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Modified Atmosphere Packaging Enhances the Effectiveness of Coolbot™ Cold Storage to Preserve Postharvest Quality of Mango Fruits

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Abstract

Recently, the Coolbot™ technology was introduced to smallholder farmers in Kenya as a low-cost alternative to conventional cold rooms. The present study sought to establish the additive benefits of cold storage under Coolbot™ cold storage and modified atmosphere packaging (MAP) in mango fruits. The participatory study was conducted in Makueni County of Kenya between November 2014 and July 2015. The mango fruits (variety 'Apple mango') were harvested at mature green stage from commercial orchards owned by smallholder farmers. The fruits were selected for uniformity and randomly separated into four batches which were subjected to four different treatments (storage conditions). The treatments included fruits packaged using Activebag® MAP or not packaged and either stored in the Coolbot cold room or at ambient room conditions. A random sample was taken at regular intervals from each of the four storage environments and evaluated for ripening and quality related changes during storage. The parameters evaluated included physiological weight loss, respiration, firmness, color, sugars and vitamin C. Results showed that cold storage extended the shelf life of mango fruits by 23 days without MAP and 28 days with MAP, in comparison to storage at ambient room conditions. Slow ripening under cold storage (with and without MAP) was evidenced by lower rates of respiration, softening, color changes and sugars accumulation compared to ambient room conditions. In addition, cold-stored mango fruits maintained better nutritional quality as evidenced by higher vitamin C levels, 59.77 mg/100mL and 51.8 mg/100mL with and without MAP respectively at the end of storage (day 40 and 35). This was significantly higher ($p<0.05$) compared to 55.17 and 51.53 mg/100 mL vitamin C for MAP packed and unpacked fruits at the end of storage under ambient room conditions (day 12). The results demonstrate the additive benefit of MAP and cold storage to preserve postharvest quality and extend the shelf life of mango fruits.

Keywords: cold storage, Coolbot, MAP, post-harvest, shelf-life

1. Introduction

Proper temperature management is critical for postharvest quality preservation of perishable commodities such as mango. The rate of deterioration of perishable commodities is reported to increase two to three-fold with every 10 ℃ increase in temperature. Therefore storage of perishable produce at their lowest safe temperature (0 ℃ for temperate crops or 10-12 ℃ for chilling sensitive tropical crops) will increase storage life by lowering respiration rate, decreasing sensitivity to ethylene gas and reducing water loss. Storage of perishable commodities at temperatures above or below safe optimum levels, is a key contributor to postharvest losses because it hastens deteriorative processes (Edmunds et al. 2003; Irtwange 2006). For majority of smallholder farmers and traders in developing countries, the requisite infrastructure for cold chain management including standard refrigeration systems or conventional cold rooms is too expensive.

In the recent past there have been efforts to find and promote low-cost alternative cold/cool storage options for smallholder farmers. One of these low-cost cold storage technologies in the Coolbot™ technology. A typical Coolbot cold room is made up of three components namely an insulated room, an air-conditioner (AC) and the Coolbot gadget (https://www.storeitcold.com) and can be easily assembled on-farm (https://www.storeitcold.com/construction-guide). The Coolbot is an electronic gadget that overrides the AC's thermostat making it possible to attain temperatures lower that normal set temperatures for standard AC (18^0C). Unlike standard cold rooms which are equipped with a humidification system, a Coolbot cold room lacks this important detail. Pilot studies on Coolbot cold room storage showed that mango fruits were prone to wilting when stored directly in the Coolbot cold room. This is because the dry cold air blown around stored produce breaks the boundary layer around the produce thereby predisposing them to rapid water loss and consequent wilting (Ambuko et al. 2017).

