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Full Length Research Paper

Effect of 1-methylcyclopropene, potassium permanganate and packaging on quality of banana

A. Zewter, K. Woldetsadik and T. S. Workneh*

School of Engineering, Bioresources Engineering, University of KwaZulu Natal, Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa.

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The experiment consisted of ten treatments some of which are: teff straw, banana leaf, perforated and non-perforated polyethylene bag. $KMnO_4$ or 1-MCP was found in polyethylene (perforated or non-perforated) and 1-MCP treated fruits were kept in open air as control. Banana fruits were assessed for important physical and chemical quality. Banana fruits treated with 1-MCP showed better fruit quality. Perforated polyethylene + 1-MCP treatment kept more percentage of fruits marketable compared to the control treatment. Polyethylene bags maintained more marketable fruits than teff straw and banana leaf. However, teff straw and banana leaf as packaging materials performed better than open air storage. $KMnO_4$ combined with the polyethylene bags had performance than polyethylene bag alone. Perforated polyethylene bag packaged fruits were able to maintain quality better than non perforated polyethylene with or without the inclusion of the chemicals. The result showed that 1-MCP combined with perforated polyethylene packaging extended shelf life of banana for over two weeks without much loss in marketability.

Key words: Banana, 1-Methylcyclopropene, teff straw, polyethylene, chemical quality, physical quality.

INTRODUCTION

Over the past few years, postharvest loss and food safety has become and continues to be the first concern for fresh produce industries (FAO, 2004). Kader (1992) estimated the extent of postharvest losses in fresh fruit and vegetables at 5 to 25% in developed countries and 20 to 50% in developing countries. Growing and marketing fresh produce in Ethiopia is complicated by high postharvest losses which are about 30% (EARO, 2000). Seifu (2003) indicated that there is lack of washing, sorting, packaging, chemical treatments and other postharvest handling practices which are reasons for the substantial amount of losses occurring. Banana is among the highly perishable fruits that have a short shelf-life and suffer severe postharvest losses (Basel et al., 2002; Decosta and Erabadupitiya, 2005). Changes in banana occur rapidly after harvesting, and the color, firmness and flavor of the fruit could be damaged during storage, especially when the fruits ripen and stored in a relatively high temperature. Shaun and Ferris (1997) stated that at ambient tropical temperatures, bananas have an average market life of 1 to 10 days depending on genotype, maturity stage at harvest and storage and handling conditions. Preventing build up of ethylene around produce is among the methods in use to delay ripening of bananas. This is achieved through the use of agents that absorb ethylene such as $KMnO_4$ (Shaun and Ferris, 1997) or block ethylene binding to its receptor (Sisler et al., 1999). In recent years, some very effective compounds that block production, action, synthesis or compete for its binding sites, such as 1-methylcyclopropenee (1-MCP), are being used for extending the shelf life of fruits, vegetables and ornamentals.

The 1-MCP compound inhibits ripening by occupying irreversibly ethylene-binding sites so that ethylene would not be able to bind and elicit subsequent signal transduction and translation in the ripening process (Serek et al., 1994). The use of 1-MCP is believed to be a new promising way of controlling ripening, senescence and other ethylene responses of climacteric fruits including

*Corresponding author. E-mail: Seyoum@ukzn.ac.za.

Figure 1. Banana fruit peel colour stage chart.

banana (Shaun and Ferris, 1997; Sisler and Serek, 1997). Modifying atmospheric composition also affects banana physiology and delays ripening (Marchal, 1998; Thompson, 1998; Jiang et al., 1999b). The techniques used to delay and manage ripening includes: temperature control and relative humidity management, modified atmosphere (MA) storage, ethylene removal, or inhibition of ethylene action through chemical means (Wills et al., 1998; Golding et al., 2005). Thus, considering the losses incurred and the lack of information in postharvest handling of banana in the country, this study was initiated to generate information for improvement of postharvest handling of banana with the specific objective of studying effect of 1-methylcyclopropene, potassium permanganate and polyethylene, banana leaf and teff straw packaging on quality and shelf life of banana.

MATERIALS AND METHODS

Sample preparation

Green mature banana fruits were obtained from Arbaminch area, south west of the capital. Harvesting was carried out manually. During harvesting, the bunches were removed from the plant by cutting a notch in the pseudo stem while supporting the bunch with a pole and slowly lowering it on to the shoulder pad of a harvester. The stem was then fully cut, leaving a 30 cm peduncle and loaded on to a pick up vehicle lined with banana leaves. After arrival to the campus, bunches were separated into hands. The hands were sorted for freedom from visual defects, uniformity of weight and shape. The hands were randomly divided into different treatment groups. Each treatment group consisted of six uniform hands (15 to 17 fingers per hand). A saturated solution of $KMnO_4$ was impregnated with 100 g ground bricks and the 1-MCP treatment was made at a rate of 500 nl L^{-1} in a sealed room having a volume of 42 m^3 for 24 h. In all of the treatments, the hands were hanged on a wooden rod except for bananas placed in teff straw and banana leaves, which were kept on a table after properly covering with the covering treatment materials.

Experimental design and treatments

The experiment was conducted using randomized complete block design with three replications involving ten treatments. The treatments consisted of keeping the mature green banana hands in: open air, banana leaf, teff straw, non-perforated polyethylene bag (XtendR film, patent NO. 6190710, Stepac, A. Ltd, Israel). Perforated polyethylene bag, non-perforated polyethylene bag + $KMnO_4$, perforated polyethylene bag + $KMnO_4$, 1-MCP + placing in open air, 1-MCP + non-perforated polyethylene bag and 1-MCP + perforated polyethylene bag. Statistical analysis of data was made using Statistical Analysis System (SAS institute Inc.) and comparison of treatment means was done using the least significance difference (LSD) test.

Data collection

On each sampling date interval, external and internal indicators were used for assessment of fruit quality and marketability. Three randomly taken fruits from the four hands were used for determination of the parameters while weight loss, decay, percent marketability and colour were determined using two hand sample per treatment, the data was recorded at 4, 8, 12, 16, 20, 24 and 28 days of storage. Temperature and relative humidity were also recorded using hygrometer (ALNOR®- Model 8612 S/N03057107) during the daytime in 2 h intervals.

Physiological weight loss

The physiological weight loss was calculated for each interval and converted into percentage of initial weight. The cumulative weight loss was expressed in percentage with respect to different treatments (Waskar et al., 1999).

Percentage marketability

The marketable quality of banana fruits was assessed according to Mohammed et al. (1999). At each storage interval, sample was randomly taken from each treatment. The descriptive quality attributes were determined by observing the level of visible mould growth, decay, shriveling or dehydration and the surface appearance characteristics such as smoothness and shininess of fruit.

Fruit peel colour and firmness

The average peel colour of the sample fruits was determined using banana maturity stage chart (Figure 1). Peel colour of individual fruit was scored on a scale of 1 (green), 2 (breaker), 3 (< 25% colour change), 4 (25 to 50% colour change), 5 (> 50% but < 100% colour change), 6 (fully yellow) and 7 (yellow with black spots) (Paull, 1996; Dadzie and Orchard, 1997). Pulp firmness of banana was determined on cross section of fruits according to the method described by Dadzie and Orchard (1997). The fruits were prepared by cutting reversely at the mid point consisting 1 cm of fruit tissue (that is with both the peel and pulp). The sample was placed on a platform and the force required to penetrate the tissue with constant depth penetrometer (model FT011 Ferli, fitted with 6 mm probe) was determined.

