

Combined Effects of 1-MCP and Export Packaging on Quality and Shelf-life of Cavendish Banana (Musa sp.)

Zenebe Woldu[1] Ali Mohammed[1] Derbew Belew[1] Yetnayet Bekelle[1] Tarekegn Aragaw[2]
1.Jimma University College of Agriculture & Veterinary Medicine, P.O.Box 307, Jimma, Ethiopia
2. Statistician, Jimma Agricultural Research Center, P.O.Box 192, Jimma, Ethiopia

Abstract
The effect of four concentration levels of 1-methylcyclopropene-1-MCP (17.5µl/L), 10.5µl/L, 3.5 µl/L and 0 µl/L or untreated control) in combination with three levels of export standard banana packaging materials with modified atmosphere (MA) storage effect was investigated under ambient conditions (22±1 °C and 80 ± 5% RH) on shelf life and physicochemical quality attributes of Cavendish banana (*Musa* AAA Group, Cavendish Subgroup, cultivar 'Poyo', syn: 'Robusta'). 1-MCP treatment with increased levels of concentration and increased levels of modified atmosphere packaging (MAP) generally extended shelf life and maintained better quality of fresh banana fruits when applied separately and in combination. The longest shelf life (36 days) with the lowest changes in physicochemical properties was obtained when fruits were kept in corrugated cardboard boxes with inner sealed or non-perforated polyethylene bags (PEP) after treatment with the highest concentration of 1-MCP 17.5µl/L. This could be credited to the higher inhibitory effect of 1-MCP on both the synthesis and action of ethylene when applied at the stated level of concentration and the stronger modified atmosphere (MA) condition created by the inner non-perforated PEP kept within the corrugated cardboard boxes. Thus, this technique could be considered as a less sophisticated and less costly postharvest handling alternative (storage and transportation) under ambient conditions to the temperature controlled (14^{o}C) reefer container-based system currently employed in Ethiopia and elsewhere for fresh banana exports.
Keywords: Cavendish banana; 1-Methylecyclopropene (1-MCP), export standard packaging; shelf-life, physicochemical quality

1. Introduction

Dessert banana and plantain *(Musa sp.)* are the fourth most important staple food crops in the world after rice, wheat and maize (Salvador et al., 2007). In Ethiopia, dessert banana, especially the Cavendish type, is the predominant fruit crop that is most widely grown and consumed. It contributes around 47.83% for producers' own consumption, 49.19% for income generation, 0.47 for animal feed and 2.52% for other purposes (CSA, 2014). Banana covers about 59.64% of the total fruit area, about 68.00% of the total fruits produced, and about 38.30% of the total fruit producing farmers in Ethiopia (CSA, 2014).

Banana is a highly perishable climacteric fruit that undergoes a very rapid metabolic process and senesces after harvest. Owing to such inherent characteristics, various handling and marketing technologies (storage, transportation, packaging, etc.) are commercially employed to extend its shelf life and maintain quality. However, in Ethiopia, the attention so far given to banana, in terms of research, extension services and overall supply-chain management has been very limited. As a result, the actors involved in the chain are invariably facing some kind of post-harvest handling challenges as the produce moves from one point to the other. The challenges are related to the inherent bulky and perishable nature of the fruits, mode of transportation (vehicles and roads), handling (loading and unloading, packaging, and storage), ripening and marketing systems.

Explaining the challenges facing the export of banana from Ethiopia, EHDA (2012) and CFC (2004) similarly reported that they are not merely related to low production and lack of markets, as Ethiopia is located in relatively close proximity to the major consumer countries of the Middle-East. Instead, they explained that the challenges are related to lack of basic logistics for cool-chain management (refrigerated trucks, reefer containers, packaging materials, packinghouses, storage structures, post harvest treatment chemicals, etc.) as well as rudimentary harvest maturity determination and harvesting techniques. According to the same report, only small trial shipments of about 80 tons were exported to Saudi Arabia (Jeddah) in 2012 using temperature controlled (14^{o}C) reefer containers rented from maritime companies abroad. Although the trend was planned to continue with an export of 1000 tons per month, it could not be materialized due the excessively high round trip rental cost of the reefer containers (7500-8000 USD) from the farm-gate in Ethiopia (Arba-Minch) to the destination market in Saudi Arabia (Jeddah). As reported by EHDA (2012), the length of time required to get the produce from the farm-gate (Arba-Minch) to the destination market in Jeddah was in the range of 4-5 days; including the 30-35 hours sea voyage from the port of Djibouti. This points out the need for an alternative less sophisticated and less costly post harvest handling technique that can extend the shelf-life of fresh banana fruits.

In the alternative, 1-methylcyclopropene (1-MCP) has variously reported to have effective results in retarding ripening, prolonging shelf life and reducing postharvest loses in a broad variety of climacteric fruits including papaya, avocado, pear, plum, apple and sapodilla (Sauri-Duch et al., 2010; Luo et al., 2009;

Kashimura et al., 2010). The impact of 1-MCP has also been reported to be more effective when applied in combination with modified atmosphere packaging-MAP (Ketsa et al., 2013; Watkins et al., 2000). The evidence above signifies that the use of 1-MCP could similarly be a promising technology to extend the postharvest life of fresh banana fruits. Since the modest manufacturer price of 1-MCP (99.9% purity) as stated by Xianyang Xiqin Biotechnology Co., Lt., China: www.molbase.com/1-Methylcyclopropene) is 18.00 USD/g or 13,000.00 USD/ kg, it can as well serve as a low costly alternative to the current use of temperature controlled reefer container-based fresh banana exporting system from Ethiopia and elsewhere in the world.

Cognizant of this, the present experiment was initiated with the objective to investigate the effect of different concentrations of 1-MCP in combination with the currently employed export standard packaging materials on shelf life and physicochemical quality attributes of fresh banana fruits.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was carried out at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), under the laboratory of the Department of Postharvest Management (PHM). JUCAVM is found in Jimma town, which is 355 km southwest of Addis Ababa, located at about 7040'N latitude and 360 50' E longitude with an altitude of 1780 meters above sea level. The mean maximum and minimum temperatures were 26.8^{0}C and 11.4^{0}C respectively, and the mean maximum and minimum relative humidity were 91.40% and 39.92% respectively.

2.2. Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with a 4*3 factorial arrangement in three replications. Blocking was found necessary since one side of the room the experiment was carried out was covered with glass windows, which could make the adjacent fruits more liable for exposure to the afternoon sun as well as to fluctuations in the external temperature. The factors were consisted of:

(1) Factor A: 1-MCP concentrations in 4 levels:

Level 1: 17.5µl/L; **Level 2:** 10.5µl/L; **Level 3:** 3.5 µl/L; and **Level 4:** 0 µl/L, untreated control.

(2) Factor B: Export standard banana packaging materials in 3 levels:

Level 1: Solid or non-perforated 5.7% Low Density (Gauge) Polyethylene (LDPE) bag with 0.91 g/cm^3 density and 0.038 mm thickness placed in telescopic corrugated cardboard boxes (local standard for banana export from Ethiopia)-(**P1)**;

Level 2: 0.25% perforated 55.7% Low Density (Gauge) Polyethylene (LDPE) bag with 0.91 g/cm^3 density and 0.038 mm thickness placed in telescopic corrugated cardboard boxes **(P2)**; and

Level 3: Standalone telescopic corrugated cardboard boxes without inner polyethylene bags (PEP) **(P3)**.

The corrugated cardboard boxes were telescopic type with ventilation holes, having two pieces, i.e. the bottom being the weight bearing part made of 5 pliers (layers) and the top was a cover made of up 3 pliers. The dimensions of the cardboard boxes were 51cm*31cm*21cm with a capacity of 13.5 to 18 kg of banana fruits depending on market preference. The inner plastic bags (PEP) were of 80cm * 80cm sized low gauge or low density polyethylene bags (LDPE). In total, the experiment was laid out with 12 treatment combinations and 36 experimental units.

