. Although 1-MCP postponed the respiration and ethylene peaks, the effect was more pronounced at 14oC than in ambient conditions. 1-MCP treatment and low-temperature storage conditions significantly reduced the ripening rate as measured by regulating the changes in pulp firmness, total soluble solids, sugar conversion rate, chlorophyll degradation, pulp pH, and total titratable acidity; keeping the quality of fruits.*

Originality/ Value: *: 'Ambul' banana fruits treated with 1ppm 1-MCP for 18h and stored at 14oC temperature ensured the longest shelf life of 30 days.*

Keywords: *'Ambul' banana, 1-methylecyclopropene, Postharvest storage, Ripening, Shelf life.*

INTRODUCTION

Bananas (*Musa* spp.), being the main fruit crop grown in Sri Lanka, are the most consumed fruit in the country (Hirimburegama *et al.*, 2004). They are cultivated over an area of 44,671 hectares, with an annual production of 0.67 million tons in Sri Lanka (Agstat., 2020). However, high postharvest losses, estimated at around 20–30% of total production, have become one of the major problems faced by the banana industry (Wasala *et al.*, 2014). Consequently, the reduction of postharvest losses has become a central pillar of sustainable global food systems and the enhancement of food security (Kikulwe *et al.*, 2018).Although several factors contribute to postharvest losses, the excess production of ethylene during ripening significantly shortens the postharvest life of bananas, leading to higher losses (Krishnakumar and Thirupathi, 2014).

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Bananas are distinctive climacteric fruits that exhibit a sudden peak in ethylene biosynthesis and respiration rate during ripening (Kumar *et al.*, 2018). Therefore, inhibiting the effects of ethylene on banana fruit ripening is crucial for extending their shelf life.One approach to achieving this is the development of transgenic plants with altered ethylene production levels, along with the use of chemical inhibitors of ethylene reception (Zhang *et al.*, 2006).

The banana cultivar 'Ambul' (Mysore-AAB) is in highest demand in the Sri Lankan market (Hirimburegama *et al.*, 2004). 'Ambul' bananas are known for their distinctive taste and small size, making them highly sought after in the export market. However, their very short postharvest life limits their transport to air freight. Extending the shelf life of 'Ambul' bananas could provide significant commercial benefits to both exporters and retailers. Therefore, prolonging the postharvest life of the 'Ambul' banana is a major strategy for the development of the banana industry in Sri Lanka.

1-methylcyclopropene (1-MCP) is a relatively new chemical tool that has been successfully identified for lengthening postharvest life and preserving the quality of fresh produce. It is stable at room temperature, active at very low concentrations, and importantly, a non-toxic GRAS compound recommended by the USDA (Blankenship and Dole, 2003). Furthermore, 1-MCP is considered a prospective compound for regulating the ripening process and preventing quality deterioration of harvested bananas at a commercial scale (Silva *et al.*, 2010). Balasuriya *et al.* (2014) stated that the green life of the cultivar 'Kolikuttu' can be prolonged for 14 days under ambient storage conditions by treating it with 1-MCP. Wasala *et al.* (2020) also revealed that treating 'Ambul' bananas with 1 ppm 1-MCP for 18 hours and 1 ppm for 12 hours extended the shelf life respectively for 19 and 17 days at ambient conditions. In addition, research conducted by Hamda *et al.* (2020) has proven that 1-MCP could prolong the shelf life of the banana cultivar Kandula for 29 days under low-temperature conditions. Therefore, the application of 1-MCP to delay ripening and preserve the quality of bananas has already been identified as a successful method to be used in Sri Lanka. The present study was carried out to examine the efficacy of low-temperature storage conditions on the shelf life of 1-MCP-treated 'Ambul' bananas.

MATERIALS AND METHODS

Plant Material

The local banana cultivar, 'Ambul' (AAB), was selected for the experiment. Mature green banana bunches consisting of 3/4 quarters full were obtained from well-maintained commercial cultivation located at Rajanganaya in the Anuradhapura district, Sri Lanka. Banana hands were separated and sorted to eliminate damaged fruits and to obtain samples of uniform maturity.

Application of 1-methylcyclopropene (1-MCP) and Storage

Glass chambers with 95 L volume capacity were used for 1-MCP treatment. Thermocouples of a digital thermometer (Model: TECPEL 506B, Thaiwan) were fixed to glass chambers to measure the inside temperature during the treatment period. Banana fruits were treated with two dosages of 1-MCP: 1 $mg{\cdot}L^{-1}$ for 12 h and 1 $mg{\cdot}L^{-1}$ for 18h. According to Wasala *et al.*, (2020), previous studies have disclosed that 1-MCP doses of 1 mg·L-1 for 18 h and 1 $mg{\cdot}L^{-1}$ for 12 h have shown the best results which suppressed the ripening of 'Ambul' bananas respectively for 19 and 17 days at ambient conditions (29 $\pm 5^{o}$ C and 69 ±7%.). Treatments were conducted at room temperature (29±3^{o}C). Each treatment consisted of approximately 30 kg of banana hands. After the treatment, banana hands were placed in plastic crates replicates. Then, banana fruits treated with two dosages were stored at ambient conditions (28 ±5^{o}C and 70 ±6% of RH) and cool room conditions (14 ±1^{o}C and 85 ±4% of RH) simultaneously. Each treatment was replicated three times.

Environmental Data Collection

Temperature values of the atmosphere and in the chamber were recorded before, during the treatment, and throughout the storage period using a digital thermometer. Relative humidity of the atmosphere was measured at each stage as above, using a digital hygrometer.

Effect of 1-MCP and Storage Conditions on Ripening of Banana Fruits

Physico-chemical quality parameters of banana fruits of all the treatments were measured before treatments and during post-treatment periods at three-day intervals. One fruit from each replicate was used for the sample analysis, and one banana hand for each replicate was used for gas analysis.

The ripening index of treated fruits was determined using the standard chart provided by Kader and Cantwell (2007). Fruit peel colour was determined using a portable colour detector (Model: Minolta, CR 400, Japan) and measurements were recorded as L^*, a^*, and b^* values. The measurements were taken at the stem end, mid-section, and floral end of fruits and then averaged. Physiological weight loss (PLW) of treated fruits during the storage phase was recorded using the same sample from each treatment. Fruit weight at each sampling point was recorded by a top-loading electrical balance (Model: ARA 20, USA). Percentage weight loss was calculated as mentioned by Ram *et al.* (2008). The pulp firmness of banana fruits was determined using a fruit firmness tester (Model: Guss, TR53205, South Africa). The chlorophyll content of banana peel was measured as described by Vasant *et al.* (2017). The total soluble solids (TSS) content in fruit pulp was determined using a portable refractometer (Model: ATAGO, HR-5, Japan) as explained by Sultani *et al.* (2010), and measurements were described as % Brix. The respiration rate was measured based on changes in CO^2 emission by the fruit. Gas samples were collected and analyzed for CO^2 production rate and ethylene production using a Gas Chromatograph (Model: SHIMADZU, GC 2014, Column temperature: 40^0 C, Carrier gas: Helium, India). The pulp-to-peel ratio of banana fruits was determined by dividing the weight of the pulp by the peel weight according to the method mentioned by Kumar *et al.* (2018). Sucrose, fructose, and glucose content of banana pulp at each sampling stage were determined according to the method described by Ncama *et al.* (2018), using High Performance Liquid Chromatography (HPLC) (Model: Thermo, Dionex Ultimate 300, India). Sucrose, glucose, and fructose peaks of banana fruits were recognized using HPLC retention times compared with authentic standards (Column oven temperature: 43^0 C, Detector flow rate: 1mL/min, Mobile phase: Acetonitrile to water 75:25). Titratable Acidity (TA) of banana was measured as mentioned by Diny *et al.* (2007). The pulp pH was measured using a glass electrode pH meter (Model: Thermo Orion 420, USA).