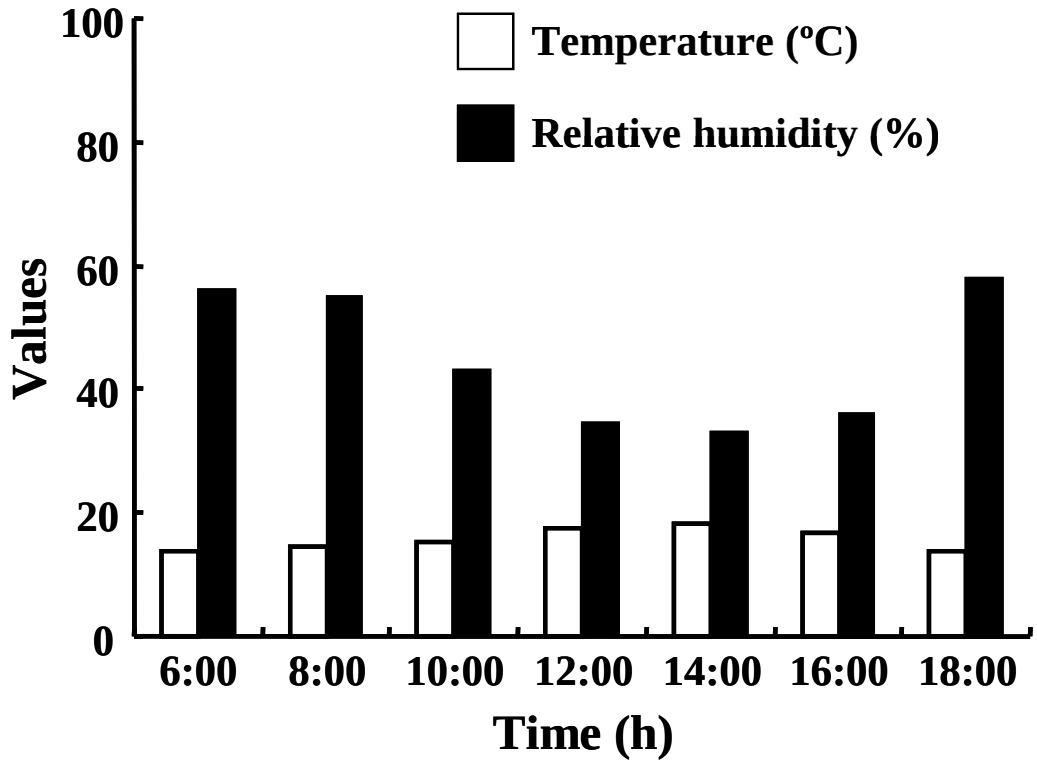

Figure 2. Average day time temperature and relative humidity of the banana storage room.

TSSs, titratable acidity and ascorbic acid

Total soluble solid (TSS) and titratable acidity (TA) contents of banana fruits was measured according to the method of Dadzie and Orchard (1997). 30 g of pulp tissue, taken from the traverse section of the sample fruits was put in 90 ml distilled water and blended for 2 min in a kitchen blender (6001x model No. 31JE35 6x.00777) and then filtered through Whathman filter paper. A drop of the filtrate was placed on the prism of a refractometer (model MiscoR with a brix reading of 0 to 32%). The recorded value was multiplied by three and recorded as TSSs of the fruit pulp. For total titratable acidity of the banana pulp, 90 ml of distilled water was added into 30 g of pulp tissue and blended for 2 min using a kitchen blender and filtered. Then 25 ml of the filtrate was transferred into 125 conical flasks to which 25 ml of distilled water and 5 drops of phenolphthalein indicator were added. Then, it was titrated with 0.1 N NaOH until the indicator changed to pink and the titre volume of NaOH added was recorded. The result was expressed as a percentage per 100 g sample in terms of the predominant acid present (malic acid). Ascorbic acid (AA) content was determined by the 2, 6-dichlorophenol indophenol method (AOAC, 1970). An aliquot of 10 ml of banana juice was diluted to 50 ml with 3% metaphosphoric acid in a 50 ml volumetric flask.

The aliquot was titrated with the standard dye to a pink end point (persisting for 15 s). The ascorbic acid content was then calculated from the titration value, dye factor and volume of the sample.

Sugar analysis

Total and reducing sugars were estimated using the techniques of Mazumdar and Majumder (2003). 10 mg of banana puree was added to 15 ml of 80% ethanol, then mixed and heated in a boiling water bath until the ethanol odor went off. After extraction, 1 ml of saturated Pb $(CH_3COO)_2$, $3H_2O$ and 1.5 ml of Na_2HPO_4 were added and the contents were mixed by gently shaking. After filtration, the extract was made up to 50 ml with distilled water. An aliquot of 1ml extract was diluted to 25 ml with 1 ml copper reagent in a test tube and heated for 20 min in a boiling water bath. After heating, the contents were cooled under running tap water without shaking. Arsenomolybdate colour reagent (1 ml) was added, mixed, made up to 10 ml with distilled water and left for about 10 min to allow colour development, after which the absorbance of the juice was determined by a spectrophotometer at 540 nm with the help of Jenway model 6100 spectrometer. For total sugar determination, sugar was first hydrolyzed with 1N HCl by heating at 70°C for 30 min. After hydrolysis, total sugar was determined following the same procedure employed for the reducing sugar.

Data analysis

Statistical analysis of data was made using Statistical Analysis System (SAS institute Inc.) and comparison of treatment means was done using the least significance difference (LSD) test.

RESULTS AND DISCUSSION

Temperature and relative humidity

The temperature recorded in the storage room ranged from 13.6 to 18.4°C during the study period (Figure 2). This range is closer to the optimum temperature for storage of bananas (Shaun and Ferris, 1997; Morelli and

Table 1. The effect of postharvest treatments on colour and firmness changes of banana fruit during storage period of 28 days.