2.3. Experimental Procedures:

2.3.1. Harvesting and transportation of banana bunches

Banana bunches from cultivar 'Poyo', syn: 'Robusta (*Musa* AAA Group, Cavendish Subgroup) were obtained from Jimma Agricultural Research Center. Fifteen matured bunches with light-green color and about three quarter full fingers were selected from the "Banana Variety Maintenance Trial" field. They were collected from prior selected and tagged plants that were healthy, robust and relatively uniform. Fruit bunches were carefully harvested late afternoon (4:00 to 5:00 p.m.) and carried on a shoulder pad of the harvesters and kept under natural tree shade for about one hour in order to stabilize them by minimizing the field heat. Bunches were then transported late afternoon to the Post Harvest Department laboratory of JUCAVM.

2.3.2. Preparation of banana hands for 1-MCP treatment and packaging

Upon arrival at the Post Harvest Department laboratory of JUCAVM, bunches were carefully unloaded and stabilized for two hours inside a ventilated room. They were then carefully de-handed in a cluster of five fingers per crown with a very sharp curved knife. Immediately after de-handing, any remaining flower residues were removed and the fruits were washed using 2% Sodium hypochloride solution for 3 minutes and further rinsed in running tap water. Fruits were then air dried at room temperature and hands were brushed with 'alum' (astringent salt based on Aluminum Sulphate) to avoid any latent infection at the wounded sites.

2.3.3. Construction of 1-MCP treatment structure

Off-white High Density Polyethylene sheet (HDPE, 0.97 g/cm^3 or 970 kg/m^3 in density and 0.250 inch thickness) was used to construct the 2m*2m*1.5m (6m^3) sized airtight 1-MCP treatment chambers within a vacant room in the Department of Post Harvest Management of JUCAVM (Figure 1). A small portable ventilation fan ((Model: REE-NOVA FH-04: 220-240V/50~60Hz, China) was installed within each of the treatment chambers for uniform mixing and distribution of 1-MCP.

2.3.4. 1-MCP preparation and treatment

Smartfresh® powder, containing 0.14% 1-MCP active ingredient was used to release 1-MCP as per the procedures described by Erkan et al., (2004) and Morreti et al., (2002). Smartfresh® powder doses of 250 mg, 150 mg and 50 mg were diluted in 20 ml distilled water heated to 50ºC to release the respective 1-MCP concentrations (17.5µl//L; 10.5µl/L and 3.5µl/L) within in the solution. Mixing of the solutions was carried out within the respective treatment chambers inside volumetric glass bickers closed with aluminum foil. After proper shaking of the solution, the bickers were opened and placed at the center of the respective chambers where the banana fruits were kept inside perforated plastic crates (Figure 1). Fruits were then withdrawn from the treatment chambers after 24 hours of exposure to 1-MCP.

Figure 1. Banana fruits being treated with 1-MCP within airtight chambers constructed using off-white transparent High Density Polyethylene (HDPE, 0.97 g/cm^3 in density and 0.250 inch thickness)

2.3.5. Withdrawal and placement of treated fruits into the packaging materials

A total of 36 of the above stated export standard banana packaging materials were obtained from Ethio-Saudi International Agricultural PLC (MIDROC-Ethiopia Group S.C.). Forty five fruits of both the 1-MCP treated and untreated fruits were then assigned into each of the 36 packaging materials randomly placed across the laboratory benches as per the design layout of the experiment. They were kept under ambient conditions (23±1^{0}C and 73 ± 1% RH) throughout the experimental period (36 days). Then 3-5 fruits were periodically taken at 7 days interval to examine the periodic changes on physicochemical quality attributes. The temperature and relative humidity of the display room was recorded three times a day (i.e. morning, mid-day and late afternoon) throughout the experimental period.

Figure 2. Bananas fruits stored within export standard corrugated cardboard boxes with and without inner low density polyethylene bags (LDPE, i.e. 0.91 g/cm^3 density and 0.038 mm thickness)

2.4. Data Collected

Data collection was started right after the arrival of the fruits but just before the application of the 1-MCP treatments; regarded as day zero (Day 0). This was considered as a benchmark to evaluate the subsequent physicochemical changes over the whole storage period (Table 1). The remaining data were collected as of the first day after the treatment period (Day 1) and then continued at seven days interval up until the fruits display significant signs of basic quality losses in terms of the following physicochemical parameters.

Table 1. Benchmark measurements of physicochemical parameters taken during day zero (before 1-MCP treatment of fruits)

	Parameter	Record
1	Av. initial finger weight (g)	124
2	Av. initial weight of fruits (5 fingers) kept for % PWL analysis (g)	620
3	Firmness (N)	25.43
4	Peel color L*	13.72
5	Peel color a*	-13.24
6	Peel color b*	47.31
7	Color chart index	1 (All Green)
8	Starch un staining index	1 (< 5% un stained)
9	TSS (^{0}Brix)	3.2
10	TA (%)	0.21
11	TSS:TA	15.24
12	P^H	5.46
13	Pulp dry matter (%)	79.67

Note: Av. bunch wt.=22.6 kg; Av. number of hands/bunch=10; Av. number of fingers/hand=17; Av. Length of fingers=19.4 cm

2.4.1. Physical parameters:

Physiological weight loss (PWL %)

Physiological weight loss of fruits was assayed throughout the experimental period by periodic weighing of five sample fingers from each experimental unit using a precision scale (model: LS200 Sartorius GMBH Gottingen, Germany). PWL was calculated using Eq. 1.

$$Weight\ loss(\%) = \frac{Initial\ weight(g) - Final\ weight(g)}{Initial\ weight(g)} \times 100 \qquad \text{Equation. 1}$$

Fruit firmness (N)

Fruit firmness was measured using a Texture Analyzer (Model: TA-XT Plus, UK) and calculated by employing the method used by Fan et al. (1999). Two whole unpeeled fingers were used periodically from each experimental unit to measure the penetration force required at opposite sides of their equatorial axes by a stainless plunger. The exerted force was automatically recorded and expressed in Newton (N).

Fruit peel color

Peel color was measured alternatively using Dole Banana Color Guide (© 2004 Dole Fresh Fruit Company, Inc., USA) and the Tri-Stimulus Colorimeter (AccuProbe HH06, USA), which was regularly calibrated before measurement with a Minolta standard white tile to L=83.14, a=-3.67 and b=10.79. Total colour change (ΔE) of the sample fruits was determined using the CIE (Commission Internationale de L'Eclairage) 1976 *L*a*b color scale* system; where L^*scale measures lightness ('light vs. dark') and varies from 100 for perfect white to zero for perfect black; a^* measures redness ('red vs. green'), and b^* measures yellowness. Total color change (ΔE) was calculated by using Eq. 2.

$$\Delta E = \sqrt{(L^*_i - L_f)^2 + (a^*_i - a_f)^2 + (b^*_i - b_f)^2} \quad \text{-----Equation 2}$$

Where:
i= initial, and f= final

2.4.2. Chemical Parameters

Pulp starch content

Starch staining was carried out after 3-5 minutes dipping of a cross-sectional cut of the unpeeled sample fruits in starch-iodine staining solution with10 g potassium iodide (KI) and 2.5g iodine (I_2) in distilled water. It was carried out as per the rapid starch staining method and chart developed by Saltveit, et al. (1982) and Sylvia et al. (1993) was used. The sample fruits were then rated based on the chart developed previously into 10 distinguishable stages with rating numbers ranging from 1 to 10 based on the percentage of unstained area, i.e. 1 for <5% unstained area, 2 (5%), 3 (10%), 4 (15%), 5 (25%), 6 (35%), 7 (45%), 8 (55%), 9 (65%) and 10 (>65%). A trend of increase in the rating number, from 1 to 10, was expressed as a characteristic pattern of starch loss during ripening.

Total soluble solids-TSS (°Brix)

Sample fruits were peeled and blended using a juice blender and TSS of the pulp juice was measured by the refractive index, expressed as °Brix, by a portable hand Refractometer (Model: SN-003007). The macerated samples were homogenized by adding about 40 ml of distilled water and filtered with cheese cloth. One to two drops of the filtrate was then placed on to the glass prism of the refractometer for reading within the scale.