Data Analysis

The experimental design adopted was the Completely Randomized Design (CRD). Parametric data collected were analyzed with the Analysis of Variance (ANOVA) using the Statistical Analysis System. Differences among treatment means were obtained by Duncan's multiple range test at a 5% significance level ($p \leq 0.05$).

RESULTS AND DISCUSSION

Effect on Physical Properties of 'Ambul' Banana

Ripeness Index of Banana Fruits The change in ripeness index of 'Ambul' banana fruits that were treated with 1-MCP and kept under both storage conditions is shown in Fig. 01. The most obvious change during ripening in banana fruit is its external color. As shown in Fig. 01, the ripeness index of banana fruits remained unchanged, maintaining a green color until 9 days in T2, 13 days in T4, 18 days in T1, and 24 days in T3. However, after these respective periods, the ripeness index began to increase during the storage period. The changing rates of ripeness index among treatments were significantly different, varying with different 1-MCP dosages and storage conditions. Bagnato *et al.* (2003) also revealed that the green life of bananas can be increased when treated with 1-MCP, with responses being concentration- and exposure-time dependent. Banana fruits stored under ambient conditions (T2 and T4) reached index five (yellow color) at 18 and 21 days, respectively. However, banana fruits stored under cool room conditions exhibited significantly lower changes in ripeness index compared to those stored under ambient conditions. The peel degreening of 1-MCP-treated bananas is delayed at 14^0C storage due to their very low sensitivity to ethylene (Bantayehu, 2017; Satekge and Magwaza, 2020). The ripeness index of T3 reached stage four on the 30th day of the storage period, which was significantly the highest shelf life among all the treatments.

Peel color of 'Ambul' banana: Fig. 02 illustrates the change of L^* value in the peel color of 'Ambul' bananas during the storage period. Banana fruit treated with 1-MCP and stored at low-temperature conditions exhibited a slower increasing rate in L^*. The L^* values of T1 and T3 indicated significantly higher increments compared to T2 and T4. The average initial L^* of all the treatments changed from 55.40 to 60.28 – 66.71 during the storage period. A similar way of color changing in bananas was also earlier described by Chen and Ramaswamy (2002). The 'L' value indicates the lightness which extends from 0 (black) to 100 (white).

Fig. 03 shows the change of a^* value in the peel color of the 'Ambul' banana during the storage period. The 'a' value indicates the turning of fruits from green (-) to red (+). Positive a^* values conform to the redness, while negative a* values correspond to the level of greenness. The* values of 'Ambul' banana fruits which were stored at ambient conditions after 1-MCP treatment increased faster than that to the low temperature.

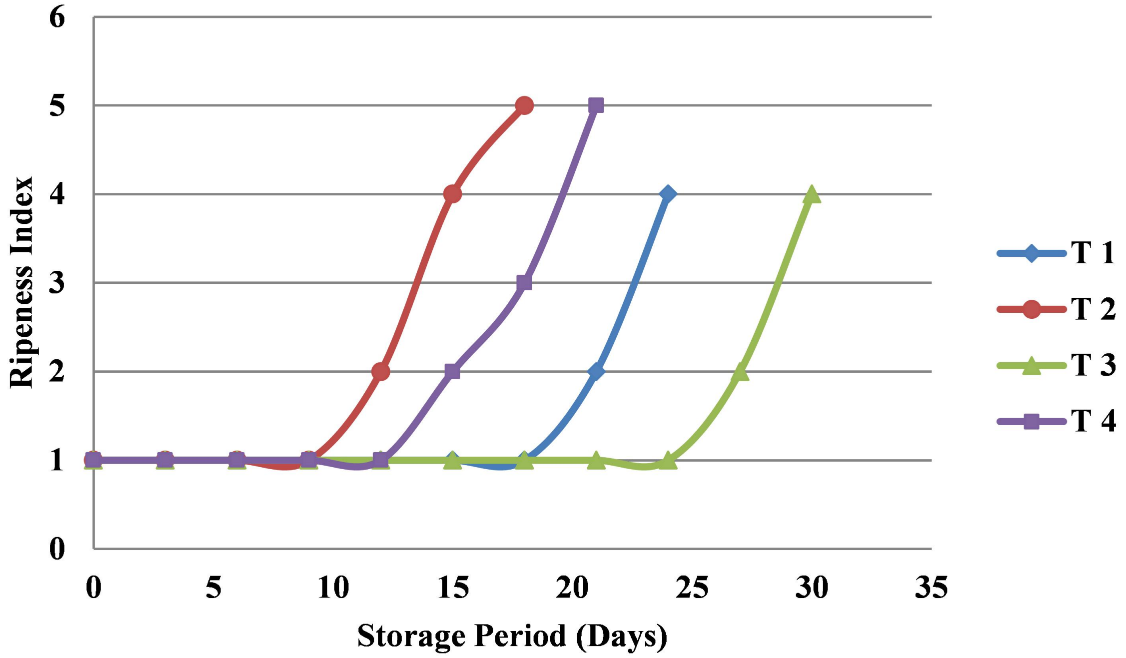

Figure 1: Effect 1-MCP treatment on ripeness index of 'Ambul' banana stored at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH) Vertical bars indicate standard error (n=5)

(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

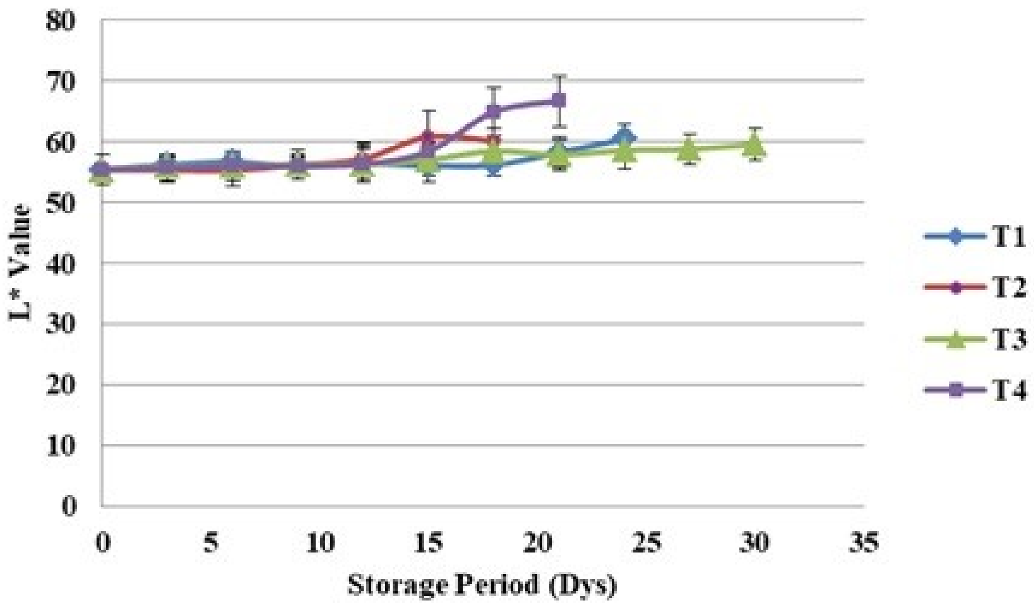

Figure 2: Effect of 1-MCP on L* value of the 'Ambul' banana stored at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5°C and 70 ±6% of RH) Vertical bars indicate standard error (n=5)

(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

Application of 1-MCP to banana fruits can significantly delay ripening for a long time when they are stored at low temperatures (Jiang *et al.*, 2004). T3 showed the highest storage period of 30 days and indicated the least changing rate of a* value of peel color. According to Abdalnoor (2007), an extended exposure time of 1-MCP increases the effectiveness of suspending the banana ripening.