Treatment	Peel colour change							Fruit firmness						
	Storage period (days)							Storage period (days)						
	4	8	12	16	20	24	28	4	8	12	16	20	24	28
Open air	4.0^{a}	5.0^{a}	6.0^{a}	7.0^{a}	_	_	_	3.87^{h}	2.37^{i}	1.6^{h}	0.2^{f}	_	_	_
Banana leaf	3.0^{b}	4.0^{b}	5.0^{b}	6.0^{b}	7.0^{a}	_	_	4.2^{g}	2.7^{h}	1.8^{g}	1.0^{e}	0.16^{e}	_	_
NP	2.0^{c}	3.0^{c}	4.7^{b}	5.7^{b}	7.0^{a}	_	_	4.5^{f}	3.1^{g}	2.1^{f}	1.1^{d}	0.2^{e}	_	_
PP	2.0^{c}	3.0^{c}	4.7^{b}	5.7^{b}	6.7^{a}	-	_	4.73^{e}	3.4^{f}	2.37^{e}	1.2^{d}	0.2^{e}	_	_
NP+$KMnO_4$	2.0^{c}	3.0^{c}	4.0^{c}	5.3^{b}	6.7^{a}	_	_	5.13^{d}	3.7^{e}	2.6^{d}	1.3^{d}	0.3^{e}	_	_
PP+$KMnO_4$	2.0^{c}	2.7^{d}	4.0^{c}	5.3^{b}	5.7^{b}	7.0^{a}	_	5.3^{cd}	4.47^{d}	4.27^{c}	3.57^{c}	1.67^{d}	0.19^{d}	_
1-MCP+NP	1.0^{e}	2.0^{e}	2.7^{d}	3.7^{c}	5.0^{c}	6.0^{b}	7.00^{a}	5.87^{b}	5.27^{b}	4.77^{b}	4.2^{b}	3.2^{b}	1.7^{c}	0.3^{b}
1-MCP+PP	1.0^{e}	1.0^{f}	2.0^{e}	2.7^{d}	3.7^{d}	4.3^{c}	5.70^{b}	6.3^{a}	5.67^{a}	5.07^{a}	4.6^{a}	3.6^{a}	2.6^{a}	1.47^{a}
1-MCP	1.3^{d}	2.0^{a}	3.0^{d}	4.0^{c}	4.7^{c}	5.7^{b}	7.00^{a}	5.5^{c}	5.0^{c}	4.4^{c}	4.0^{b}	2.9^{c}	2.4^{b}	0.27^{b}
Teff straw	3.0^{b}	4.0^{b}	5.0^{b}	5.7^{b}	7.0^{a}	_	_	4.2^{g}	2.7^{h}	1.8^{g}	1.0^{e}	0.17^{e}	_	_
Significance	***	***	***	***	***	*	*	***	***	***	***	***	***	***
SE	0.06	0.06	0.10	0.16	0.13	0.24	0.20	0.04	0.025	0.036	0.046	0.031	0.046	0.02
CV	8.56	6.15	7.70	9.70	6.50	8.20	5.10	2.52	2.11	3.74	6.54	6.86	5.25	4.90

NP = Non-perforated polyethylene, PP = perforated polyethylene. Means within the same column followed by different letters are significantly different at $P < 0.05$ or $P < 0.001$. $KMnO_4$ = Potassium permanganate; 1-MCP = 1-methylcyclopropene. *, ***, indicate significant difference at $p < 0.05$ and 0.001 respectively. Colour stage 1 (green), 2 (breaker), 3 (< 25% colour change), 4 (25 to 50% colour change), 5 (> 50% but < 100% colour change), 6 (fully yellow) and 7 (yellow with black spots).

Kader, 2002). Therefore, it indicates suitability of the storage room for banana storage that helps to keep fruits for about one week by reducing the rate of respiration without causing chilling injury. According to Shaun and Ferris (1997), optimum storage temperature for banana is 13 to 14°C. At this temperature, storage life of mature fruits was 1 to 2 weeks which is similar to the result of the present study. The storage room relative humidity ranges from 33 to 58% during the day time which was very low compared to the recommended optimum for banana (Figure 2). Banana fruits are usually stored and ripened at relative humidity of 90 to 95% which will prevent moisture loss and early browning of the skin (Morreli and Kader, 2002). According to Shaun and Ferris (1997), a relative humidity of 90% provides the best compromise for storing banana. The observed fluctuation in temperature and relative humidity of the storage room was not good from the point of view of safe and effective storage of perishable commodities according to Burdon (1997), which calls for looking other storage alternatives than at ambient temperature.

To keep water loss from fresh produce as low as possible, it must be kept in a moist atmosphere (FAO, 1989) that could reduce water loss and increase storage life.

Peel colour change

The colour change of banana fruit during the storage period of 28 days has shown significant ($P \leq 0.001$) difference among the treatments on each sampling date (Table 1). The fastest colour change was observed in open-air stored fruits where fruits reached full yellow colour (stage 6) on the 12th day. On the same day, fruits stored in banana leaf and teff straw were at advanced peel colour development stage (stage 5) next to those stored in open air while those treated with 1-MCP were still at a breaker to light yellow colour stages (stages 2 to 3). Banana fruits packaged in polyethylene bags showed delay in colour change than those packaged using teff straw, banana leaf and banana fruits stored in open air. A slight delay in colour change was also observed in banana fruits kept in polyethylene bag with inclusion of $KMnO_4$ which could be attributed to its ethylene absorbing capacity (Shaun and Ferris, 1997). The

longest delay in colour change was observed in fruits treated with 1-MCP and placed in perforated polyethylene in which the fruits were just at full yellow colour stage on the last date of storage (28 days). The peel colour development from green to yellow (stages 1 to 6) in this study is in agreement with the 1 to 2 weeks duration reported before (Siriboon and Banlusilp, 2004; Dharmasenal and Kumari, 2005; Salvador et al., 2006). The conversion of green colour of the peel into yellow as a result of chlorophyll degradation is an indicator of senescence that is enhanced by high rate of respiration which in turn is regulated by temperature, ethylene, O_2 and CO_2 gases (Pinto et al., 2004). The senescence of the fruits is evidenced by the strong negative correlation of this parameter with ascorbic acid, marketability and firmness as well as its strong positive correlation with parameters like total sugar, TSS and weight loss (Table 6). The open air stored fruits which have access to O_2 and also exposed to slight increases in concentration of ethylene that could enhance respiration (Wills et al., 2000), showed change in colour from green to yellow faster than the rest of the treatments.

The observed delay in colour change of banana fruits packaged in banana leaf and teff straw as compared to banana fruits stored under open air could be due to retarded respiration as a result of the modified atmosphere (O_2 depletion and CO_2 accumulation) by the packaging materials. This was further improved by the polyethylene packaging which confirms previous reports that indicated modified atmosphere packaging with polyethylene typically delayed initiation of banana fruit ripening by reducing the ratio of O_2:CO_2 and thus extended the shelf life of the fruits (Scott and Roberts, 1966; Dong et al., 2001, 2002). The reason that most of the perforated polyethylene bag packaged fruits after treatment with 1-MCP had most delayed colour change could be associated with the fact that 1-MCP have retarding effect on the synthesis of ethylene (Jiang and Joyce, 2000; Blakenship and Dole, 2003; Huber et al., 2003) and, hence, reduced the respiration rate of the fruits. Moreover, the perforated polyethylene bags could allow escape of ethylene inside the package to the environment which might have lowered concentration of ethylene in the package space. The delay in colour development of 1-MCP treated fruits is in agreement with the result obtained by Pelayo et al. (2003). Golding et al. (1998) also reported that 1-MCP delayed onset of peel de-greening up to 34 days and slowed down rates of colour change in banana.