Generally fresh fruits and vegetables contain high amounts of water (>80%) which predisposes them to wilting due to physiological water loss. Maintenance of an environment low vapor pressure deficit (VDP) around the stored produces) is important to prevent water loss and wilting. A low VPD can be achieved through modified atmosphere packaging (MAP). In addition MAP creates an environment of altered gaseous composition of higher CO_2 and lower O_2 concentration (Sabir et al., 2011; Gomes et al., 2012). This environment disfavors deteriorative processes such as respiration and ethylene production which require oxygen (Al-Ati and Hotchkiss, 2003). Transpiration water loss in harvested commodities is also associated with loss of water soluble vitamins including vitamin C (Valero and Serrano, 2010). Modified Atmosphere Packaging has been found to extend shelf life and preserve quality in various horticultural commodities including mangoes (Githiga et al. 2014). Previous studies have shown that combining cold storage with MAP creates a synergistic or additive effect that is superior to either technology applied independently. A study conducted by (Kelany et. al. 2010) on "Kent" mangoes showed that cold storage at 10^oC combined with MAP maintained quality and prolonged the shelf life (to 6 weeks) compared to cold storage alone where the shelf life was extended for only 2-3 weeks. The shelf life of mango fruits was extended up to 21 days using MAP compared to the shorter shelf life of 12 day for fruits not subjected to MAP as observed by Ramayya et al. (2012).

The objective of this study was to evaluate the effectiveness of cold storage under Coolbot cold room in combination with modified atmosphere packaging to preserve quality and extend the shelf life of mango fruits.

2. Materials and Methods

2.1 Experiment Setup and Materials

The study was conducted from November 2014 to July 2015 in Makueni County, a major mango producing region of Kenya. A popular mango fruit variety, 'Apple' was harvested from smallholder commercial farms at physiological maturity (101 days after bloom). Harvesting was done by handpicking during the early morning hours to minimize heat load on the fruits. The mango fruits were packed into crates lined with moistened newspaper to cushion them from mechanical damage and reduce field heat during transportation. The fruits were selected for uniformity, washed with 5% acetic acid to disinfect and left to air dry. Fruits were randomly separated into four similar batches which were subjected to four treatments (storage conditions). The treatments included Coolbot cold room preset at 10 ±2 ℃ or ambient room temperature conditions (24-35 ℃). For each of the two storage temperatures, the fruits were either packed with Activebag® MAP or left unpackaged.

During the storage period three fruits were randomly sampled from each treatment after every three days for the first 15 days and thereafter every five days, for measurement of ripening-related and quality changes until the end of marketable stage which was pre-determined.

The parameters including respiration rate, physiological weight loss, peel/pulp color, firmness changes, sugars and vitamin C were determined using standard protocols. Respiration rate was determined using gas chromatographs model (GC-9A, Shimadzu Corp., Kyoto, Japan). A digital weighing balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan) was used to determine physiological weight loss. Peel and pulp firmness were measured using a penetrometer (Model CR-100D, Sun Scientific Co. Ltd, Japan). Vitamin C was determined using the AOAC (1996) method. Sugars were determined using high performance liquid chromatography(HPLC) (Model LC-10AS, Shimadzu Corp., Kyoto, Japan) fitted with a refractive index (RI) detector.

The data was subjected to Analysis of Variance (ANOVA) using Genstat 15^{th} edition and the means were separated by Least Significant Difference (LSD) at P=0.05.

3. Results

3.1 Respiration Rate

Respiration rate increased gradually as the fruits ripened (Figure 1). In fruits stored at ambient room conditions, the respiration peak was higher (53.9 mL/Kg/Hr) and appeared earlier (day 9) compared to cold-stored fruits which had a smaller respiration peak (52.6 mL/Kg/Hr) which appeared 16 days later. Combining cold storage with MAP significantly delayed and reduced the peak (47.1 mL/Kg/Hr) which was observed on day 30.