The positive b^* values represent the yellowness level while negative b^* values indicate the blueness. The b^* values of the 'Ambul' banana fruits stored at ambient conditions increased rapidly in storage, while the samples kept in a cool room showed a lower change in b^* values (Fig. 04). The b^* value of T2 was significantly different ($p<0.05$) compared to other treatments at 18th day in storage, and also T4 at the 21st day and T1 at the 24th day showed same results. 'Ambul' banana fruits of T3 reached a light yellow color after 30 days of cool room storage with the longest shelf life, and it indicated the least changing rate of b^* of banana peel. Further, b^* of T3 remained almost unchanged for 27 days of storage period. 1-MCP decreases the chlorophyll degradation that is responsible for color changes of fruits during the ripening and the degree of effect was dependent on concentration and exposure time (Harris *et al*., 2000; Watkins, 2006).

Pulp firmness of the 'Ambul' banana: Table 01 presents the efficacy of 1-MCP and low-temperature storage on the pulp firmness of the 'Ambul' banana. As demonstrated by the results, the pulp firmness of fruits of all the treatments has decreased during the storage period. Jaiswal *et al.*, (2015) stated that ripening reduces the fruit firmness as a result of changes in cell wall structure due to structural alternations of pectin, hemicellulose, and cellulose. As indicated in Table 1, the pulp firmness did not show any significant difference ($p\leq0.05$) in all the treatments until the 9th day. After that, a significant difference in firmness was observed among treatments. Results further showed a rapid decline in pulp firmness of T4 stored at ambient conditions. Banana fruits of T2 and T4 reached ripen stages, respectively at the 21st and 18th of storage days resulting in lower final pulp firmness values compared to the T1 and T3 which had been kept at cool room conditions. 1-MCP application for 18 h exhibited a relatively slower decrease in pulp firmness. Changing of pulp firmness of banana fruits stored at low temperatures after 1-MCP application was slower compared to ambient conditions. T3 depicted the least changing rate of pulp firmness among all the treatments. As mentioned by Cutillas-Hurralde *et al.*, (2006) this happened because lower storage temperature delays the breakdown of the cell wall and, the degradation of polysaccharides in fruits.

Physiological Weight Loss of 'Ambul' Banana : The cumulative physiological weight loss of banana fruits for different treatments and stored at ambient and cool room conditions are presented in Table 2. The physiological weight loss of bananas is one of the major determinants of shelf life and postharvest quality. The weight loss from fresh fruits mainly occurs through the peel by vapor pressure and deterioration due to metabolic activities. Furthermore, respiration also contributes to the weight drop due to the loss of carbon atoms from the fruits (Ali *et al.*, 2004). The cumulative weight loss of all the treatments gradually increased during the storage period. The final cumulative physiological weight loss of 1-MCP-treated fruits kept under ambient conditions was comparatively higher than that of the samples stored under cool room conditions. The increasing rate of the cumulative value of this parameter was significantly ($p \leq 0.05$) lower in T1 and T3 than in T2 and T4 during the storage period, with T3 exhibiting the lowest rate of change and the highest shelf life for the 'Ambul' banana. In cold storage, the evaporation loss may be reduced due to higher relative humidity, and the respiration rate may be reduced due to lower temperature, causing slower weight reduction. Previous studies have proven that 1-MCP treatment results in a minimal reduction in weight loss during storage due to a decrease in the respiration process (Cock *et al.*, 2012).

Effect on 'pulp-to-peel ratio' of banana fruit: The pulp-to-peel ratio is an important measurement of fruits that indicates the ripening conditions. As appeared in Table 3, the pulp-to-peel ratio of banana fruits increased from 2.55 to 4.65-6.88 during the storage period. According to Kumar *et al*., (2018), pulp starch converts to simple sugars and moisture transpires through the peel usually during ripening increasing the pulp-to-peel ratio. Up to 9 day period, the pulp-to-peel ratio of all fruit samples remained almost unchanged and treatments did not show any significant difference ($p\leq0.05$). Thereafter, fruits started to increase the 'Pulp to peal ratio' in all samples, which may be due to reduced cell wall integrity of peel tissues with ripening. However, bananas stored under cold storage showed a relatively lower rate of increase. Banana fruits stored at low temperatures usually indicate lower metabolic rate and lower transpiration indicating a reduced pulp-to-peel ratio (Ahmad *et al*., 2006).

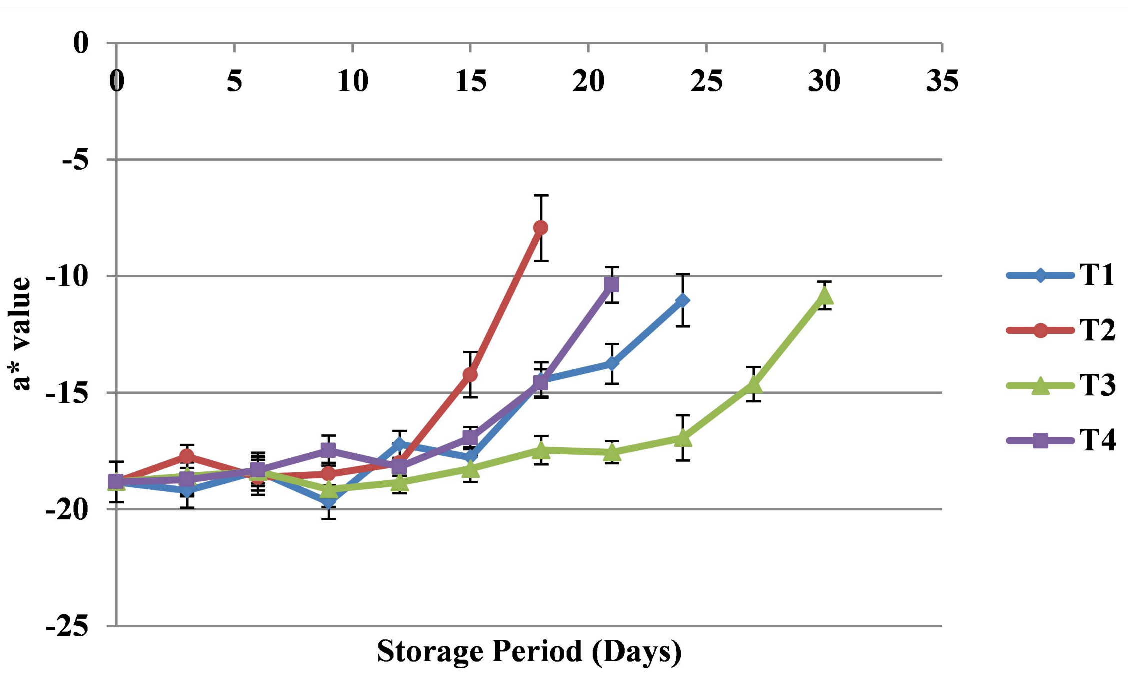

Figure 3: Effect of 1-MCP on a* value of the 'Ambul' banana stored at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH) Vertical bars indicate standard error (n=5)

(T1=1x12 (1-MCP concentration; mg L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