Fruit firmness

A significant ($P < 0.001$) variation was observed in the firmness of banana fruit that received different post-harvest treatments (Table 1). The result shows reduction in fruit firmness steadily over the period of 28 days. Fruits stored in the open air lost firmness faster than all other treatments tested. Fruits treated with 1-MCP and kept in perforated polyethylene bag remained the most firm. Fruits nested in dry banana leaf and teff straw recorded second in firmness. Modified atmosphere created by polyethylene bags improved fruit firmness over the treatments by teff straw and banana leaf nesting; inclusion of $KMnO_4$ in the bags showed further improvement. Moreover, the 1-MCP treatment resulted in maintaining fruits more firm than those treated with $KMnO_4$. As regards to the polyethylene bag in relation to keeping the banana fruits firm during storage, overall better performance was recorded in perforated than non-perforated ones. Strong and positive correlation was also observed between firmness of fruits and ascorbic acid content and marketability of the fruits while it showed negative correlation with colour, and weight loss (Table 6) indicate that the treatments delayed loss of firmness and improved marketability and quality of the fruits. As indicated earlier, the steady reduction in fruit firmness during the storage period is a natural process of ripening of almost all fleshy fruits as a result of biochemical changes of the cellular structure (Brady, 1987; Seymour, 1993; Dharmasenal and Kumari, 2005). According to Seymour (1993), softening of fruits is related to a change in cell wall components and starch degradation. The starch granules, packed in the tissue of banana flesh give rise to the toughness of the unripe fruit and when hydrolyzed to sugar, there will be an increase in cell wall solubility which is an indication of ripening but also higher incidence of mechanical damage (Dadzie and Orchard, 1997), as further evidenced by its strong positive correlation with peel thickness (Table 6).

The overall differences in fruit firmness followed the pattern of colour change discussed earlier (Table 1). This is due to the fact that both are results of the same cause, ripening. With advance in ripening, there will be breakdown of the cell walls, reduction in the cohesion of the middle lamella due to the solubilization of the pectic substance (Palmer, 1971; Smith et al., 1989), and movement of water from the skin to the flesh as a result of osmosis (Dadzie and Orchard, 1997), all of which result in softening of the fruits. Accordingly, the variation observed in fruit firmness in this study could be attributed to the direct and indirect effects of the treatments on the rate of respiration and ripening. The effect of teff straw, banana leaf and polyethylene bag in delaying loss of firmness compared to the open air could be due to modified atmosphere created by using these packaging materials that reduced the rate of respiration and retarded tissue break down during slow ripening (Kotecha and Babasaheb, 1995). Similarly, the perforated polyethylene compared to the non-perforated ones might have imparted its effect through removal of ethylene which plays catalytic role in enhancing respiration (Fresh, 2001; Pelayo et al., 2003). The effects of $KMnO_4$ and 1-MCP on fruit firmness coincides with the results obtained

Table 2. The effect of postharvest treatments on marketability (%) and physiological weight loss of banana fruit during storage period of 28 days.

Treatment	Percentage marketability (%)							Physiological weight loss (%)						
	Storage period (days)							Storage period (days)						
	4	8	12	16	20	24	28	4	8	12	16	20	24	28
Open air	86.70^{d}	74.00^{f}	54.67^{f}	32.23^{g}	_	_	_	4.79^{a}	8.49^{a}	12.24^{a}	18.97^{a}	_	_	_
Banana leaf	95.93^{c}	85.63^{e}	60.13^{e}	42.47^{f}	31.63^{d}	_	_	3.50^{c}	5.78^{c}	8.60^{b}	14.40^{b}	19.10^{a}	_	_
NP	96.43^{bc}	86.60^{e}	62.60^{de}	45.53^{e}	32.87^{d}	_	_	2.87^{d}	4.55^{d}	7.60^{c}	13.10^{c}	18.70^{b}	_	_
PP	96.60^{bc}	87.53^{e}	65.47^{d}	45.86^{e}	33.13^{d}	_	_	2.68^{e}	4.17^{e}	6.77^{d}	10.40^{d}	17.70^{c}	_	_
NP+$KMnO_4$	97.03^{bc}	92.70^{d}	77.06^{c}	63.43^{d}	33.53^{d}	_	_	2.27^{f}	3.60^{f}	6.23^{e}	9.10^{e}	16.80^{d}	_	_
PP+$KMnO_4$	97.33^{b}	96.03^{c}	77.20^{c}	64.30^{d}	43.10^{c}	32.30^{c}	_	1.80^{g}	3.20^{g}	5.32^{f}	8.20^{f}	15.50^{e}	16.50^{a}	_
1-MCP+NP	100.00^{a}	98.50^{ab}	87.46^{b}	76.30^{b}	60.90^{b}	46.17^{b}	32.63^{b}	1.49^{i}	2.04^{i}	3.10^{h}	6.30^{h}	9.60^{g}	13.50^{c}	17.20^{b}
1-MCP+PP	100.00^{a}	99.00^{a}	91.90^{a}	87.46^{a}	73.70^{a}	59.57^{a}	44.43^{a}	0.77^{j}	1.57^{j}	2.60^{i}	5.10^{i}	8.53^{h}	11.53^{d}	12.60^{c}
1-MCP	100.00^{a}	97.00^{bc}	87.40^{b}	73.60^{c}	58.47^{b}	46.03^{b}	32.50^{b}	1.70^{h}	2.65^{h}	4.40^{h}	7.10^{g}	11.00^{f}	14.50^{b}	18.60^{a}
Teff straw	95.97^{c}	86.33^{e}	60.37^{e}	43.0^{f}	32.70^{d}	_	_	3.60^{b}	5.88^{b}	8.57^{b}	14.41^{b}	19.00^{a}	_	_
Significance	***	***	***	***	***	***	***	***	***	***	***	***	***	***
SE	0.21	0.35	0.58	0.36	0.6	1.12	0.25	0.024	0.018	0.026	0.036	0.039	0.05	0.07
CV (%)	0.70	1.24	2.53	1.99	4.06	4.22	1.20	2.95	1.37	1.27	1.06	0.80	0.74	0.72

NP = Non-perforated polyethylene, PP = perforated polyethylene. Means within the same column followed by different letters are significantly different. $KMnO_4$ = Potassium permanganate; 1-MCP = 1-methylcyclopropene. *** indicate significant difference at $p < 0.001$.

by Scott et al. (1970), Jobling (2000) and Shashirekha et al. (2007) for the former treatment and by Sisler and Blankenship (1996) and Matthis (2003) for 1-MCP. The delay in firmness of fruit stored in polyethylene bag in combination with ethylene absorber $KMnO_4$ could be due to re-action of potassium permanganate with ethylene to produce carbon dioxide and water, thus limiting the role of ethylene on ripening (Jobling, 2000). Likewise, the delay in firmness of 1-MCP treated fruits could be due to the 1-MCP inhibition action on ethylene that stimulates fruit ripening.

As noted by Sisler and Blankenship (1996) and Mattheis et al. (2003), 1-MCP binds irreversibly to ethylene receptors and ripening of treated fruit will be delayed until new binding site is synthesized which could explain results observed in this study.