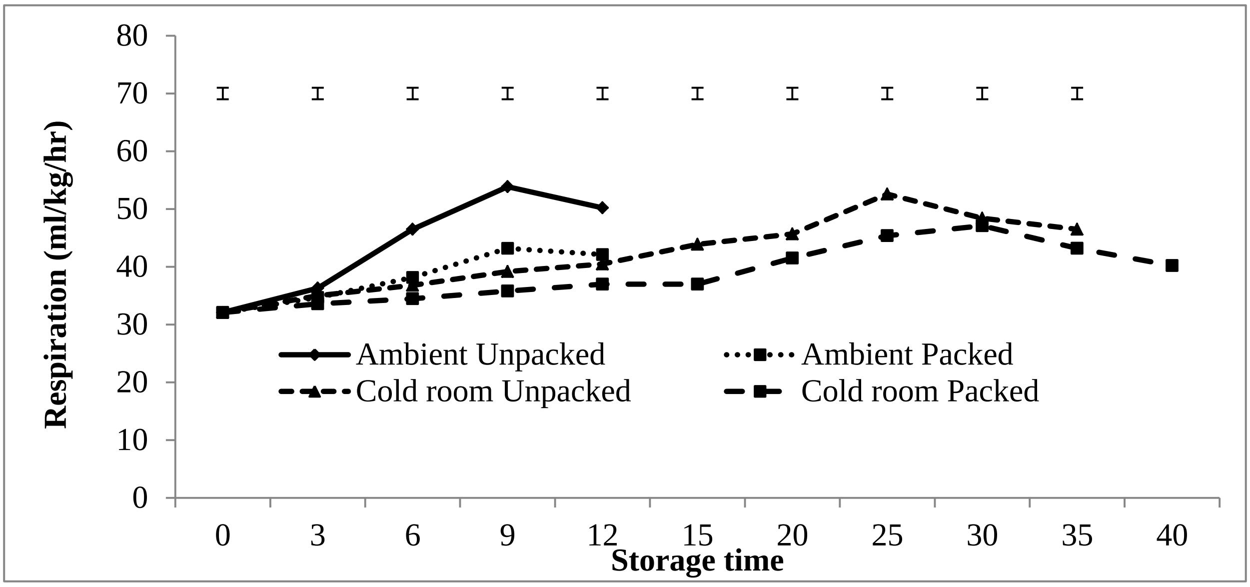

Figure 1. Respiration patterns of ‘Apple’ mango variety stored in the Coolbot cold room or at ambient room conditions with (packed) or without (unpacked) Active bags® MAP. Top bars represent least significant difference (LSD) of the means (p=0.05)

3.2 Physiological Weight Loss

Weight loss increased gradually with storage time and as ripening progressed. Fruits stored at ambient room conditions lost significantly ($p<0.05$) more weight compared to cold-stored fruits (Figure 2). Packaging significantly ($p<0.05$) reduced weight loss. Fruits stored at ambient room conditions lost 6.39% of their initial weight by the end of storage period (day 12) compared to the 5.93% (day 35) for fruits stored in the Coolbot™ cold room. An additive effect was observed in weight loss reduction where only 4.19% of the initial weight was lost in packaged fruits under cold storage.