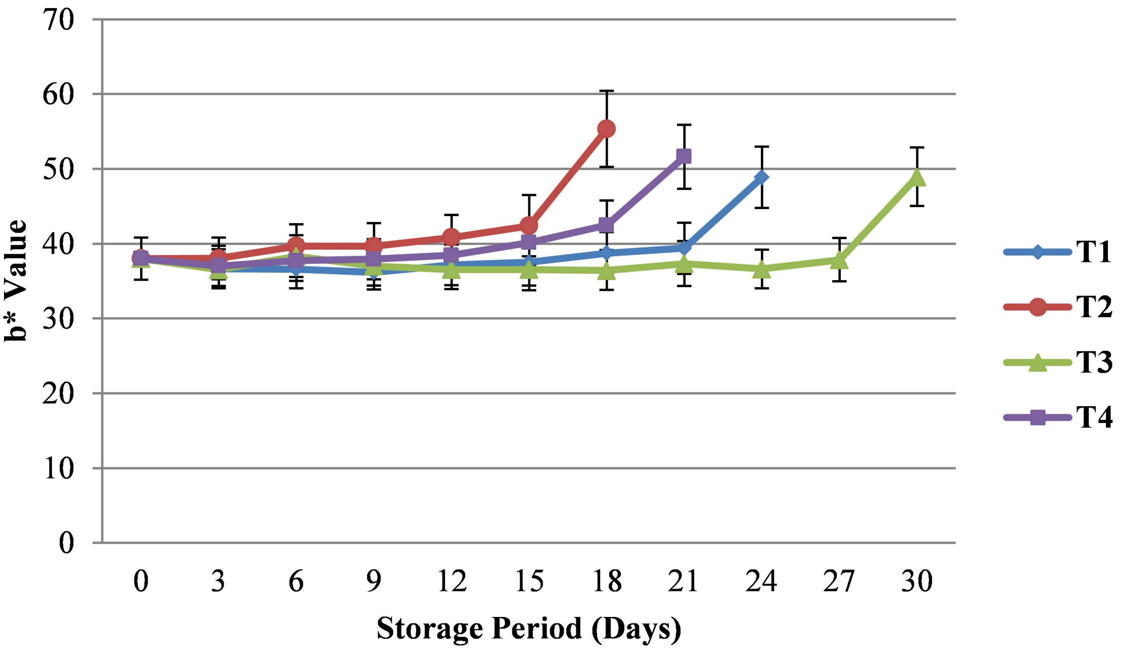

Figure 4: Effect of 1-MCP on b* value of the 'Ambul' banana stored at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH) Vertical bars indicate standard error (n=5)

(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

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Table 1: Effect of 1-MCP treatment on pulp firmness of 'Ambul' banana during the storage at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)

Treatments	Pulp firmness (N)										
	Initial	Day 3	Day 6	Day 9	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27	Day 30
T1	77.6a	77.0a	77.5a	76.9a	75.5ab	76.2a	64.4b	52.1b	34.7b	-	-
T2	77.6a	76.2a	76.3a	76.4a	72.7b	56.2b	37.5c	20.1c	-	-	-
T3	77.6a	76.9a	77.3a	77.5a	77.6a	74.8a	75.3a	69.7a	60.4a	42.6	38.4
T4	77.6a	77.7a	76.4a	71.4b	52.6c	37.8c	19.9d	-	-	-	-

Values with the same letters in each column are not significantly different at $p \leq 0.05$.
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

Table 2: Effect of 1-MCP treatments on cumulative physiological weight loss of 'Ambul' banana during the storage at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)

Treatments	Cumulative physiological weight loss (%)									
	Day 3	Day 6	Day 9	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27	Day 30
T1	0.19b	0.35b	1.42b	1.83c	2.61b	5.54c	7.42b	9.64a	-	-
T2	0.61a	1.02a	2.42a	4.72a	6.35a	10.84a	-	-	-	-
T3	0.13b	0.31b	1.67b	1.76c	2.11b	3.06d	2.63c	4.75b	6.32	9.65
T4	0.86a	0.99a	2.33a	3.86b	5.50a	7.62b	11.44b	-	-	-

Values with the same letters in each column are not significantly different at $p \leq 0.05$.
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

Table 3: P Effect of 1-MCP on 'pulp to peel ratio' of 'Ambul' banana stored at ambient and cool room conditions

	Pulp-to-peel ratio										
	Initial	Day 3	Day 6	Day 9	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27	Day 30
T1	2.55a	2.58a	2.68a	2.68a	2.95b	2.94c	3.14c	3.58b	4.65a	-	-
T2	2.55a	2.54a	2.72a	3.41a	3.95a	5.76a	6.88a	-	-	-	-
T3	2.55a	2.53a	2.74a	2.76a	2.86b	2.84c	2.94c	3.06c	3.45b	3.56	4.89
T4	2.55a	2.73a	2.83a	2.81a	3.03b	3.80b	4.27b	5.86a	-	-	-

Values with the same letters in each column are not significantly different at $p \leq 0.05$.
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

Effect on Biological Properties of 'Ambul' Banana

Ethylene Production Rates of Banana Fruits:

The ethylene production rate of 'Ambul' banana fruits at ambient and cool room storage conditions after 1-MCP treatment is shown in Fig. 05. The endogenous ethylene of climacteric fruits regulates the major changes associated with the ripening process. The ethylene production rate followed an increasing trend in all treatments during the post-treatment storage period. The ethylene evolution rate of all treatments remained unchanged until 9 days of storage, maintaining its green life. The 1-MCP application delays ethylene production from fruits due to the intervention of 1-MCP in the autocatalytic ethylene production process, as ethylene binding sites might be irreversibly congested by 1-MCP (Manenoi *et al.*, 2007). Subsequently, ethylene production in T2 increased significantly, reaching a peak of 2.8μLkg^{-1}hr^{-1} on the 15th day. Other treatments followed the same pattern at different time intervals. T4, T1, and T3 reached ethylene peak production consecutively on the 21st day (2.9μLkg^{-1}hr^{-1}), 24th day (2.1μLkg^{-1}hr^{-1}), and 30th day (2.1μLkg^{-1}hr^{-1}). The lowest ethylene peaks were detected in T1 and T3, which were stored under cool room conditions. In addition, T3 showed the significantly ($p \leq 0.05$) least changing rate of ethylene evolution and the highest shelf life among the treatments of 'Ambul' banana.

Thus, low temperatures and extended exposure periods can be used to delay the commencement of ripening in climacteric fruits. Lowering the temperature not only decreases ethylene production by the tissues but also minimizes the rate of tissue response to ethylene action (Supannaklang and Shiesh, 2018).

Respiration rates of banana fruits: The effect of different treatment periods of 1-MCP and storage conditions on the respiration rate of banana fruits is shown in Fig: 06.

The results indicated a typical climacteric respiratory pattern in the storage of 1-MCP-treated 'Ambul' bananas. An almost constant respiration rate was observed in all the treatments until 12 days of storage. Then, the respiration rate in T2 rapidly increased on the 15th day of storage. The respiration rate of the treatments was significantly different according to treatment duration and storage conditions in the latter part of the storage time. The same pattern in respiration rate was also observed in other climacteric fruits, with lower values at the initial storage duration (Rahman *et al.*, 2014). In another earlier study, Golding *et al.* (1998) discovered the suppression of respiration in banana fruits when treated with 1-MCP. T4, T1, and T3 reached their respiration peaks consecutively on the 21^{st} day ($45 mLkg^{-1}hr^{-1}$), 24^{th} day ($42 mLkg^{-1}hr^{-1}$), and 30^{th} day ($40 mLkg^{-1}hr^{-1}$). The results further elaborated that exposure to a longer treatment period of 1-MCP and storage at low temperatures delayed the respiration peak of banana fruits. Krishnakumar and Thirupathi (2014) have earlier reported that prolonged exposure of fruits to 1-MCP can regulate the respiration rate at a lower level. T3, which was treated with $1 mgL^{-1}$ 1-MCP for 18 hours and stored under cool room conditions, exhibited the most delayed respiration peak of 'Ambul' banana for 30 days among all the treatments.