Percentage marketability

There was significant ($P \leq 0.001$) variation in the percentage marketability of the banana fruits subjected to different postharvest treatments throughout the storage period (Table 2). The highest percentage marketability was observed in bananas treated with 1-MCP and kept in perforated polyethylene followed by 1-MCP treated fruits kept either in the open air or in non-perforated polyethylene. Except fruits treated with 1-MCP and kept in perforated polyethylene (PP), marketability of fruits in all other treatments was below 90% on day 12th of storage. The effect of 1-MCP + PP on % marketability on this date was 68% more compared to fruits in the open air and about 52% better than fruits kept either in banana leaf or teff straw. The $KMnO_4$ treatment also improved marketability of fruits by 41, 28 and 20% compared to fruits kept in open air, banana leaf and teff straw and polyethylene bags, respectively, on the 12th day of storage. Fruits which were placed both in non-perforated and perforated polyethylene bags with $KMnO_4$ also retained significantly more percentage marketable fruits throughout the storage period compared to fruits placed in open air, teff straw, banana leaf and polyethylene bags alone. The banana leaf and teff straw treated fruits had about 10% more marketable fruits than open air stored fruits on the 12th day of storage. Out of all the polyethylene bag stored fruits with and without $KMnO_4$ and 1-MCP treatments, those placed in perforated polyethylene retained relatively more marketable

fruits than those in bags without perforation. In all treatments, the percentage marketability of fruits decreased with time due to wilting, shriveling and decay, which could be due to the progress of ripening process with time. The increment in unmarketability of the fruits can further be evidenced by the strong correlation of marketability with physical quality parameters like firmness (0.91**) and skin colour (0.85**) which also relate with chemical quality of the fruits (Table 6). Banana fruits which were placed in open air started to show symptom of shriveling and wilting in addition to symptom of browning earlier than other treatments which subsequently made them completely unmarketable after 16th day of storage.

Marketability percentage of fruits stored in open air was 32.2% on the 16th day of storage, while fruits kept in teff straw and banana leaf had 43.0 and 42.5%, respectively. The difference could be due to the effect of lower relative humidity in open air as compared to the later treatments (Morreli and Kader, 2002). The polyethylene improvement of percentage marketability over the teff straw and banana leaf could be due to increased relative humidity under the former environment. Moreover, the effect of the polyethylene could partially be due to possible difference in air composition around the fruits that might have suppressed respiration. This result is in line with reports of Dong et al. (2001, 2002) that showed modified atmospheric packaging increased shelf life of banana through decreasing rate of respiration as a result of differential O_2:CO_2 composition and through conservation of moisture around the fruit. On the other hand, the higher number of marketable fruits in the perforated than non-perforated polyethylene packages could be due to increased ventilation which might have reduced the effect of ethylene as well as excess humidity since ventilation is one of the strategy to remove excess humidity that may favor decay organisms (Shaun and Ferris, 1997). The combined effect of the packaging material and ethylene absorbers could be attributed to partly to the moisture conservation by the polyethylene bags around the produce thereby reducing moisture loss and shriveling of the banana fruit as well as to reduced concentration of ethylene and consequently slowing down the rate of respiration. As mentioned earlier, on the 20th day of storage, more of the fruits placed in the open air were unmarketable while fruits treated with 1-MCP and placed in perforated polyethylene bag maintained about 74.0% of the fruits in a marketable condition. The low relative humidity in the open air could be the main cause for the rapid deterioration of the fruits due to moisture loss, which resulted in shriveled and brownish fruits. Moreover, a slight increment in ethylene amount around the fruits could have also contributed to the rapid loss of fruits in the open air (Kotecha and Babasaheb, 1995) through their respiration enhancing effects.

As indicated by Kays (1997) and Wills et al. (2000), fresh produce can release between 0.017 and 0.06 ppm ethylene during marketing and storage, an amount that can cause a 10.0 to 30.0% loss of the produce.

Physiological weight loss

Variation was observed in the percent weight loss of banana fruits handled under different storage conditions (Table 2). The differences were significant ($P \leq 0.001$) among all treatments during the storage period of 28 days. The highest weight loss was recorded in banana fruits kept in the open air storage which was followed by those packaged in banana leaf and teff straw. The polyethylene bag treatments reduced weight loss significantly compared to the packaging in banana leaf and teff straw, which is commonly practiced by the local banana growers and traders. Inclusion of potassium permanganate ($KMnO_4$) in fruits packaged in polyethylene further reduced the weight loss. All treatments with 1-MCP reduced weight loss better than the remaining treatments. Keeping 1-MCP treated fruits in perforated polyethylene was found to be the best in lowering weight loss than placing in non-perforated one or open air. Perforated polyethylene reduced weight loss of banana both in the absence and presence of $KMnO_4$ and 1-MCP as compared to the non-perforated polyethylene with or without the chemicals. In all treatments, the percentage weight loss increased with storage time as ripening progressed, which possibly resulted from transpiration and respiration of the fruits. Excess energy produced from the respiration process in the form of heat is released from the fruit by evaporation of water causing a weight loss (Siriboon and Banlusilp, 2004; Dharmasenal and Kumari, 2005). Similarly, increase in the membrane permeability following the respiratory climacteric could result in loss of moisture through the peel (Siriboon and Banlusilp, 2004) as evidenced in this study by the shrinkage on the peel. The highest percentage of weight loss on day 16 was about 19.0% for fruits kept in the open air after which all fruits in this treatment were discarded. The low storage room relative humidity (35 to 58%), in addition to possible respiratory loss, could have aggravated the weight loss at ambient while in other treatments either of these causes might have been affected. This result corresponds with the weight loss value reported by Dharmasenal and Kumari (2005) for fruits stored under open ambient condition for the same period.

The lower weight loss obtained from fruits placed in polyethylene bags with perforation compared to those in non-perforated ones could be due to removal of ethylene which has a catalytic role in increasing respiration (Jobling, 2000) while also maintaining RH in the package thus reducing water loss. The removal of ethylene and/or inhibition of its effect in the storage environment is funda-mental to maintaining postharvest quality of climacteric produce (Saltveit, 1999). Fruits which were placed in

Table 3. The effect of postharvest treatments on TSS (°Brix) content of banana fruit during storage period of 28 days.

Treatment	Storage period (days)						
	4	8	12	16	20	24	28
Open air	6.2^{a}	17.8^{a}	21.9^{a}	18.9^{b}	_	_	_
Banana leaf	5.3^{b}	17.3^{ab}	19.2^{b}	22.0^{a}	19.0^{b}	_	_
NP	5.3^{b}	17.1^{ab}	18.6^{b}	21.5^{a}	18.5^{bc}	_	_
PP	5.3^{b}	16.9^{ab}	18.3^{b}	21.7^{a}	18.7^{bc}	_	_
NP+$KMnO_4$	5.2^{b}	16.7^{b}	18.0^{b}	21.5^{a}	18.5^{bc}	_	_
PP+$KMnO_4$	5.2^{b}	16.2^{b}	17.4^{b}	19.5^{b}	21.9^{a}	18.9^{b}	_
1-MCP+NP	4.9^{c}	9.97^{d}	12.6^{c}	16.4^{c}	19.9^{b}	22.2^{a}	18.4^{b}
1-MCP+PP	3.9^{d}	8.7^{e}	11.9^{c}	16.4^{c}	17.3^{c}	19.3^{b}	21.3^{a}
1-MCP	4.9^{c}	11.3^{c}	13.7^{c}	16.6^{c}	19.1^{b}	21.7^{a}	17.9^{b}
Teff straw	5.3^{b}	17.2^{ab}	18.8^{b}	21.9^{a}	18.9^{b}	_	_
Signifiance	***	***	***	***	***	**	**
SE	0.04	0.2	0.45	0.23	0.27	0.4	0.33
CV (%)	2.28	4.20	8.30	3.80	4.30	3.90	3.01