Titratable acidity (TA %)

Titratable acidity was measured by titrating the pulp filtrates with 0.1N NaOH solution with 2 to 5 drops of phenolphthalein until the indicator light pink color was depicted. The volume of NaOH used up was then recorded and TA was expressed as percentage of malic acid equivalent in the pulp weight of the titrate as calculated using Eq. 3.

$$\text{Titratable Acidity (\%)} = \frac{V_1 * N * E}{V_2} \times 100 \quad \text{-----Equation 3}$$

Where:

N = Normality of NaOH

V_1 = Volume of NaOH used

E = Equivalent weight of acid,

V_2 = Volume of sample taken for estimation

TSS to TA ratio

The ratios between total soluble solids and titratable acidity were determined by dividing the values of TSS to the values of TA of the same sample fruit.

Pulp pH

The pH of the sample fruit juice was measured using a bench top digital pH meter (model: CP-505, Poland).

Pulp dry matter (DM %)

Dry matter percentage (DM %) in the pulp was determined according to the method of AOAC (2005). A 20 gram of the blended fruit juice was periodically taken into a calibrated petridish and placed in the digital oven (model: CP2 + 055F300D19,UK) for about 12 hours at 60°C . Weight of the samples was measured before and after oven drying using an electronic analytical balance (Model: PGW753 ABJ220-4M, Germany). Finally the dry matter content of the pulp was calculated using Eq. 4.

$$\text{Dry Matter (\%)} = \frac{\text{Final Dry Weight (g)}}{\text{Initial Wet Weight (g)}} \times 100 \text{ --------Equation 4}$$

2.5. Statistical Analysis

The experimental data were analyzed through the Analysis of Variance (ANOVA) by employing SAS software version 9.2, GLM Model. The Least Significant Differences (LSD %) test was used to determine the level of significance at 5% ($P < 0.05$) as well as for mean separation.

3. Results and Discussion

3.1. Physical Parameters

Physiological weight loss (PWL %)

Statistically significant differences *($p \leq 0.05$)* on PWL were observed at different storage durations when fruits handled under different treatments. PWL was generally increased as the storage period prolonged irrespective of treatments (Table 2). The trend correspondingly showed strong positive correlations with peel color change (R=0.56), starch un staining (R=0.41), TSS (R=0.59), TA (R=0.34), and TSS:TA (R=0.48) as well as negative correlations with pH (R=-0.53) and firmness (R=-0.60) (Table 12). The two-way interaction effect between packaging materials and 1-MCP showed statistically significant ($p \leq 0.05$) effect on PWL as of the 29th day of storage period.

1-MCP treated fruits with increased concentrations from 10.5µl/L to 17.5µl/L and stored in corrugated cardboard boxes with inner non-perforated PEP (P1) exhibited significantly *($p \leq 0.05$)* low weight loss (17.47-19.90%) at the end of 36 days long storage period. However, since the 17.5µl/L and 10.5µl/L concentrations of 1-MCP showed statistically non-significant *($p \leq 0.05$)* differences, the lower concentration of 10.5µl/L could be considered economically more acceptable in terms of PWL reduction. The result was generally in line with similar studies reported by different authors (Sisler et al., 2003; Sir iboon et al., 2004). The phenomena was similarly attributed to the property of 1-MCP in blocking the action of ethylene that has a direct relationship with respiration and fruit ripening. A similar phenomena on the effect of polyethylene packaging (PEP) on litchi fruits were reported that fruits exhibited less PWL on the 18th day of storage when kept in sealed or non-perforated PEP than those kept inside perforated PEP and totally unpackaged (De Reuck et al., 2009). This could be similarly attributed to the higher relative humidity, lower air movement around the fruits, and less oxygen depletion with subsequently less release of CO_2 created as a result of the modified atmosphere created within the non-perforated (P1) PEP (De Reuck et al., 2009; Sisler et al ., 2003). De Reuck et al. (2009) also reported that integrated treatments of 1-MCP and modified atmosphere packaging (MAP) significantly ($p<0.001$) lower PWL than when the two factors were applied separately.

Conversely, the highest PWL loss (31.30%) was recorded for 1-MCP untreated fruits stored within the standalone corrugated cardboard boxes (P3), which at the same time lost their shelf life much faster (as of the 22nd day of storage) than the rest of the treatments. Likewise, this phenomena could be attributed to the fact that the ethylene triggered increase in respiration rate, as a result of the increase in metabolic process and membrane permeability, led the 1-MCP untreated fruits faster into deterioration with subsequent increase in respiratory water loss through the peel.

Table 2. Physiological weight loss (%) of banana fruits as affected by 1-MCP and packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	2.10	6.53	8.10	9.30	15.70[c]	17.47[e]
P1 *10.5µl/L	3.90	12.03	12.27	13.67	18.50[c]	19.90[e]
P1 *3.5µl/L	5.50	14.67	16.40	16.60	26.13[b]	31.23[bc]
P1 *Untreated	9.80	16.10	19.63	20.17	-	-
P2 *17.5µl/L	2.23	10.47	12.00	15.67	21.25b[c]	24.73[d]
P2 *10.5µl/L	10.63	12.97	15.07	17.07	27.78[b]	28.50[c]
P2 *3.5µl/L	14.03	16.50	18.13	19.80	27.45[b]	32.40[b]
P2 *Untreated	19.60	20.63	20.90	24.27	-	-
P3 *17.5µl/L	2.30	10.87	18.03	19.83	25.48[b]	27.70[cd]
P3 *10.5µl/L	6.40	13.20	18.83	26.00	36.92[a]	43.53[a]
P3 *3.5µl/L	14.10	18.23	20.73	26.43	40.47[a]	43.87[a]
P3 *Untreated	20.57	20.73	20.93	31.30	-	-
LSD (5%)	8.57	11.61	12.05	11.12	6.92	3.55
SE ±	5.06	6.85	7.12	6.57	5.94	2.05
CV (%)	54.62	47.10	41.64	32.82	22.30	6.85

* *In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$;* ***P1=*** *Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

Firmness (N)

Results on fruit firmness generally revealed a decreasing trend over the storage period irrespective of treatments (Table 3). The trend also demonstrated strong negative correlations with total peel color change (R=-0.71), starch un staining (R=-0.58), TSS (R=-0.65), TA (R=-0.28), PWL (-0.60) and TSS/TA ration (R=-0.56) , color index (R=-0.56) as well as positive correlation with P^H (R=0.58) and pulp dry matter (R=-0.51) (Table 12). Statistically significant (*$p \leq 0.05$*) interaction effects between the two factors were observed throughout the storage period. Fruits treated with the highest concentration of 1-MCP (17.5µl/L) maintained significantly (*$p \leq 0.05$*) higher firmness (18.67N) during the last day of the storage period (day 36) when stored in combination with the non-perforated PEP (P1). On the contrary, the highest loss in firmness (14.80 N) with all treatment combinations were recorded for 1-MCP untreated fruits stored within the standalone corrugated cardboard boxes (P3), which at the same time lost their shelf life much faster (as of the 22[nd] day of storage) than the rest of the treatments.

The results were generally in agreement with several findings that 1-MCP treated banana fruits maintained higher firmness over various storage periods than their equivalent untreated ones (Watkins, 2006; Lohani et al., 2004; Mattheis 2003; Zeweter et al., 2012). This was attributed to the inhibitory action of 1-MCP on ethylene synthesis and action by way of its irreversible binding ability to the receptors. De Reuck et al. (2009) also reported that the integrated application of 1-MCP and modified atmosphere packaging (MAP) using sealed or non-perforated PEP maintained significantly higher (p<0.00) firmness of litchi fruits than when the two factors were applied separately. This was similarly attributed to the strong modified atmosphere condition created within the overall sealed package which resulted in lower rate of respiration, reduction in fruit tissue breakdown and delay in the onset of ripening. Softening and the parallel increase in respiration rate in climacteric fruit ripening is generally attributed to several ultra structural and chemical metabolic changes and the de novo synthesis of cell wall hydrolases that result in the degradation of the cell wall, solubilization of pectins and movement of water from the peel to the pulp through osmotic pressure (Lohani et al., 2004; Dharmasenal et al., 2005).