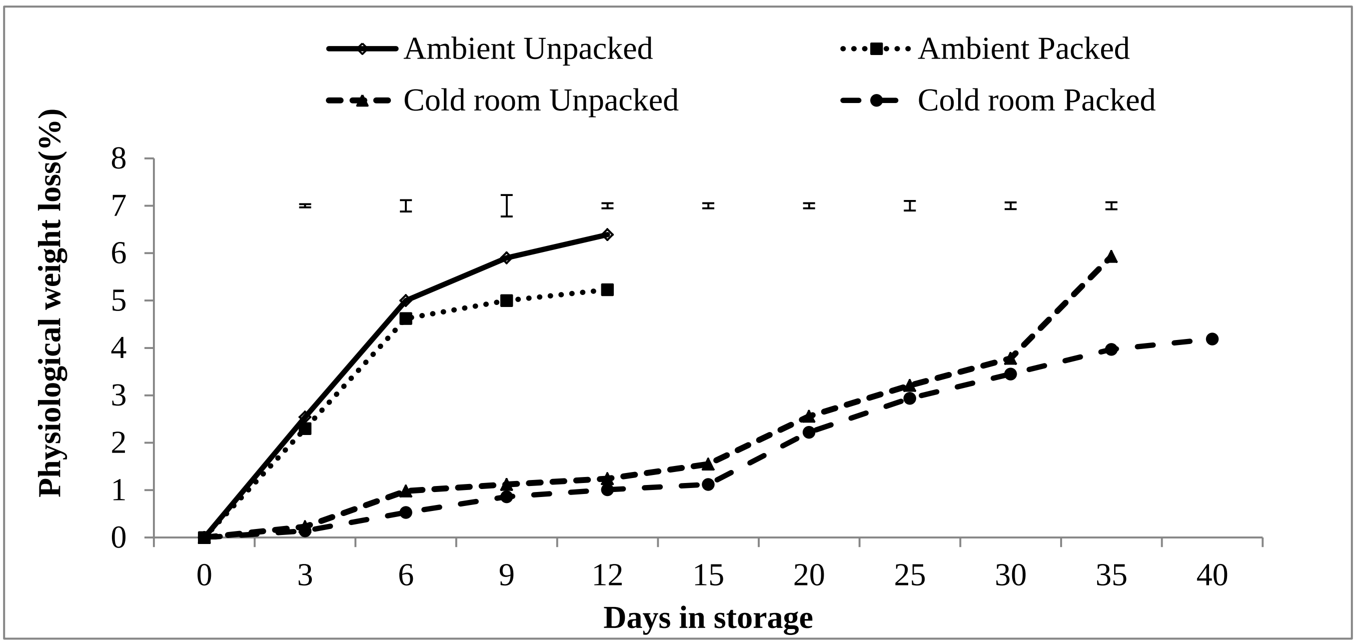

Figure 2. Physiological weight loss (%) of ‘Apple’ mango variety stored in the Coolbot cold room and at ambient room conditions with (packed) or without (unpacked) Active bags® MAP. Top bars represent LSD of means ($p<0.05$)

3.3 Peel and Flesh Firmness

As ripening progressed peel and flesh firmness reduced leading to softening in all fruits (Figure 3 and 4). Cold storage and MAP significantly (p<0.05) slowed down the rate of softening. For fruits stored at ambient room conditions, peel and flesh firmness reduced from 56.8N to 28.1N and 40.9N to 17.6N by the end of marketable quality (day 12). Cold stored fruits softened at a slower rate with peel and flesh firmness at 49.23N and 33.7N respectively on day 12. Where cold storage was combined with MAP softening was significantly slowed with peel and flesh firmness retained at 40.6N and 30.5N respectively by the end of storage period (day 40).