NP = Non-perforated polyethylene, PP = perforated polyethylene. Means within the same column followed by different letters are significantly different. $KMnO_4$ = Potassium permanganate; 1-MCP = 1-methylcyclopropene. **, *** indicate significant difference at $P < 0.01$and 0.001, respectively.

non-perforated and perforated polyethylene bags after treated with 1-MCP showed the lowest weight loss. Here, the effectiveness of 1-MCP in combination with polyethylene bag could be due to combined effect of the polyethylene bag and 1-MCP. The polyethylene bag conserved moisture around the fruit since loss of water during storage is one of the main causes of weight loss in fruits (Thompson, 1998). The advantage of perforated over non-perforated polyethylene with 1-MCP could be the ventilation effect in the former treatment. The effect of the 1-MCP is the slowing down of respiration which leads to reduced weight loss and thus maintaining them edible for longer periods of time (Huber et al., 2003; Yueming et al., 1999). This result is in agreement with the observation of Ahmed et al. (2001) who reported the longest shelf life (about 58 days) in 1-MCP treated and sealed bananas than in either untreated or treated but unsealed ones.

Total soluble solids

Postharvest treatments with different packaging materials and chemicals significantly ($P \leq 0.001$) affected the TSS content of banana fruits (Table 3). Fruits placed in open air showed a faster increment in their TSS content, increasing from 6.2 ºBrix on day 4 to 21.9 ºBrix on day 12 and dropping to 18.9 ºBrix on day 16. On the other hand, fruits treated with 1-MCP were the slowest to reach their TSS peak, increasing from 3.9 ºBrix on day 4 to 21.3 ºBrix on day 28. Banana fruits covered by teff straw and banana leaf, those kept in non-perforated polyethylene with or without $KMnO_4$, and those stored in perforated polyethylene attained their respective peak of TSS levels, which were all on 16th day of storage. The $KMnO_4$ plus perforated polyethylene treatment delayed peak TSS (21.9 ºBrix) to 20 days while the 1-MCP treatments with non-perforated polyethylene and open-air storage delayed the peak fruit TSS development to 24 days. The observed increment in TSS content during ripening of fruits and decrease after attaining peak levels followed natural fruit ripening and senescence processes that have also been exhibited in related traits including colour change, firmness and fruit marketability which are typical of postharvest change in climacteric fruit (Pinto et al., 2004). This result is in agreement with the report of Dharmasenal and Kumari (2005) and Salvador et al. (2006) that showed increase in TSS contents of different banana varieties from 0 to 17 °Brix over a storage period of 16 days. The slightly more amount of TSS at the peak of ripening in the present study could be due to differences in the type of cultivars studied (Dadzie and Orchard, 1997) and effects of the treatments applied.

In agreement with this result, Hernandez et al. (2006) also reported that bananas at three ripening stages; unripe, half ripe and ripe stage contained TSS levels of 2.5, 17.3 and 22.8 ºBrix, respectively. The observed increment in TSS content of fruits placed in open air is an indication of high respiration rate and ripening thereby resulting in quality deterioration with the onset of senescence (Pal and Roy, 1988). On the other hand, delay in the increment of TSS content of fruits stored in perforated polyethylene bag after 1-MCP treatment could be due to slow down of ripening as a result of binding of 1-MCP with ethylene receptor and removal of ethylene by ventilation through the perforation. Ripening retardation effect of 1-MCP was also associated with an apparent delay in the onset of elevated ethylene evolution and

Table 4. The effect of postharvest treatments on total and reducing sugar content (g 100 g $^{-1}$ FW) of banana fruit during storage period of 28 days.

Treatment	Total sugar							Reducing sugar						
	Storage period (day)							Storage period (day)						
	4	8	12	16	20	24	28	4	8	12	16	20	24	28
Open air	10.0^{a}	14.3^{a}	20.2^{a}	16.0^{e}	-	-	-	3.6^{a}	9.8^{a}	17.8^{a}	14.6^{d}	-	-	-
Banana leaf	8.0^{b}	13.0^{b}	15.0^{b}	20.6^{a}	17.0^{b}	-	-	2.3^{b}	8.3^{b}	12.7^{b}	18.5^{a}	15.5^{b}	-	-
NP	5.9^{c}	8.0^{d}	12.9^{d}	19.1^{c}	15.8^{de}	-	-	2.1^{c}	5.5^{d}	11.0^{d}	17.6^{c}	14.56^{d}	-	-
PP (back space)	5.0d	7.0^{e}	11.8^{e}	19.1^{c}	15.9^{d}	-	-	1.4^{d}	5.2^{e}	10.1^{e}	17.5^{c}	14.5^{d}	-	-
NP+$KMnO_4$	3.9^{e}	6.2^{f}	8.9^{g}	18.7^{d}	15.6^{e}	-	-	1.3^{d}	4.7^{f}	8.4^{f}	17.4^{c}	14.4^{d}	-	-
PP+$KMnO_4$	2.0^{f}	4.1^{g}	9.8^{f}	13.9^{f}	17.6^{a}	14.5^{d}	-	0.8^{e}	2.1^{g}	7.1^{g}	12.7^{e}	16.7^{a}	13.7^{c}	-
1-MCP+NP	1.3^{g}	3.0^{i}	7.9^{h}	12.9^{g}	15.7^{de}	20.8^{a}	15.8^{c}	0.4^{f}	1.3h	4.1^{i}	10.3^{g}	13.4^{e}	18.6^{a}	15.6^{b}
1-MCP+PP	1.0^{g}	2.0^{j}	5.1^{i}	9.9^{h}	12.8^{f}	15.9^{c}	17.1^{b}	0.4^{f}	0.7i	3.1^{j}	6.6^{h}	10.3^{f}	13.5^{c}	16.6^{a}
1-MCP	2.0^{f}	3.6^{h}	8.0^{h}	13.8^{f}	15.9^{d}	19.5^{b}	15.8^{c}	0.7^{e}	1.4^{h}	4.7^{h}	11.1^{f}	13.5^{e}	17.3^{b}	14.3^{c}
Teff straw	7.9^{b}	10.7^{c}	14.4^{c}	20.0^{b}	16.5^{c}	-	-	2.3^{b}	6.4^{c}	12.1^{c}	17.8^{b}	14.9^{c}	-	-
Signifiances	***	***	***	***	***	***	**	***	***	***	***	***	***	**
SE	0.06	0.03	0.04	0.05	0.05	0.14	0.20	0.02	0.04	0.04	0.04	0.05	0.14	0.20
CV (%)	4.22	1.43	1.04	0.96	0.90	1.64	2.27	5.14	2.47	1.38	0.96	0.95	1.79	2.21

NP = Non-perforated polyethylene, PP = perforated polyethylene. Means within the same column followed by different letters are significantly different. $KMnO_4$ = Potassium permanganate; 1-MCP = 1-methylcyclopropene. ** and ***, indicate significant difference at $P < 0.01$ and 0.001, respectively.

respiration (Jiang et al., 1999a). This result is in agreement with the report of Zhou et al. (2004) and Golding et al. (2005) in which 1-MCP treatment of banana fruit delayed the increase of TSS as well as onset of several physiological responses related to ripening that could extend the shelf life of the fruits with better quality maintenance.