Table 3. Firmness (N) of banana fruits as affected by 1-MCP and packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	25.90[a]	23.93[a]	22.90[a]	20.47[a]	18.93[a]	18.67[a]
P1 *10.5µl/L	24.77[ab]	23.23[ab]	21.27[ab]	20.00[a]	16.20[ab]	15.60[ab]
P1 *3.5µl/L	23.87[bc]	21.57[bc]	20.53[bc]	19.67[a]	15.85[b]	14.77[ab]
P1 *Untreated	22.00[de]	21.53[bc]	20.57[bc]	17.33[ab]	-	-
P2 *17.5µl/L	23.00[bcd]	21.50[bc]	20.93[abc]	20.30[a]	16.65[ab]	15.90[ab]
P2 *10.5µl/L	22.77[cd]	21.37[bcd]	20.70[b]c	19.80[a]	16.02[ab]	15.20[ab]
P2 *3.5µl/L	22.43[cde]	20.90[cd]	20.17[bc]	19.10[a]	15.22[bc]	12.07[bc]
P2 *Untreated	20.77[ef]	19.33[cd]	18.80[cd]	15.87[b]	-	-
P3 *17.5µl/L	22.13[cde]	20.63[cd]	20.27[bc]	19.97[a]	16.38[ab]	15.47[ab]
P3 *10.5µl/L	21.77[de]	20.57[cd]	20.03[bc]	19.60[a]	15.42[bc]	14.53[bc]
P3 *3.5µl/L	21.43[de]	20.40[cd]	19.17[bcd]	17.67[ab]	12.72[c]	10.57[c]
P3 *Untreated	19.30[f]	19.17[d]	17.53[d]	14.80[b]	-	-
LSD (5%)	1.85	2.30	2.16	3.21	2.95	4.10
SE $\pm$	1.09	1.36	1.28	1.90	2.54	2.37
CV (%)	4.86	6.43	6.31	10.13	15.91	16.06

** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$;* ***P1=*** *Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

Peel color

The obvious manifestations of the banana fruits during the storage period in terms of the gradual decline of the green peel color were clearly observed in the present experiment with different intensities across the different treatments regimes (Tables 4 and 5). Results for both the total peel color change (ΔE) and color index (Tables 4 and 5) indicate that there was significant (*p ≤ 0.05)* interaction effect between 1-MCP application and packaging treatments. The highest concentration of 1-MCP (17.5µl/L) when combined with the non-perforated PEP (P1) maintained the lowest peel color change (34.33 in ΔE and 1.67 in color index) at the end of the 36 days long storage period. Similarly, peel color change (52.27 in ΔE and 6.00 in color index) with all treatment combinations were recorded for 1-MCP untreated fruits stored within the standalone corrugated cardboard boxes (P3) on the 22nd day of the storage period.

The results basically agreed with previous findings of Moretti1 et al. (2002) that treatments with higher concentrations of 1-MCP delayed total carotenoids synthesis and color development and thus extended shelf life in tomato fruits. Results also concurred with other reports that the delay in banana peel color change could be attributed to the combined effect of the modified atmosphere *(*MA) condition created within the packages as a result of the fully sealed or non-perforated inner PEP (P1) as well as the direct inhibitory action of 1-MCP on both the synthesis and action of ethylene (Salvador et al. 2006; Bassetto et al., 2005; Siriboon et al., 2004; Dharmasenal et al., 2005). This signifies the fact that the respiration rate of fruits was restricted and thus the change in peel color was retarded as a result. The highest and fastest peel color change observed on fruits that were not treated with 1-MCP and kept inside the standalone corrugated cardboard boxes (P3), was similarly substantiated by Wills et al. (2000) and Pinto et al. (2004). Such fruits could possibly have more access to O2 and more exposure to increases in the concentration of ethylene, which subsequently enhanced the respiration rate, chlorophyll degradation and ultimately the conversion of the green peel color into yellow.

Table 4. Total peel color change of banana fruits as affected by 1-MCP and packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	4.77^{d}	13.63^{c}	20.40^{c}	23.47^{c}	33.68^{c}	34.33^{b}
P1 *10.5µl/L	8.60^{cd}	14.77^{bc}	23.97^{bc}	32.93^{abc}	37.60^{c}	43.17^{ab}
P1 *3.5µl/L	17.83^{abcd}	25.53^{abc}	31.47^{abc}	36.03^{abc}	56.88^{ab}	60.60^{ab}
P1 *Untreated	22.33^{abc}	32.07^{ab}	38.70^{abc}	43.27^{abc}	-	-
P2 *17.5µl/L	6.93^{cd}	18.80^{bc}	21.90^{c}	28.43^{bc}	39.65^{c}	40.83^{ab}
P2 *10.5µl/L	10.60^{bcd}	20.07^{bc}	30.23^{abc}	35.70^{abc}	39.82^{bc}	43.23^{ab}
P2 *3.5µl/L	22.07^{abc}	29.83^{abc}	34.30^{abc}	40.70^{abc}	59.80^{a}	62.70^{ab}
P2 *Untreated	27.00^{ab}	38.17^{a}	44.30^{ab}	48.00^{ab}	-	-
P3 *17.5µl/L	9.23^{cd}	19.30^{bc}	29.13^{abc}	29.37^{abc}	41.80^{bc}	41.67^{ab}
P3 *10.5µl/L	15.87^{abcd}	23.83^{abc}	30.60^{abc}	36.73^{abc}	50.33^{abc}	52.53^{ab}
P3 *3.5µl/L	22.23^{abc}	30.07^{abc}	34.33^{abc}	40.90^{abc}	65.22^{a}	66.80^{a}
P3 *Untreated	30.70^{a}	38.40^{a}	46.33^{a}	52.27^{a}	-	-
LSD (5%)	17.07	17.86	22.20	23.08	17.08	29.56
SE ±	10.08	10.54	13.11	13.63	14.67	17.08
CV (%)	61.06	41.56	40.78	36.52	31.08	34.47

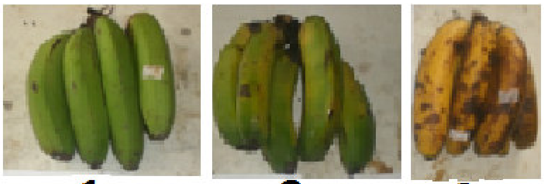
** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05;* ***P1=*** *Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

Table 5. Peel color index of banana fruits as affected by 1-MCP and packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	1.33	1.34	1.37^{c}	1.38^{e}	1.50^{f}	1.67^{e}
P1 *10.5µl/L	1.33	1.68	2.00^{cb}	2.33^{ed}	2.50^{e}	2.67^{d}
P1 *3.5µl/L	1.67	1.69	2.33^{cb}	3.33^{cbd}	4.83^{c}	5.53^{bc}
P1 *Untreated	1.67	1.69	2.67^{b}	4.00^{cb}	-	-
P2 *17.5µl/L	1.33	1.33	1.33^{c}	1.33^{e}	1.50^{f}	1.69^{e}
P2 *10.5µl/L	1.67	1.68	2.33^{cb}	2.33^{ed}	3.33^{d}	3.33^{d}
P2 *3.5µl/L	1.67	1.69	2.67^{b}	4.33^{b}	5.50^{b}	5.67^{ba}
P2 *Untreated	1.67	1.69	4.33^{a}	6.00^{a}	-	-
P3 *17.5µl/L	1.33	1.34	1.67^{cb}	1.67^{e}	2.50^{e}	2.67^{d}
P3 *10.5µl/L	1.67	1.68	2.67^{b}	3.00^{cd}	4.50^{c}	4.67^{c}
P3 *3.5µl/L	1.67	1.69	2.67^{b}	4.33^{b}	6.33^{a}	6.33^{a}
P3 *Untreated	1.67	1.69	4.67^{a}	6.00^{a}	-	-
LSD (5%)	0.83	0.79	1.01	1.06	0.44	0.76
SE ±	0.49	0.47	0.59	0.63	0.38	0.44
CV (%)	30.40	29.60	23.27	18.83	10.39	11.67

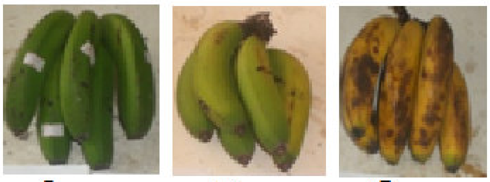
** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.0.;* ***P1=*** *Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