Effect on Chemical Parameters of 'Ambul' Banana

*Pulp pH of Banana Fruit:*Pulp pH values of banana fruits stored at ambient and cool room conditions after 1-MCP treatments are presented in Table 4. As indicated in Table 3, the pulp pH value of banana fruits in all the treatments exhibited a gradual reduction during storage. The results further elaborated that the pH of the treatments was not significantly different and remained almost unchanged for the initial 12 days of storage. Thereafter, the pH value reduced significantly at different rates among the treatments. Newilah *et al.* (2009) stated that the pulp pH of banana decreases during ripening, and also mentioned that the pH decline has been attributed to the production of malic acid as ripening advances. The higher decline rates of pH were observed in T2 and T4, which were stored under ambient conditions. Meanwhile, T1 and T3 showed a significantly lower reduction rate of pH. Previous research has proven that banana fruits stored at lower temperatures take a considerably longer period to ripen. The sensitivity of banana fruits to ethylene is significantly lower in cold storage conditions (Bantayehu, 2017). 'Ambul' banana fruits treated with $1 mgL^{-1}$ for 18 hours and kept at low temperature (T3) showed the least change in pH and the longest shelf life.

Total Soluble Solids (TSS): Measurement of TSS is usually given in "Brix Degrees". Fig. 07 shows the effect of 1-MCP treatments on banana fruits during ambient and cool room storage conditions.

All treatments exhibited parallel patterns and increasing rates in TSS during the entire storage time. Sultani *et al.*, (2010) described that changes of TSS value and ripening showed a positive correlation in banana. The initial TSS was 5.8^0, which was almost constant in all treatments until 12^{th} day and increased afterwards. But in T2, the TSS content increased until 18^{th} day and reached the maximum level of 19.4^0. T4, T1 and T3 reached the maximum level of TSS respectively at 21^{st}, 24^{th} and 30^{th} days of storage. T1 and T3 indicated significantly lower changing rate TSS compared to other treatments. This may be due to t he delayed ripening rate of banana fruits stored in cool room conditions. A significant ($p \leq 0.05$) least increase rate in TSS content of 'Ambul' banana during the storage was observed in T3. Cock *et al.*, (2013) revealed that the application of 1-MCP decreases the conversion rate of starch into simple sugars in pineapple under refrigeration conditions.

Sugar composition of fruit: Fig. 08, 90 and 10 elaborate on the change in sucrose, fructose and glucose contents in 1-MCP treated 'Ambul' banana fruits in the storage period. The sweetness of fruits during ripening is influenced by the composition and amount of accumulated sugars (Itai and Tanahashi, 2008). As demonstrated by Fig. 08, 09 and 10, banana fruits had higher sucrose concentrations during ripening stages compared to fructose and glucose. This indicates that sucrose is a major soluble sugar in banana fruits. Sugar concentrations of all the treatments initially remained at a lower increasing rate but later exhibited a progressive increase in sucrose, fructose and glucose contents during the fruit storage period. The sugar contents of 1-MCP treated banana fruits under ambient storage showed faster production rates while comparatively

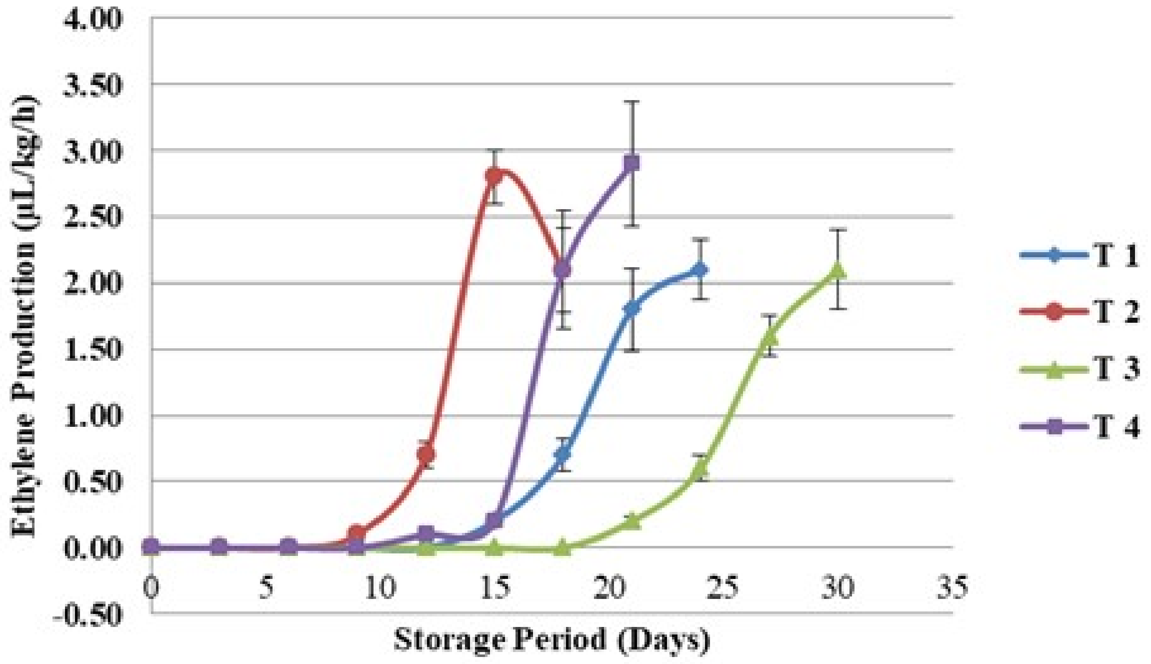

Figure 5: Ethylene production rate of 1-MCP treated banana fruits at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH).
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions).

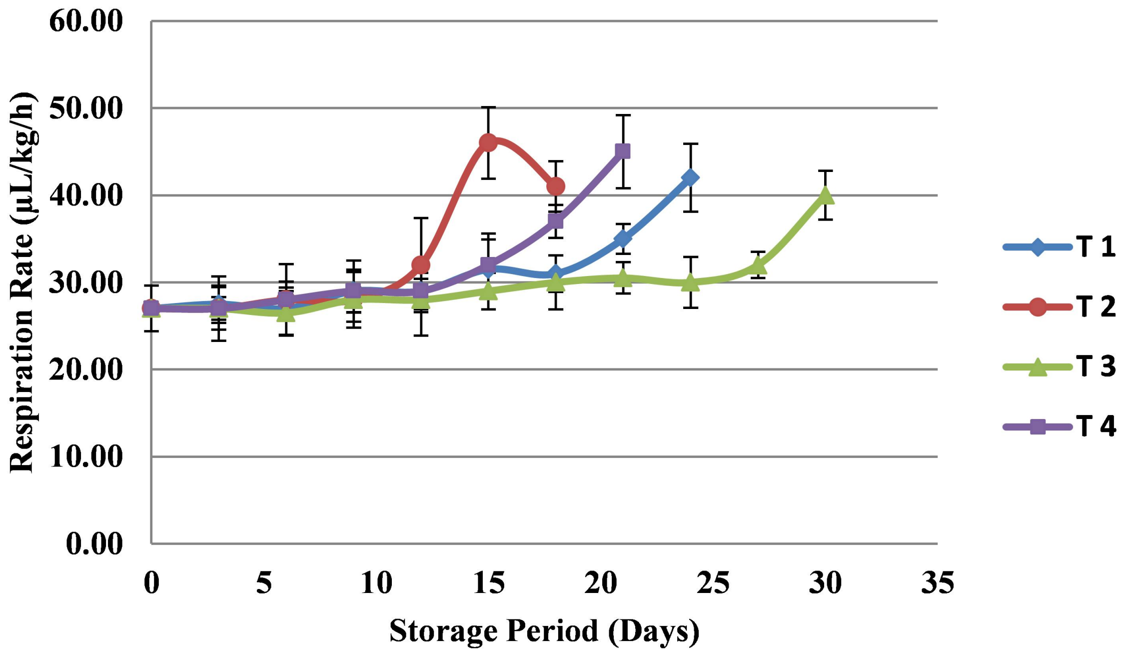

Figure 6: Respiration rate of 1-MCP treated banana fruits at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