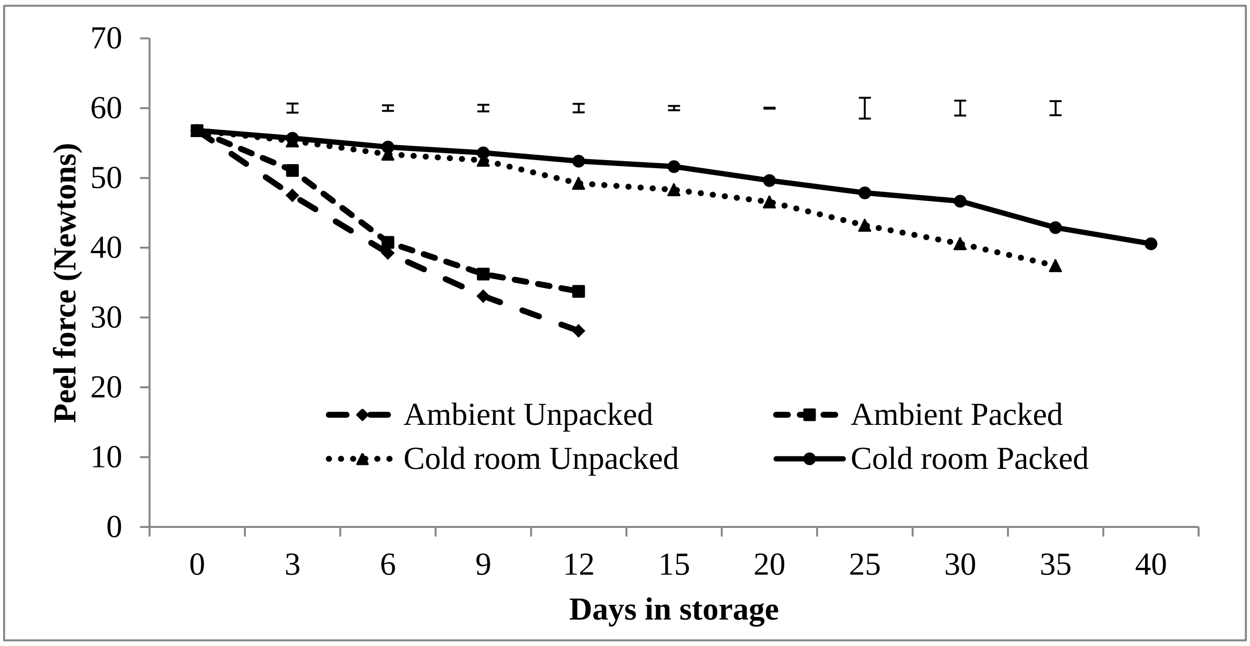

Figure 3. Change in peel firmness in 'Apple' mango variety stored either in the Coolbot cold room or at ambient room conditions with (packed) or without (unpacked) Active bags® MAP. Top bars represent least significant difference (LSD) of the means (p=0.05)

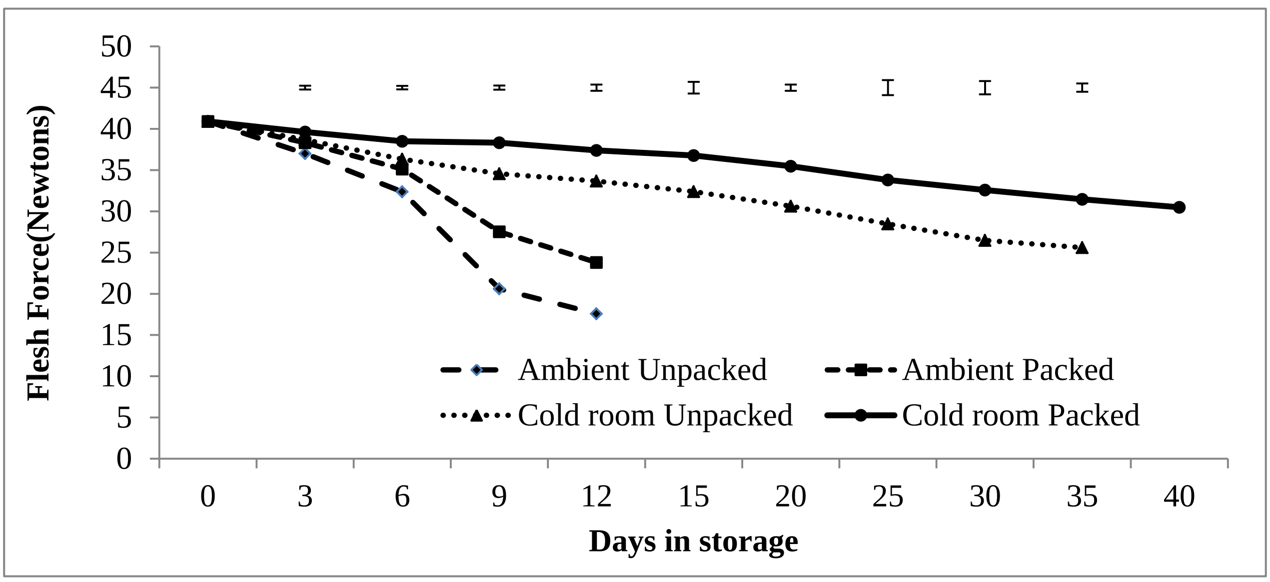

Figure 4. Change in flesh firmness in 'Apple' mango variety stored either in the Coolbot cold room or at ambient room conditions with (packed) or without (unpacked) Active bags® MAP. Top bars represent least significant difference (LSD) of the means (p=0.05)

3.4 Flesh Color (Hue Angle)

Flesh colour reduced as ripening progressed in all fruits irrespective of the treatment. Cold-stored fruits retained significantly ($p<0.05$) higher hue angle throughout storage (Figure 5). In fruits stored at ambient room conditions hue angles reduced from 91.5° to 58.53° by the end of storage (day 12) compared to 79.57° for fruits stored in the cold room 23 days later. MA packaging enhanced shelf life and slowed reduced the rate of colour changes.