Note: *1=All Green; 2=Light Green; 3=50% Green: 50% Yellow; 4=More Yellow than Green; 5=Yellow with Green Tips; 6=Fully Yellow; and 7=Yellow Flecked with Brown*



1 2 3

Figure 3. Peel color change of banana fruits treated with P1*17.5µl/L (1), P1*10.5µl/L (2) & P1*3.5µl/L (3) During 36 days of storage



4 5 6

Figure 4. Peel color change of banana fruits treated with P2*17.5µl/L (4), P2*10.5µl/L (5) & P2*3.5µl/L (6) During 36 days of storage

7 8 9

Figure 5. Peel color change of banana fruits treated with P3*17.5µl/L (7), P3*10.5µl/L (8) & P3*3.5µl/L (9) During 36 days of storage

3.2. Chemical Characteristics

Pulp starch content

Significant differences *($p \leq 0.05$)* in starch un staining was observed on fruits stored under different treatments (Table 6). A blue-black color due to starch staining was observed more on unripe fruits than those that have lost their starch content due to the ripening process. The proportion of starch stained area was slightly but consistently decreased over the storage period irrespective of treatments. This trend of gradual decrease in starch staining could be attributed to the corresponding increase in the hydrolysis of starch into simple sugars. The results were also supported by reports of previous findings that starch hydrolysis is a very important postharvest biochemical change which occurs during the ripening process of banana fruits and causes the accumulation of sugar that are responsible for the increase in pulp TSS content and sweetening of the fruit (Tourky et al., 2014).

Results also showed that there was significant *($p \leq 0.05$)* interaction effect between 1-MCP and packaging treatments in starch un staining throughout the 36 days storage period. Banana fruits treated interactively with the highest concentration of 1-MCP (17.5µl/L) and non-perforated PEP (P1) showed the lowest proportion of starch un staining (1.73) at the end of the 36 days long storage period. The results were in agreement with the report of Jiang et al. (1999) that the greatest longevity of about 58 days was realized with 1-MCP treated banana fruits (at either of 0.5 or 1.0 µl/l) and kept inside sealed polyethylene bags (0.03 mm thick) due to the suppression of ethylene (C_2H_4) evolution, reduced rate of respiration, reduced rate of starch hydrolysis into simple sugars, and delayed ripening.

The highest level of starch un staining was exhibited by 1-MCP untreated (9.33) fruits that were kept inside the standalone corrugated cardboard boxes (P3). This is an indication of high rate of respiration and the subsequent onset of the climacteric peak and ripening stage that brought about a more rapid deterioration in shelf life of banana fruits (Hernandez et al., (2006).

Table 6. Pulp starch content of banana fruits as affected by 1-MCP and packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	1.33^{b}	1.33^{e}	1.33^{f}	1.67^{g}	1.73^{e}	1.73^{d}
P1 *10.5µl/L	1.33^{b}	1.33^{e}	1.67^{ef}	2.33^{f}	4.33^{d}	5.33^{c}
P1 *3.5µl/L	1.33^{b}	1.67^{e}	2.00^{ed}	4.33^{e}	8.17^{b}	10.00^{a}
P1 *Untreated	2.33^{a}	3.33^{c}	3.33^{c}	6.33^{d}	-	-
P2 *17.5µl/L	1.33^{b}	1.33^{e}	1.33^{f}	1.67^{g}	2.33^{e}	2.33^{d}
P2 *10.5µl/L	1.33^{b}	1.67^{e}	1.67^{ef}	2.33^{f}	5.33^{cd}	6.33^{b}
P2 *3.5µl/L	1.67^{b}	1.67^{e}	2.33^{d}	6.33^{d}	9.67^{a}	10.00^{a}
P2 *Untreated	2.33^{a}	4.33^{b}	5.33^{a}	8.33^{b}	-	-
P3 *17.5µl/L	1.33^{b}	1.33^{e}	1.33^{f}	2.00^{gf}	2.33^{e}	2.33^{d}
P3 *10.5µl/L	1.67^{b}	1.67^{e}	1.67^{ef}	2.33^{f}	6.33^{c}	6.33^{b}
P3 *3.5µl/L	1.67^{b}	2.33^{d}	4.33^{b}	7.67^{c}	9.67^{a}	10.00^{a}
P3 *Untreated	2.67^{a}	5.33^{a}	5.33^{a}	9.33^{a}	-	-
LSD (5%)	0.54	0.54	0.54	0.50	1.05	0.50
SE ±	0.32	0.32	0.32	0.30	0.90	0.29
CV (%)	18.99	14.13	12.19	6.53	17.13	5.00

** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05; P1= Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

TSS (^{0}Brix)

Table 7 shows Total Soluble Solids (TSS) content was gradually but consistently increased throughout the storage period irrespective of treatments. The results were generally in agreement with previous findings that the amount of sugars usually increases along with fruit ripening through biosynthesis processes or degradation of polysaccharides (Bassetto et al., 2005).

Results also showed that there was significant *($p \leq 0.05$)* interaction effect between 1-MCP and packaging treatments throughout the 36 days long storage period. The highest TSS (9.57 ^{0}Brix) was recorded on the 22nd day of the storage period from 1-MCP untreated fruits that kept inside the standalone corrugated cardboard boxes without inner PEP (P3). This could be an indication of the rapid deterioration in shelf life of the fruits as a result of the onset and progress of the climacteric peak caused by the higher rate of respiration (Hernandez et al., 2006). The lowest TSS (8.00 ^{0}Brix) at the end of the 36 days long storage period was on the contrary recorded from fruits treated with the highest concentration of 1-MCP (17.5µl/L) and kept inside the non-perforated inner PEP (P1). This could also be due to the reduced rate of starch hydrolysis into simple sugars and delayed ripening. Lower amounts of TSS in fruits treated with 1-MCP were also verified in other studies (Bassetto et al., 2005, Watkins et al., 2000).

Table 7. Total Soluble Solids (^{0}Brix) of banana fruits as affected by 1-MCP and packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	6.07^{b}	6.23^{c}	6.60^{e}	6.90^{d}	7.70^{c}	8.00^{g}
P1 *10.5µl/L	6.20^{b}	6.30^{c}	6.70^{e}	7.00^{d}	9.37^{bc}	10.07^{e}
P1 *3.5µl/L	6.23^{b}	6.40^{c}	6.80^{de}	8.13^{bcd}	11.20^{b}	12.33^{c}
P1 *Untreated	6.23^{b}	6.40^{c}	6.97^{cde}	8.60^{abc}	-	-
P2 *17.5µl/L	6.10^{b}	6.30^{c}	6.67^{e}	7.00^{d}	9.10^{bc}	9.20^{f}
P2 *10.5µl/L	6.20^{b}	6.30^{c}	7.40^{bcd}	7.87^{dc}	10.23^{bc}	10.93^{d}
P2 *3.5µl/L	6.23^{b}	6.47^{bc}	7.43^{bcd}	8.70^{abc}	11.47^{b}	13.00^{b}
P2 *Untreated	6.63^{a}	6.87^{ab}	8.00^{ab}	9.47^{a}	-	-
P3 *17.5µl/L	6.20^{b}	6.33^{c}	6.67^{e}	7.00^{d}	10.17^{bc}	10.53^{d}
P3 *10.5µl/L	6.23^{b}	6.37^{c}	7.50^{bc}	9.00^{abc}	11.15^{b}	12.20^{c}
P3 *3.5µl/L	6.27^{b}	6.53^{bc}	7.93^{ab}	9.33^{ab}	14.97^{a}	20.33^{a}
P3 *Untreated	6.67^{a}	7.00^{a}	8.37^{a}	9.57^{a}	-	-
LSD (5%)	0.32	0.43	0.64	1.28	2.61	0.41
SE ±	0.19	0.25	0.38	0.75	2.24	0.24
CV (%)	2.98	3.94	5.21	9.17	21.19	2.01

** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05; P1= Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

Titratable Acidity (TA %)

Although the percentage values were recorded in a narrow range, a progressive increase up until the 22nd day and then a gradual decline as of the 29th day of the storage period was observed with titratable acidity (TA) in all treatments (Table 8). Similar results were also reported by Zeweter et al. (2012) that TA content in banana fruits treated with 1-MCP was increased as the storage period progressed from 4 to 28 days and slightly declined towards the end.