Table 4: Pulp pH of 1-MCP treated banana fruits at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)

	pH value										
	Initial	Day 3	Day 6	Day 9	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27	Day 30
T1	5.10a	5.16a	5.00a	5.04a	5.02a	4.88ab	4.79b	4.63b	4.42b	-	-
T2	5.10a	5.09a	5.00a	4.96a	4.83b	4.44b	4.40c	-	-	-	-
T3	5.10a	5.10a	5.08a	5.04a	5.03a	5.05a	5.00a	4.89a	4.94a	4.83	4.61
T4	5.10a	5.02a	5.01a	5.04a	5.06a	4.60b	4.48c	4.28c	-	-	-

Values with the same letters in columns are not significantly different (p=0.05).
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions).

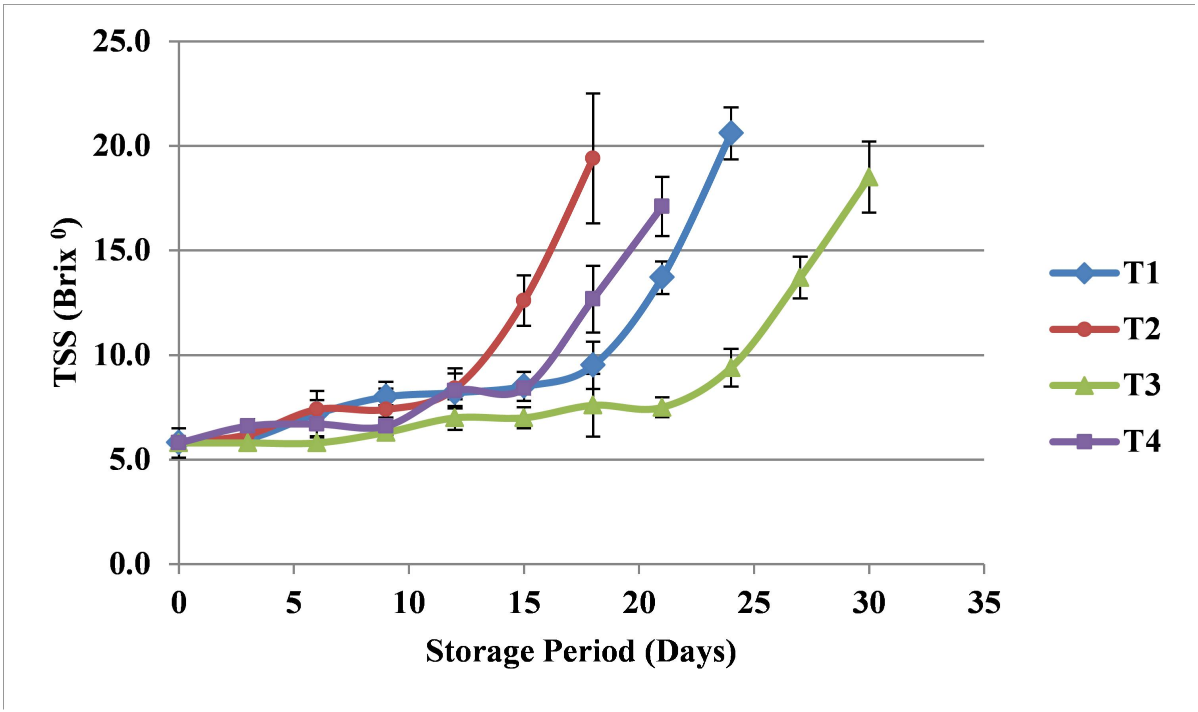

Figure 7: Total Soluble Solids content of 1-MCP treated banana fruits at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)
Vertical bars indicate standard error (n=5)
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

lower rates in cool room storage. When the fruit ripening rate decreases, a declined sugar conversion rate is indicated in the pulp. According to Silva *et al.*, (2010), delaying of 1- MCP treated banana ripening process is more effective at low temperature storage conditions. T2 exhibited the rapid conversion rate of sucrose, fructose and glucose with the onset of ripening and also the highest sugar contents at the end of the storage period respectively; sucrose: 15.2 mg/ g, fructose: 6.1 mg/ g and glucose: 3.1 mg/ g of fresh weight. However, T4 indicated the lowest sugar conversion rate and lowest sucrose, fructose and glucose concentrations after 30 days of storage period subsequently 10.2 mg/ g, 4.6 mg/ g and 2.3 mg/ g of fresh weight.

Titratable Acidity (TA): The change in titratable acidity (TA) of banana of different 1- MCP treatment times and storage conditions is presented in Fig. 11. As shown in Fig. 11, TA of all treated banana has shown an increase during the storage period. The TA level in banana gradually increased up to the 12th day.The significant ($P \leq 0.05$) differences among the treatments were observed afterwards. Rahman *et al.*, (2014) also stated that the TA in banana pulp rises with the onset of the ripening process and subsequently pH decreases as ripening progresses. 1-MCP treated banana fruits which were stored at ambient conditions exhibited a rapid rise in TA significantly ($P \leq 0.05$) in contrast to low temperature storage. T3 which was applied 1 mg·L^{-1} 1-MCP for 18 hours and stored at cool room conditions showed the significantly least increasing

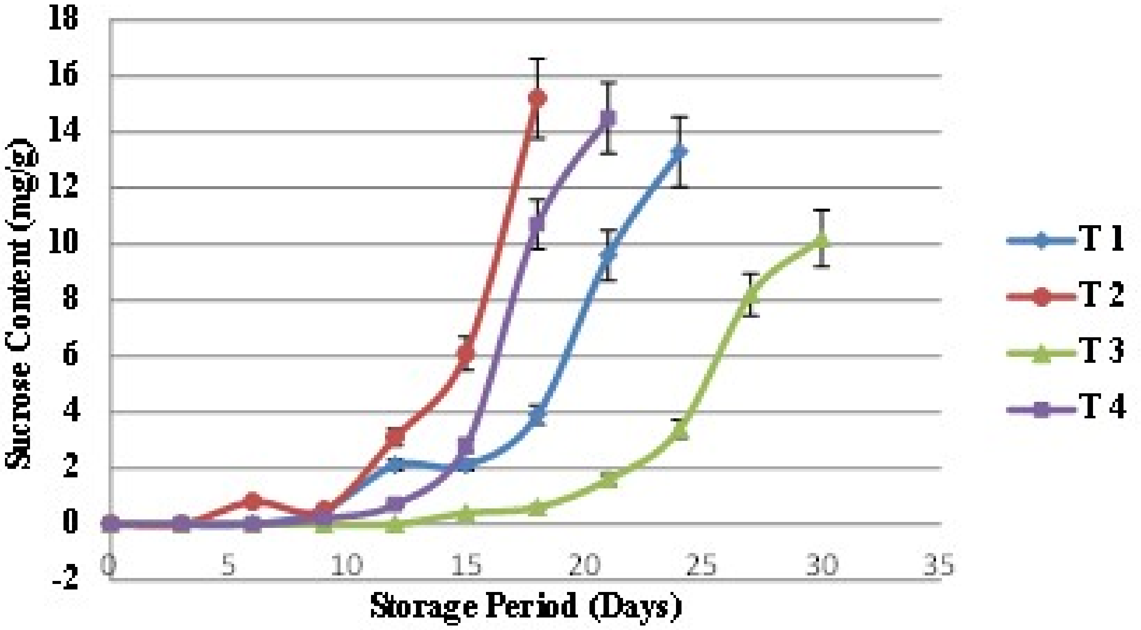

Figure 8: Change in sucrose content of 1 MCP-treated banana fruit during storage at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)
Vertical bars indicate standard error (n=5)
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