Sugar contents

Table 4 display the total and reducing sugar contents of banana fruits exposed to different postharvest treatments, respectively. As shown in the table, the amount of total and reducing sugars in the fruits increased with advance in storage time starting from 0.80 and 0.18 g 100 g $^{-1}$ FW on the first storage day, respectively. Then both decreased after reaching a peak on different dates, while the sugar shows increment up to the fourth day starting from 0.6 g 100 g $^{-1}$ FW on the first storage day in all of the treatments, but some of the treatments showed increment for longer time. The conversion of starch to sugar was rapid in fruits which were stored in open air compared to all other treatments considered in this study. The fruits stored in open air showed an increase in their total and reducing sugar contents to peaks of 20.2 g 100 g $^{-1}$ and 17.6 g 100 g $^{-1}$ FW on the 12th day of storage, respectively. While the sugar was at its highest level on 4th day of storage; fruits, which were packed in the teff straw, banana leaf, and polyethylene bags with no 1-MCP and $KMnO_4$ and the non-perforated polyethylene bags with $KMnO_4$ inclusion all, reached their respective peaks of total and reducing sugar levels on the16th day of storage. On the other hand, the sugar attained a peak on day 4 of storage. The 1-MCP treated fruits kept in non-perforated polyethylene bags and those kept in the open air showed an increment in their total and reducing sugar contents. The observed increment in the total amount of sugar could be due to the conversion of starch to sugar as ripening progresses with a decline after attaining certain peak as fruits enter senescence stage, which is in agreement with reports of Morrelli and Kader (2002).

As indicated by Pinto et al. (2004), a decrease in starch content accompanied by an increase in TSS and total sugar is typical of postharvest changes in climacteric fruit. In *Musa cavendish* bananas, starch hydrolysis and sugar synthesis are normally complete on reaching full ripeness

(Salvador et al., 2006). In this study, the sugar content of the fruits during the storage period ranged from 1.0 g 100 g^{-1} FW to 20.8 g 100 g^{-1} FW which is in agreement with that reported by Robinson (1996). The author reported that the fruits declined from starch content of about 20.0 to 23.0 g 100 g^{-1} FW at harvest to 1.0 to 2.0 g 100 g^{-1} FW in ripe fruits, while the amount of sugars increased in about the same proportion. This also compared reasonably well with total sugar contents of 16.2 g 100 g^{-1} FW reported by Southgate (1976) and 14.1 g 100 g^{-1} FW reported by Kayisu et al. (1982) in a ripe banana fruit. Rapid increment in the total and reducing sugar as well as a rapid decrease in sugar contents of fruits stored in open air could be due to faster ripening process which converts starch in-to sugar, while the slower rate in the rest of the treatments could be due to the effects of the treatments in delaying the ripening process (Dong et al., 2001, 2002; Morrelli and Kader, 2002; Golding et al., 2005). The teff and banana leaf covers could have increased CO_2 while slightly reducing O_2 level around the fruits as a result of respiration; this in turn could have slowed down respiration rate and ripening as compared to fruits in the open air. With polyethylene bags having more control over the gas exchange with the surrounding air, the levels of CO_2 and O_2 around the fruits could have further slowed down conversion of starch to sugars.

The delay in increase of the sugars by inclusion of $KMnO_4$ in the polyethylene and treatments with 1-MCP could be attributed to the ethylene removal effect of $KMnO_4$ (Jobling, 2000) and ethylene inhibition effect of 1-MCP through competition for a receptor site (Sisler and Blankenship, 1996; Jiang and Joyce, 2000; Zhou et al., 2004) thereby delaying climacteric respiration triggering effects of ethylene (Wills et al., 1998; Mattheis et al., 2003). The observed small amount of reducing sugar at the early period of ripeness followed by increment as ripening progresses could be due to the higher amount of sugar at the early stage of ripeness which is in agreement with the report of Robinson (1996). According to the author, the ratio of sugars at the early period of ripeness is about 65:20:15 for sucrose, glucose and fructose, respectively. The observed decrease in sugar content of banana as ripening progressed is in agreement with reports of Robinson (1996) and Southgate (1976). The effects of the postharvest treatments on the amount of sugars followed a proportional pattern to that of reducing sugars. The reduction in the amount of sugar was faster in open-air stored fruits, which declined from 6.4 g 100 g^{-1} FW on the 4th day to 1.5 g 100 g^{-1} FW on the 16th day of storage. This could be due to rapid ripening as compared to the other treatments, fruits stored in polyethylene bag in combination with $KMnO_4$ showed delayed decline in sugar content which could be related to delay in ripening as $KMnO_4$ reacts with ethylene and limit its catalytic role on respiration (Shaun and Ferris, 1997). The observed delay in reduction of sugar content of 1-MCP treated fruits could also be because of the effect of 1-MCP on ethylene action (Sisler and Blankenship, 1996). Perforated polyethylene packaging after treatment with 1-MCP showed further delay in ripening process as observed in the amount of sugar of the fruits.

The explanation for this could be the inhibitory action of ethylene by 1-MCP (Mattheis et al., 2003), reduced ethylene production under modified atmosphere packaging (Scott and Roberts, 1966) and removal of ethylene by ventilation (Fresh, 2001).

Titratable acidity

There was highly significant ($P \leq 0.001$) difference in the titratable acidity (TA) content of banana fruits receiving different postharvest treatments throughout the storage period (Table 5). In all of the treatments, the amount of TA increased as ripening progressed, being 0.30 g 100 g^{-1} FW on the first date of storage and reaching 0.54 to 0.58 g 100 g^{-1} FW at their peak, and a slightly declined towards the end of the ripening stage. The pattern of increase and fall after reaching peak contents was similar to that of total and reducing sugars as well as other parameters presented earlier. This could be associated to ripening stages of the fruits which were influenced by the storage treatments. The TA content of fruits stored in an open air started to decline on the 16th day of storage after it reached its peak on the 12th day. Fruits stored in banana leaf, teff straw, non-perforated and perforated polyethylene bag, non-perforated polyethylene bag in combination with $KMnO_4$ all declined in their titratable acidity contents on day 20 after reaching their peaks on the 16th day. Fruits placed in perforated polyethylene bag in combination with $KMnO_4$ showed a decline in their titratable acidity on the 24th storage date while the 1-MCP treated fruits, except those placed in perforated polyethylene bag showed decline on the 28th day of storage. In the later treatment, TA content of fruits was still increasing on the last day of storage. This result is in agreement with observations by Siriboon and Banlusilp (2004) who reported that TA increased to its peak, which coincided with the accumulation of ethylene and ripening, then started to decline afterwards.

Hernandez et al. (2006) also reported the amount of TA at; unripe, half ripe and ripe maturity stages were 0.30, 0.57 and 0.45 g 100 g^{-1}FW, respectively. This range is similar to the present observation, but with a slight difference to that of Dadzie and Orchard (1997), which could be due to cultivar difference.

Ascorbic acid

A significant ($P \leq 0.001$) difference was observed in the ascorbic acid (AA) content of banana fruits receiving different postharvest treatments (Table 5). Fruits which were placed in open air showed a faster decrease in AA

Table 5. The effect of postharvest treatments on titrable acidity and ascorbic acid (g 100 g^{-1} FW) content of banana fruit during storage period of 28 days at Haramaya University.