Statistical analysis indicate that there was significant ($p \leq 0.05$) interaction effect between 1-MCP and packaging treatments on TA of banana fruits from day one to the 22nd day of the storage period. the overall trend across the 36 days storage period showed that changes in TA content were lower (0.29 %) when fruits were treated with the highest concentrations of 1-MCP (10.5µl/L - 17.5µl/L) and stored inside non-perforated PEP (P1). This could be similarly attributed to the combined effect of the modified atmosphere (MA) condition created within sealed or non-perforated packages coupled with the direct inhibition of 1-MCP on both the production and action of ethylene (Salvador et al., 2006; Bassetto et al., 2005; Siriboon et al.; Dharmasenal et al., 2005). This may also signify the fact that the respiration rate of the fruits was retarded consequently and thus rate of utilization of the respiratory substrates such as organic acids was so minimal in this case. Kader (1992) similarly stated that lower fruit acidity due to postharvest treatments that delay respiration could be a result of a reduced utilization rate of respiratory substrates such as organic acids.

Table 8. Titratable acidity (%) of banana fruits as affected by 1-MCP and export standard packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	0.30^{b}	0.31^{b}	0.32^{c}	0.33^{bc}	0.31	0.29
P1 *10.5µl/L	0.30^{ab}	0.32^{ab}	0.32^{c}	0.33^{abc}	0.32	0.29
P1 *3.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.33^{c}	0.33	0.32
P1 *Untreated	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.35^{a}	-	-
P2 *17.5µl/L	0.30^{ab}	0.32^{ab}	0.32^{bc}	0.34^{abc}	0.32	0.30
P2 *10.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.31
P2 *3.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.32
P2 *Untreated	0.32^{ab}	0.33^{a}	0.34^{ab}	0.35^{ab}	-	-
P3 *17.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.31
P3 *10.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.31
P3 *3.5µl/L	0.31^{ab}	0.33^{a}	0.33^{abc}	0.34^{abc}	0.34	0.32
P3 *Untreated	0.32^{a}	0.33^{a}	0.34^{a}	0.35^{ab}	-	-
LSD (5%)	0.02	0.02	0.02	0.02	0.03	0.03
SE ±	0.01	0.01	0.01	0.01	0.03	0.02
CV (%)	3.92	3.57	2.88	3.98	7.86	6.51

** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; P1= Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

TSS:TA ratio

The sugar to acid ratio, which is often considered as a ripening index (RI), determines the sugar-acid balance of the ripening fruits. It is also known as one of the post harvest quality attributes that influence the perception of consumers. In the present experiment, statistically significant differences *($p \leq 0.05$)* were observed in the sugar to acid ratio of banana fruits stored under different treatments. TSS content was generally increased throughout the storage period across all treatments (Table 9).

Interaction effects between treatments of 1-MCP and packaging materials showed significant *($p \leq 0.05$)* differences across the 36 days long storage period. The lowest sugar to acid ratio (27.67) was similarly recorded at the end of the storage period from fruits treated with the highest concentration of 1-MCP (17.5µl/L) and kept inside non-perforated inner PEP (P1). On the other hand, the highest sugar to acid ratio (28.44) was recorded on the 22nd day of the storage period from 1-MCP untreated fruits kept in the standalone corrugated cardboard boxes (P3). The phenomena in the later case is tantamount to the increase in respiration rate and oxidation as the storage period proceeded, increase in the subsequent utilization of the respiratory substrates such as organic acids, and increase in starch hydrolysis and accumulation of simple sugars in the event of the fruit ripening process with subsequent decline in shelf life (Macwan et al., 2014).

Table 9. TSS: TA ratio of banana fruits as affected by 1-MCP and export standard packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	18.70^{d}	18.98^{d}	19.80^{e}	20.60^{d}	24.95^{c}	27.67^{e}
P1 *10.5µl/L	19.49^{cd}	19.70^{cd}	20.87^{cde}	21.05^{d}	28.69^{bc}	31.85^{cde}
P1 *3.5µl/L	19.76^{bcd}	20.26^{bcd}	21.14^{cde}	23.01^{cd}	34.97^{bc}	41.76^{b}
P1 *Untreated	20.10^{bcd}	20.35^{bcd}	21.26^{cde}	26.40^{abc}	-	-
P2 *17.5µl/L	18.97^{cd}	19.36^{cd}	19.90^{e}	20.80^{d}	27.97^{bc}	29.95^{de}
P2 *10.5µl/L	19.72^{bcd}	19.92^{bcd}	22.11^{cd}	23.41^{cd}	31.03^{bc}	34.54^{c}
P2 *3.5µl/L	20.30^{abcd}	20.48^{abcd}	22.47^{bc}	24.87^{bc}	36.10^{b}	42.16^{b}
P2 *Untreated	21.34^{ab}	21.50^{ab}	24.74^{a}	28.13^{ab}	-	-
P3 *17.5µl/L	19.81^{bcd}	19.81^{bcd}	20.25^{de}	20.92^{d}	30.57^{bc}	33.06^{cd}
P3 *10.5µl/L	19.94^{bcd}	20.57^{abc}	22.32^{c}	25.78^{abc}	34.78^{bc}	40.11^{b}
P3 *3.5µl/L	20.70^{abc}	20.94^{abc}	24.38^{ab}	27.71^{ab}	48.26^{a}	68.54^{a}
P3 *Untreated	21.94^{a}	22.27^{a}	25.72^{a}	28.44^{a}	-	-
LSD (5%)	1.56	1.98	2.01	3.46	10.58	4.28
SE $\pm$	0.92	1.17	1.19	2.04	9.09	2.47
CV (%)	4.53	5.82	5.38	8.41	27.50	6.37

** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05; P1= Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

P^{H}

Table 10 below shows that the P^{H} of the pulp generally decreased steadily over the storage period irrespective of treatments. The results are in agreement with the findings reported by Tourky et al. (2014) in that as the storage period or ripening process advances, total acidity could increase resulting in a decrease in fruit pH. A similar result was reported by Hernandez et al. (2006) that as the storage period progresses, the evolution of ethylene and respiration rate may increase with a subsequent decrease in pulp p^{H}.

Results also show that there was significant ($p < 0.05$) interaction effect between 1-MCP and packaging treatments on the pH of banana fruits throughout the 36 days long storage period. Fruits treated with the highest concentration of 1-MCP (17.5µl/L) and stored in combination with non-perforated PEP (P1) maintained the highest P^{H} (4.13) at the end of the storage period. This concurs with previous reports that the inhibitory action of 1-MCP on ethylene production and action in combination with the higher modified atmosphere condition created as a result of the non-perforated PEP might have created a reduction in the rate of respiration and overall metabolic process of the fruits (Mattheis et al., 2003; Jobling, 2000).

Table 10. Pulp P^{H} of banana fruits as affected by 1-MCP and export standard packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	5.40^{a}	5.37^{a}	5.30^{a}	5.20^{a}	4.63^{a}	4.13^{a}
P1 *10.5µl/L	5.37^{ab}	5.37^{a}	5.23^{ab}	5.17^{a}	3.87^{ab}	3.03^{ab}
P1 *3.5µl/L	5.33^{ab}	5.27^{ab}	5.17^{ab}	5.03^{ab}	3.62^{ab}	2.63^{b}
P1 *Untreated	5.30^{b}	5.27^{ab}	5.10^{ab}	4.33^{ab}	-	-
P2 *17.5µl/L	5.40^{a}	5.33^{ab}	5.23^{ab}	5.17^{a}	3.80^{ab}	3.33^{ab}
P2 *10.5µl/L	5.33^{ab}	5.30^{ab}	5.17^{ab}	5.10^{ab}	3.72^{ab}	2.63^{b}
P2 *3.5µl/L	5.33^{ab}	5.27^{ab}	5.10^{ab}	4.87^{ab}	3.42^{ab}	2.57^{b}
P2 *Untreated	5.30^{b}	5.23^{b}	5.07^{ab}	4.30^{b}	-	-
P3 *17.5µl/L	5.40^{a}	5.30^{ab}	5.23^{ab}	5.03^{ab}	3.78^{ab}	3.30^{ab}
P3 *10.5µl/L	5.33^{ab}	5.27^{ab}	5.17^{ab}	4.90^{ab}	3.45^{ab}	2.60^{b}
P3 *3.5µl/L	5.33^{ab}	5.23^{b}	5.10^{ab}	4.37^{ab}	3.00^{b}	2.53^{b}
P3 *Untreated	5.30^{b}	5.23^{b}	5.03^{ab}	4.20^{b}	-	-
LSD (5%)	0.10	0.11	1.00	0.93	1.45	1.43
SE $\pm$	0.06	0.06	0.59	0.55	1.25	0.82
CV (%)	1.05	1.18	11.72	11.20	33.74	27.73

** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05; P1= Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

Pulp dry matter (%)

Pulp dry matter is basically a reverse of the pulp moisture content in that as the later increases with the advance in the storage or ripening period, as a result of carbohydrate breakdown and moisture migration through osmotic pressure from the peel to the pulp, percent dry matter correspondingly decreases (Tourky et al., 2014; Kurmani et al., 2010; Sarode et al., 2009). Likewise, the data in Table 11 below illustrates that the pulp dry matter of banana fruits was steadily decreased over the storage period irrespective of treatments.

Interaction effects of 1-MCP treatments and packaging treatments showed significant ($p < 0.05$) differences throughout the storage period. The highest percentage (70.50%) in dry matter content was recorded at the end of the 36 days storage period from banana fruits treated with the highest concentration of 1-MCP (17.5µl/L) and kept inside the non-perforated PEP (P1). This shows a greater delay in the degradation of dry matter content of the fruits corresponding to the extension in shelf life of banana fruits. This is similarly attributed to the higher modified atmosphere condition created by the non-perforated PEP, which resulted in a greater reduction in the rate of respiration and overall metabolic process of the fruits (Mattheis et al., 2003; Jobling, 2000). On the other hand, the lowest percentage of dry matter (69.13%) was recorded on the 22nd day of the storage period from 1-MCP untreated fruits and kept within the standalone corrugated cardboard boxes (P3). Such a rapid decline in pulp dry matter content was attributed to the increase in pulp TSS as a result of the continued starch hydrolysis into simple soluble sugars (Patil et al., 2015).

Table 11. Pulp dry matter content (%) of banana fruits as affected by 1-MCP and packaging materials

Treatments	Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	78.80^{a}	77.40^{a}	76.33^{a}	75.80^{a}	71.20^{a}	70.50^{a}
P1 *10.5µl/L	78.63^{a}	75.73^{ab}	75.23^{ab}	73.93^{ab}	65.93^{ab}	60.27^{ab}
P1 *3.5µl/L	76.60^{a}	75.53^{ab}	74.40^{abc}	73.53^{ab}	61.82^{abc}	59.73^{abc}
P1 *Untreated	75.90^{a}	75.17^{ab}	74.27^{abc}	72.60^{bc}	-	-
P2 *17.5µl/L	75.30^{a}	74.50^{abc}	73.40^{abcd}	72.40^{bc}	60.30^{abc}	57.13^{abcd}
P2 *10.5µl/L	75.23^{a}	74.37^{abc}	72.93^{bcde}	71.93^{bcd}	59.58^{abc}	56.43^{abcd}
P2 *3.5µl/L	75.03^{a}	73.87^{abc}	72.80^{bcde}	71.73^{bcd}	57.97^{abc}	49.03^{bcd}
P2 *Untreated	74.90^{a}	73.67^{abc}	72.20^{cde}	71.50^{bcd}	-	-
P3 *17.5µl/L	74.70^{a}	73.23^{bc}	72.00^{cde}	70.33^{cd}	56.18^{abc}	40.10^{cd}
P3 *10.5µl/L	74.57^{a}	73.00^{bc}	71.67^{cde}	70.30^{cd}	54.17^{bc}	37.67^{d}
P3 *3.5µl/L	73.67^{a}	73.00^{bc}	71.20^{de}	69.83^{cd}	48.20^{c}	37.13^{d}
P3 *Untreated	71.93^{b}	71.20^{c}	70.43^{e}	69.13^{d}	-	-
LSD (5%)	9.88	3.80	2.96	2.97	16.06	20.01
SE ±	5.83	2.24	1.75	1.76	13.80	11.56
CV (%)	7.89	3.02	2.39	2.44	23.19	22.23

** In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; P1= Export standard cardboard boxes with non-perforated PEP;* ***P2=*** *Export standard cardboard boxes with perforated PEP* ***P3=*** *Standalone export standard cardboard boxes (without inner PEP)*

Table 12. Pearson correlation coefficient among different physicochemical parameters of banana fruits subjected to 1-MCP and packaging materials

	Firmness	TSS	P^{H}	TA	TSS:TA	Starch Index	PWL	PulpDM	Color Index	PeelColT	
Firmness	1										
TSS	-.65**	1									
P^{H}	.58**	-.69**	1								
TA	-.28**	.16*	-.11	1							
TSS:TA	-.56**	.95**	-.65**	-.15*	1						
Starch Index	-.58**	.71**	-.48**	.32**	.61**	1					
PWL	-.60**	.59**	-.53**	.34**	.48**	.41**	1				
PulpDM	.51**	-.49**	.59**	-.15*	-.43**	-.29**	-.44**	1			
Color Index	-.56**	.71**	-.48**	.38**	.59**	.89**	.48**	-.33**	.65**	1	
PeelColT	-.71**	.61**	-.55**	.36**	.50**	.62**	.56**	-.45**	.55**	.61**	1

**. Correlation is significant at the 0.01 level (2-tailed);
*Correlation is significant at the 0.05 level (2-tailed).

Where:

PulpDM= Pulp diameter; PWL= Physiological weight loss; PeelCol T= Total peel color change

Note: *Starch content was indirectly measured through the iodine-staining method and expressed in terms of the unstained area of the pulp (refer starch data collection procedure under Materials and Methods).*

4. Conclusions

One-methylcyclopropene (1-MCP) treatment with increased levels of concentration and modified atmosphere packaging (MAP) generally extended shelf life and maintained better quality of banana fruits when applied both independently and in combination.

However, the present study also revealed that the highest concentration of 1-MCP (17.5µl/L) in combination with non-perforated PEP exhibited higher shelf life while maintaining lower changes in all the physicochemical quality attributes tested when stored within the export standard corrugated cardboard boxes. This was essentially attributed to the combined effect of the modified atmosphere (MA) condition created within the packages as a result of the fully sealed or non-perforated inner PEP and the direct inhibitory effect of 1-MCP on both the synthesis and action of ethylene. Thus, this technique may be considered as a less sophisticated and less costly postharvest handling alternative under ambient conditions (22$\pm$1 °C and 80 $\pm$ 5% RH) as compared to reefer container-based system currently employed in Ethiopia and elsewhere for fresh banana exports.

The current study was carried out on the most commonly and widely grown banana cultivar in Ethiopia (Musa AAA Group, Cavendish Subgroup, cultivar ‘Poyo’, syn: ‘Robusta’). However, as reported with some other fruit crops, changes in physicochemical parameters during storage periods and response to postharvest treatments could be cultivar dependent. Thus further research on different cultivars of banana, with and without different genomes, needs to be done to investigate any differences that may exist among the present treatments.

The nature of ripening and effect on the physicochemical parameters of banana fruits following such extended storage period after 1-MCP treatment needs to be studied and compared with other storage treatments such as temperature and relative humidity controlled systems using the conventional refer containers.

5. ACKOWLEDGEMENTS

The authors are highly thankful to the Department of Post Harvest Management of Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) for the partial financial support and for providing the laboratory facilities to carry out the present experiment. We also acknowledge Jimma Agricultural Research Center for providing the fruits for this study.