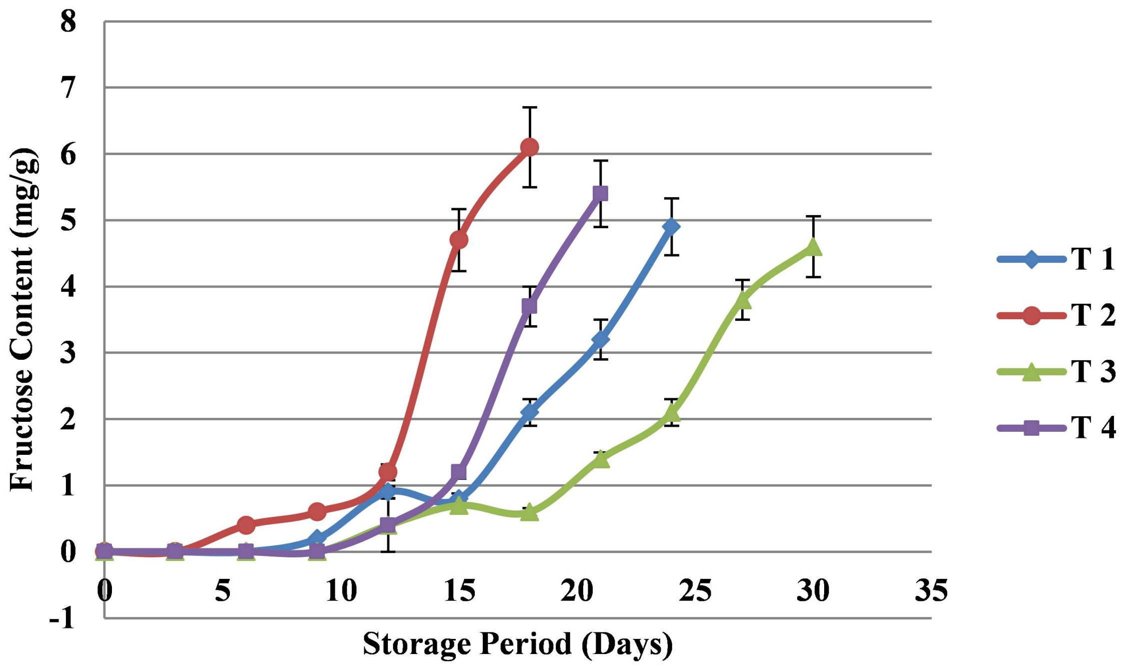

Figure 9: Change in fructose content of 1 MCP-treated banana fruit during storage at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)
Vertical bars indicate standard error (n=5)
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

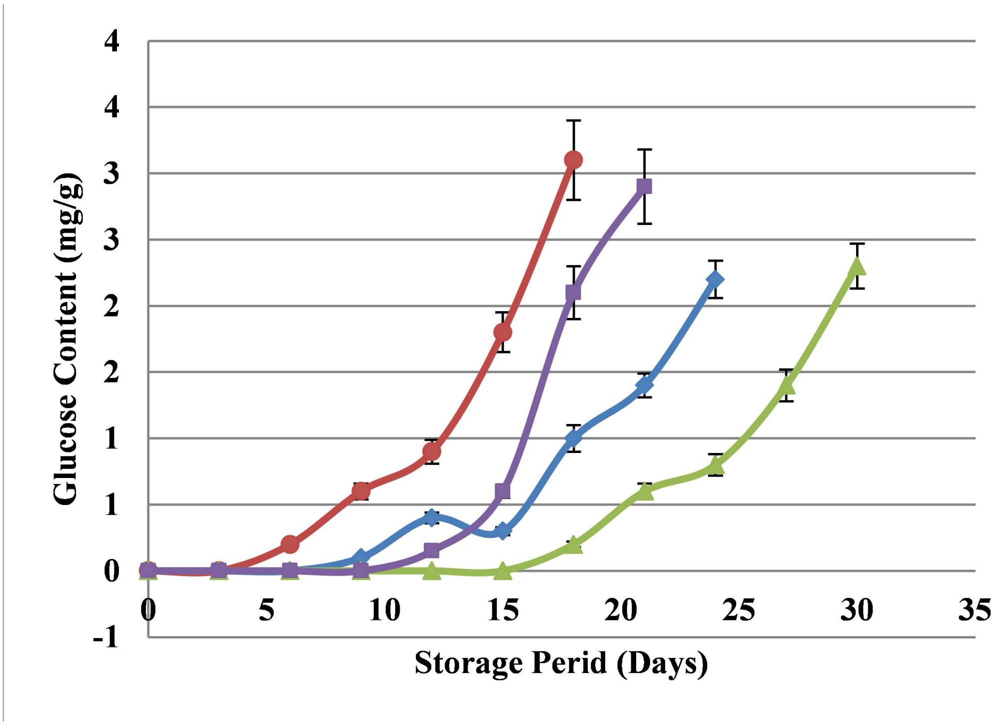

Figure 10: Change in glucose content of 1 MCP-treated banana fruit during storage at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)
Vertical bars indicate standard error (n=5)
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