Treatment	Titratable acidity							Ascorbic acid						
	Storage period (day)							Storage period (day)						
	4	8	12	16	20	24	28	4	8	12	16	20	24	28
Open air	0.46^{a}	0.51^{a}	0.58^{a}	0.45^{h}	_	_		12.8^{b}	12.7^{c}	8.5^{d}	7.0^{e}	_	_	_
Banana leaf	0.37^{b}	0.47^{b}	0.56^{b}	0.57^{a}	0.46^{e}	_	_	12.9^{b}	12.8^{c}	8.8^{d}	8.0^{de}	6.7^{b}	_	_
NP	0.35^{c}	0.46^{c}	0.54^{c}	0.56^{b}	0.45^{g}	_	_	13.4^{a}	12.9^{cb}	10.4^{c}	8.5^{d}	6.9^{b}	_	_
PP	0.35^{d}	0.45^{d}	0.53^{d}	0.56^{b}	0.44^{i}	_	_	13.4^{a}	12.9^{cb}	10.5^{c}	8.7^{d}	6.9^{b}	_	_
NP+$KMnO_4$	0.33^{e}	0.44^{e}	0.51^{e}	0.54^{c}	0.46^{f}	_	_	13.4^{a}	13.1^{ab}	11.6^{b}	9.0^{d}	6.9^{b}	_	_
PP+$KMnO_4$	0.32^{f}	0.43^{f}	0.49^{f}	0.53^{d}	0.55^{a}	0.46^{c}	_	13.4^{a}	13.2^{a}	13.0^{a}	11.1^{c}	7.0^{b}	6.6^{c}	_
1-MCP+NP	0.307^{h}	0.41^{g}	0.46^{h}	0.53^{e}	0.54^{b}	0.57^{a}	0.47^{b}	13.4^{a}	13.3^{a}	13.1^{a}	11.6^{bc}	10.3^{a}	8.3^{b}	7.0^{b}
1-MCP+PP	0.306^{h}	0.40^{h}	0.45^{i}	0.50^{g}	0.53^{d}	0.54^{b}	0.57^{a}	13.5^{a}	13.3^{a}	13.1^{a}	13.1^{a}	10.5^{a}	9.3^{a}	8.2^{a}
1-MCP	0.313^{g}	0.41^{g}	0.47^{g}	0.52^{f}	0.53^{c}	0.57^{a}	0.46^{c}	13.4^{a}	13.3^{a}	13.1^{a}	12.7^{ab}	7.0^{b}	6.7^{c}	6.4^{c}
Teff straw	0.35^{c}	0.47^{b}	0.54^{c}	0.57a	0.45^{h}	_	_	13.2^{a}	12.8c	10.4^{c}	8.3^{de}	6.8^{b}	_	_
Significance	***	***	***	***	***	***	***	***	***	***	***	***	***	***
SE	0.0003	0.0003	0.0004	0.0005	0.0003	0.0005	0.0005	0.05	0.05	0.13	0.25	0.13	0.15	0.05
CV (%)	0.34	0.23	0.27	0.32	0.19	0.18	0.18	1.22	1.14	3.60	8.11	5.12	3.90	1.08

NP = Non-perforated polyethylene, PP = perforated polyethylene. Means within the same column followed by different letters are significantly different. $KMnO_4$ = Potassium permanganate; 1-MCP = 1-methylcyclopropene. ***, indicate significant difference at $P < 0.001$.

content than fruits kept in modified atmosphere storage or than those fruits treated with $KMnO_4$ or 1-MCP. Fruits nested in teff straw and banana leaf lost AA was faster than those packaged in polyethylene bags. Banana fruits placed in polyethylene bags in combination with the ethylene absorber, $KMnO_4$ showed about 9.0% decline in their AA content after the 12 days compared with 4 days of storage. After 20 days of storage, the AA content of fruits stored in PP bags in the presence or absence of $KMnO_4$ was not significantly ($P \leq 0.05$) different. The AA content of the fruits strongly correlates with the marketability (Table 6). In this case, both of them showed a decline with ripening, which is an indication of quality deterioration with senescence. The result of this study is in agreement with the report of Wenkam (1990) and Lee and Kader (2000) who indicated a decline in AA content banana fruits during ripening. The range of ascorbic acid which was 6.4 to 13.5 mg 100 g^{-1} FW also agree with the report of Leong and Shui (2002), USDA-ARS (2004), Hernandez et al. (2006) and Vanderslice and Higgs (1990) who reported vitamin C values of 2.1 to 18.7 mg 100 g^{-1} FW in Cavendish bananas.

The difference in the AA levels among fruits in the different treatments could be due to the effects of respective treatments on ripening as described for other parameters in the earlier sections.

CONCLUSION

Utilizing improved postharvest practices often results in reduced postharvest losses. The regulation of ripening is an extremely important factor in supplying the consumer with fruits of acceptable eating quality. The techniques used to delay and manage ripening includes: temperature control and relative humidity management, modified atmosphere packaging, ethylene removal, or inhibition of ethylene action through chemical means. This is achieved through the use of agents that absorb ethylene or block ethylene binding to its receptor. Preventing build up of ethylene around produce is among the methods in use to delay ripening of bananas. The shelf life and quality of bananas were observed to be improved when fruits were packaged in teff straw and banana leaf than kept in an open air. Banana fruits packaged in polyethylene bags and stored under ambient conditions were found to be better in terms of freshness as well as maintenance of

Table 6. Correlation of physical and chemical parameters of Dwarf Cavendish banana subjected to different postharvest treatments.

Parameter	1	2	3	6	7	9	11	12
1. Ascorbic acid								
2. Marketability	0.8**							
3. Reducing sugar	-0.8**	-0.8**						
6. Titratable acidity	-0.1	-0.1	0.6**					
7. Color	-0.8**	-0.9**	0.8**	0.03				
9. Total sugar	-0.8**	-0.7**	0.9**	0.6**	0.7**			
11.Total soluble solid	-0.7**	-0.7**	0.9**	0.6**	0.7**	0.9**		
12. Firmness	0.9**	0.9**	-0.8**	-0.1	-0.9**	-0.8**	-0.8**	
14. Weight loss	-0.9**	-0.8**	0.7**	-0.1	0.8**	0.7**	0.6**	-0.8**

*, ** indicate significance at $P < 0.05$ and 0.01, respectively.

chemical qualities during storage compared to the teff straw and banana leaf. The $KMnO_4$ treatment in combination with polyethylene packaging was also found to be better than polyethylene packaging alone in maintaining the quality of banana stored under ambient conditions. But, the 1-MCP treatment was found to be the best of all treatments in maintaining the chemical quality as well as extending shelf life during storage under ambient conditions, which was further improved by combining with perforated polyethylene bags.

The modified atmosphere created by perforated bags was observed to give better quality banana compared to atmosphere created by non-perforated polyethylene bags. Therefore, the result clearly showed that packaging film with relatively higher permeability to gases due to perforation after treatment with 1-MCP are preferred for maintaining normal respiration of banana without the occurrence of substantial loss in marketability and freshness quality.

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