6. REFERENCES

- AOAC. 2005. Official Methods of Analysis. 18th Edn., Association of Official Analytical Chemists, Washington DC., USA.
- Bassetto, E.; Jacomino, A.P.; Pinheiro, A.L. and Kluge, R.A. 2005. Delay of ripening of ‘Pedro Sato’ guava with 1-methylcyclopropene. Postharvest Biol. Technol., 35: 303-308. DOI: 10.1016/j.postharvbio.
- Bassetto, E.; Jacomino, A.P.; Pinheiro A.L. 2005. Conservation of 'Pedro Sato' guavas under treatment with 1-methylcyclopropene. Pesquisa Agropecuária Brasileira. On-line version ISSN 1678-3921. Pesq. agropec. bras. vol.40 no.5 Brasília May 2005. http://dx.doi.org/10.1590/S0100-204X2005000500002
- CFC (Common Fund for Commodities). 2004. Development of organic banana production and export in Sudan and Ethiopia to the Middle East and Europe. FC/CC/34/FISGB/10. Appraisal Report
- CSA (Central Statistical Agency of Ethiopia). 2014. Agricultural Sample Survey. Report on Area and Production of Major Crops. Volume I, VII and VIII. Statistical Bulletin 578. Addis Ababa, Ethiopia
- De Reuck, K.; Sivakumar, D. and Korsten, L. 2009. Integrateted application of 1-methylcyclopropene and modified atmosphere packaging to improve quality retention of litchi cultivars during storage. Postharvest Biology and Technology 52: 71-77
- Dharmasenal, D.A.N. and Kumari, A.H.M.R.R. 2005. Suitability of charcoal-cement passive evaporative cooler for banana ripening. J. Agric. Sci. 1: 1.
- Ekman, J.H.; Clayton, M.; Biasi, W.V. and Mitcham, E.J. 2004. Interactions between 1-MCP concentration, treatment interval and storage time for ‘Bartlett’ pears. Postharvest Biol. Technol., 31: 127-136. DOI: 10.1016/j.postharvbio.2003.07.002
- Ethiopian Horticulture Development Agency (EHDA). 2012. Annual Report. Addis Ababa, Ethiopia
- Fan, X.; Blannkenship, S.M. and Mattheis, J.P. 1999. 1–methylcyclopropene inhibits apple ripening. Journal of the American Society for Horticultural Science, v. 124, p. 690-695.
- Hernandez, Y., Lobo, M.G. and Gonzalez, M. 2006. Determination of vitamin C in tropical fruits: A comparative evaluation of methods. Food Chem. 96: 654- 664.
- Jobling, J. 2000. Postharvest Ethylene: A critical factor in quality management. Sydney postharvest laboratory information sheet. Sydney, Australia. http://postharvest.com.au/EthylenePDF.PDF
- Kader, A.A. 1992. Postharvest technology of horticultural crops. Oakland: University of California.p. 269
- Kashimura, Y.; Hayama, H. and Ito, A. 2010. Infiltration of 1-methylcyclopropene under low pressure can reduce the treatment time required to maintain apple and Japanese pear quality during storage. Postharvest Biol. Technol. 57:14-18.
- Ketsa, S. S.; Wisutiamonkul, A. and Van Doorn, W.G. 2013. Apparent synergism between the positive effects of 1-MCP and modified atmosphere on storage life of banana fruit. Journal of Postharvest Biology and Technology . 85: 173-178. Copyright © 2013 Elsevier B.V. DOI: 10.1016/j.postharvbio.2013.05.009
- Kulkarni, S.G.; Kudachikar, V.B. and Prakash, M.N.K. 2010. Studies on physicochemical changes during

artificial riepening of banana (Musa sp.); variety 'Robusta'. J. Food Sci. Technol., 48 (6): 730-734

- Lohani, S., P.K.; Trivedi and Nath, P. 2004. Changes in activities of cell wall hydrolases during ethylene induced ripening in banana: Effect of 1-MCP, ABA and IAA. Postharvest Biol. Technol., 31: 119-126. DOI: 10.1016/j.postharvbio.2003.08.001
- Luo, Z.; Xie, J., Xu, T. and Zhang, L. 2009. Delay ripening of "Qingnai" plum (Prunus salicina Lindl.) with 1-methylcyclopropene. Plant Sci. 177:705-709
- Macwan, RM; Vihol, N.J. and Shah, R.J. 2014. Effect of post harvest application of growth regulators, wax emulsion and packaging on bio-chemical parameters of banana cv. "Robusta". African Journal of Agricultural Science and Technology (AJAST) .Vol. 2, Issue 2, pp. 68-70. February, 2014 http://www.oceanicjournals.org/ajast ©2013 Oceanic Journals)
- Mattheis, J.P.; Fan, X. and Argenta, L. 2003. Management of climacteric fruit ripening with 1-Methylcyclopropene, an inhibitor of ethylene action. Proceeding of plant growth regulators. Acta Hort. 1:20-25.
- Moretti1, C.L.; Araújo A.L.; Marouelli W.A.; Silva, C.W.L. 2002. 1-Methylcyclopropene delays tomato fruit ripening. Horticultura Brasileira, v. 20, n. 4, p. 659-663, dezembro 2002.----t Biol. Technol., 33: 1-9. DOI: 10.1016/j.postharvbio.2003.12.007
- Patil, S.K., Shanmugasundaram, S. 2015. Physicochemical Changes during Ripening of Monthan Banana. International Journal of Technology Enhancements and Emerging Engineering Research, Vol. 3, Issue 02. 18 ISSN 2347-4289
- Pinto, A.C., R.E. Alues and E.C. Pereira, 2004. Efficiency of different heat treatment procedures in controlling disease of mango fruits. Proceedings of the Seventh International Mango Symposium. Acta Hort. 645: 551-553.
- Saltveit, M.E., Jr., and S.A. Hale. 1982. Determining the maturity of North Carolina apples. North Carolina Agr. Ext. Bul. AG-282. Chiquita Brands, Inc. (n.d.) your guide to greater profits. Chiquita Brands, Cincinnati, Ohio
- Salvador, A., T. Sanz and S.M. Fiszman, 2006. Changes in colour texture and their relationship with eating quality during storage of two different dessert bananas. Postharvest Biol. Technol. 43: 319-325.
- Salvador, A., Arnal, L., Manterde, A. and Cuquerella, J. 2007. Reduction of chilling injury sysptoms in persimmon fruit cv. 'RojoBrillante by 1-MCP, Postharvest Biology and Technology 33:285-281
- Sarode, S.C. and Tayade, N.H. 2009. Physio-chemical changes during ripening in Williams Zeling and Grand nain banana. J. Dairy. Foods Home Sci., 28: 220-224.
- Sauri-Duch, E.; Centurión-Yah, A.R. and Vargas-Vargas, L. 2010. Alternative tropical fruits in order to increment the offer to European market. Acta. Hort. 864:305-316.
- Sir iboon, N. and Banlusilp, P. 2004. A Study on the Ripening Process of Namwa W% (%(% Faculty of Biotechnology, Assumption University Bankok, Thailand.
- Sisler, E.C. and Serek M. 2003. Compounds interacting with the ethylene receptor in plants. Plant Biol 5: 473–80.
- Sylvia M. Blankenship, Donna D. Ellsworth, and Ronald L. Powell .1993. Ripening Index for Banana Fruit Based on Starch Content. Technology and Product reports.HortTechnology, pp.338-339
- Tourky, M.N., Tarabih, M.E. and El-Eryan, E.E. 2014. Physiological Studies on the Marketability of Williams Banana Fruits. American Journal of Plant Physiology, 9: 1-15.
- Watkins, C.B.; Nock, J.F. and Whitaker, B.D. 2000. Responses of early, mid and late season apple cultivars to postharvest application of 1-methylcyclopropene (1-MCP) under air and controlled atmosphere storage conditions, Postharvest Biol. Technol. 19: 17–32.
- Watkins, C.B. 2006. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnol. Adv. 24:389-409.
- Wills, R.B.H., M.A., War., T. and V.V.V. Ku, 2000. Ethylene levels associated with fruit and vegetables during marketing. Australian Exp. Agri. 40: 357-492.
- Zeweter A.; Woldetsadik K. and Workneh T.S. 2012. African Journal of Agricultural Resaerch Vol. 7 (16), pp. 2425-2437. DOI: 10.5897/AJAR11.1203. ISSN 1991-637X©2012 Academic Journals. http://www.academicjournals.org/AJAR