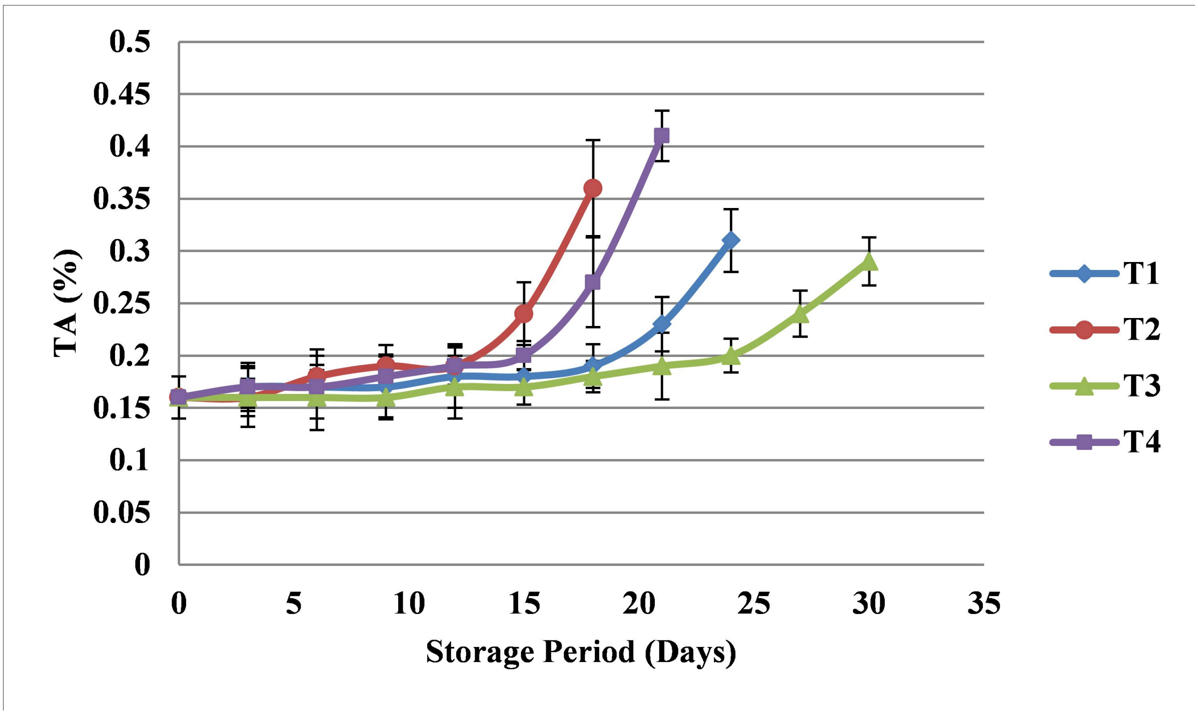

Figure 11: Change in TA of banana fruits during ambient storage fruits at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±76% of RH)
Vertical bars indicate standard error (n=5)
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

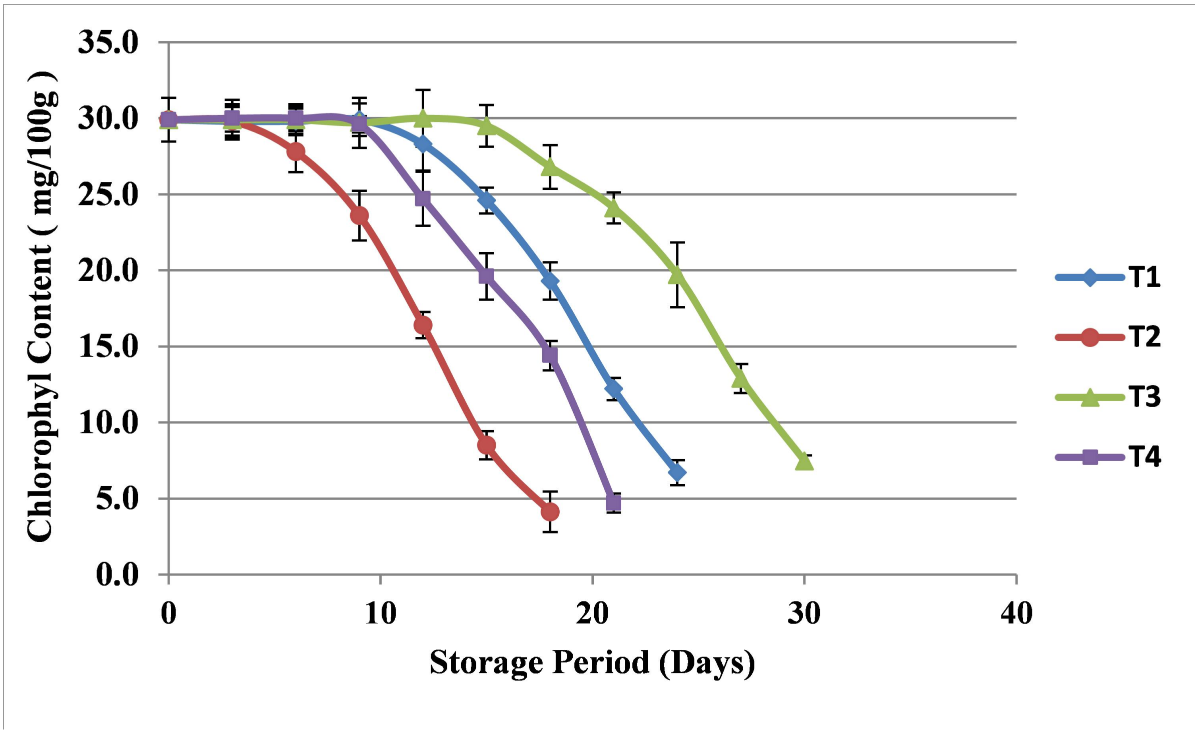

Figure 12: Change in chlorophyll content of banana fruits during storage at cool room conditions (14 ±1° C and 85 ±4% of RH) and ambient conditions (28 ±5° C and 70 ±6% of RH)
Vertical bars indicate standard error (n=5)
(T1=1x12 (1-MCP concentration; mg·L^{-1} x exposure time; hours,) at cool room conditions, T2=1x12 at ambient conditions, T3=1x18 at cool room conditions, T4=1x18 at ambient conditions)

rate in TA of 'Ambul' banana.

Chlorophyll content of banana: The chlorophyll content of banana fruits during the ambient and cool room storage conditions is presented in Fig. 12. Chlorophyll breakdown of banana peel is the first visual change that occurs during the ripening process of banana. The chlorophyll content of banana fruits in all the treatments initially remained unchanged but later started to decline in parallel with ripening. Hershkovitz *et al.*, (2005) have stated that 1-MCP maintain a green colour peel due to the suppression of ethylene and controlled chlorophyllase activity. The chlorophyll degradation in T2 rapidly took place after the 6 days of storage period from 30 to 4.1 mg/ 100 g of fresh weight. However, bananas which were stored at low temperature after 1-MCP treatment indicated comparatively lower decline rates and end values of chlorophyll content. 1-MCP significantly retarded banana at low storage temperature due to the inhibition formation of new ethylene receptors and subsequently pathways for chlorophyll degradation are disrupted by regulating chlorophyllase activity (Jian *et al.*, 2004; Silva *et al.*, 2010). 'Ambul' banana fruits treated with 1 mg·L-1 1-MCP for 18 hours and stored at cool room conditions (T3) showed the significantly ($P<0.05$) lowest rate of chlorophyll degradation during the storage.

Effect of 1-MCP in low temperature storage on shelf life of banana cultivar 'Ambul'

Significant differences in the shelf life of 1-MCP treated 'Ambul' banana were observed corresponding to the exposure time and storage temperature. When banana fruits were treated with 1-MCP and stored at ambient conditions, they reached to full ripen stage and the shelf life of T2 and T4 were 18 and 21 days, respectively. But at 14 °C, 1-MCP delayed the ripening to a significant period and the visual quality of fruits was maintained at an acceptable level with a light green colour stage at the end of storage. The green life of T1 and T3 were 24 and 30 days. Hamda *et al.*, (2020) have reported similar results: delaying the ripening of 'Kandula' banana fruits which were treated with 0.5 ppm 1-MCP for 6 hrs and stored at 14 °C temperature. Jiang *et al.*, (2004) also previously revealed that 'Zhonggang' banana were stored up for two months at 13°C after 200 nL/L 1-MCP for 24 hrs application.

CONCLUSION

The study reveals that the application of low temperature storage conditions (14 °C) for 'Ambul' banana fruits treated with 1-MCP remarkably extends the green life compared to the ambient conditions. Further, exposing banana fruits to 1-MCP for 18 hours was also more effective in delaying the ripening of banana fruits. In addition, 1-MCP treatment followed by storage at cool room conditions suppressed most of the fruit quality changes associated with banana ripening. When 'Ambul' banana fruits are treated with 1 $mg{\cdot}L^{-1}$ 1-MCP for 18 hours and stored at 14 ±1° C and 85 ±4% of RH conditions, the ripening process can be delayed up to 30 days.

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