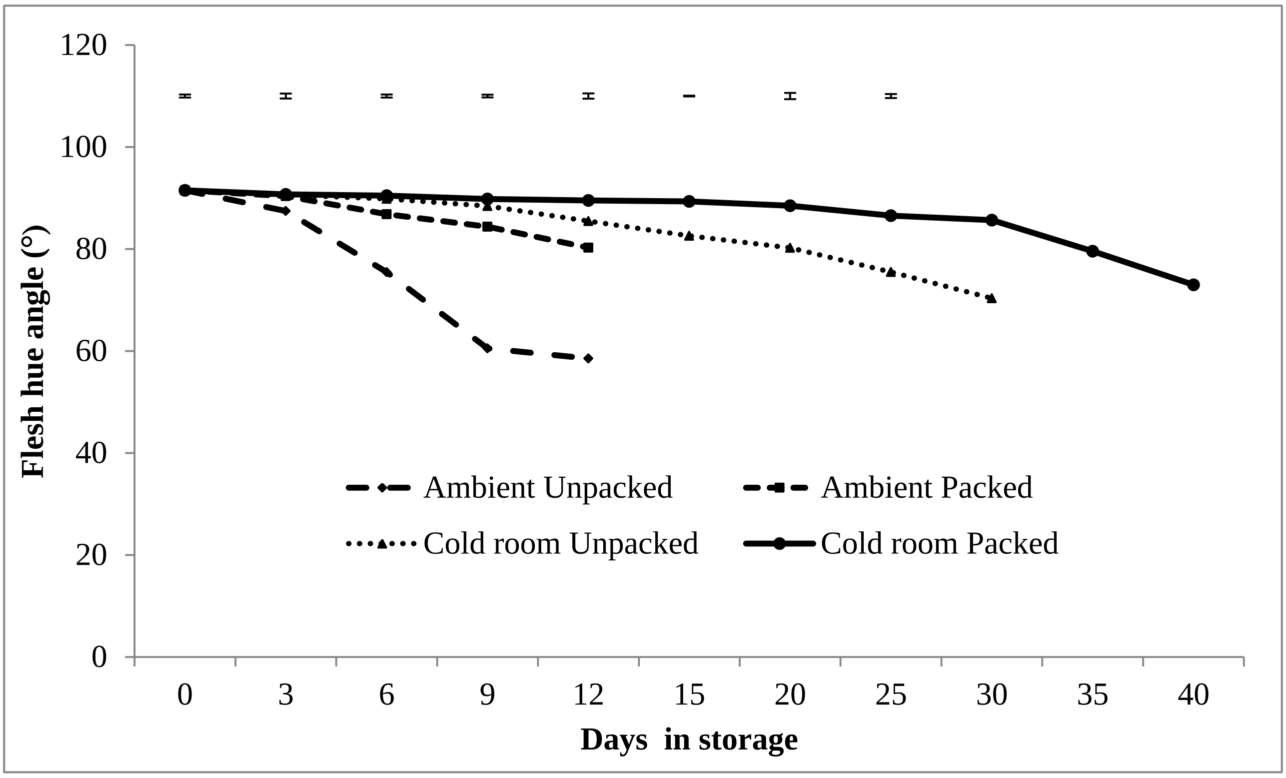

Figure 5. Change in flesh hue angle of 'Apple' mango variety stored either in the Coolbot cold room or at ambient room conditions with (packed) or without (unpacked) Active bags® MAP. Top bars represent least significant difference (LSD) of the means ($p=0.05$)

3.5 Changes in Vitamin C Content

Vitamin C content significantly decreased with ripening and storage time but the loss rate was slowed down by cold storage (Figure 6). Vitamin C levels decreased faster from the initial 110.70mg/100mL to 51.53 mg/100mL for fruits stored at ambient room conditions at the end of storage (day 12) compared to 51.8 mg/100mL (day 35) for cold- stored fruits. Cold- stored packed fruits retained as high as 59.8 mg/100mL vitamin C at the end of storage period which was 5 days later (day 40) after unpacked fruits had been discarded.

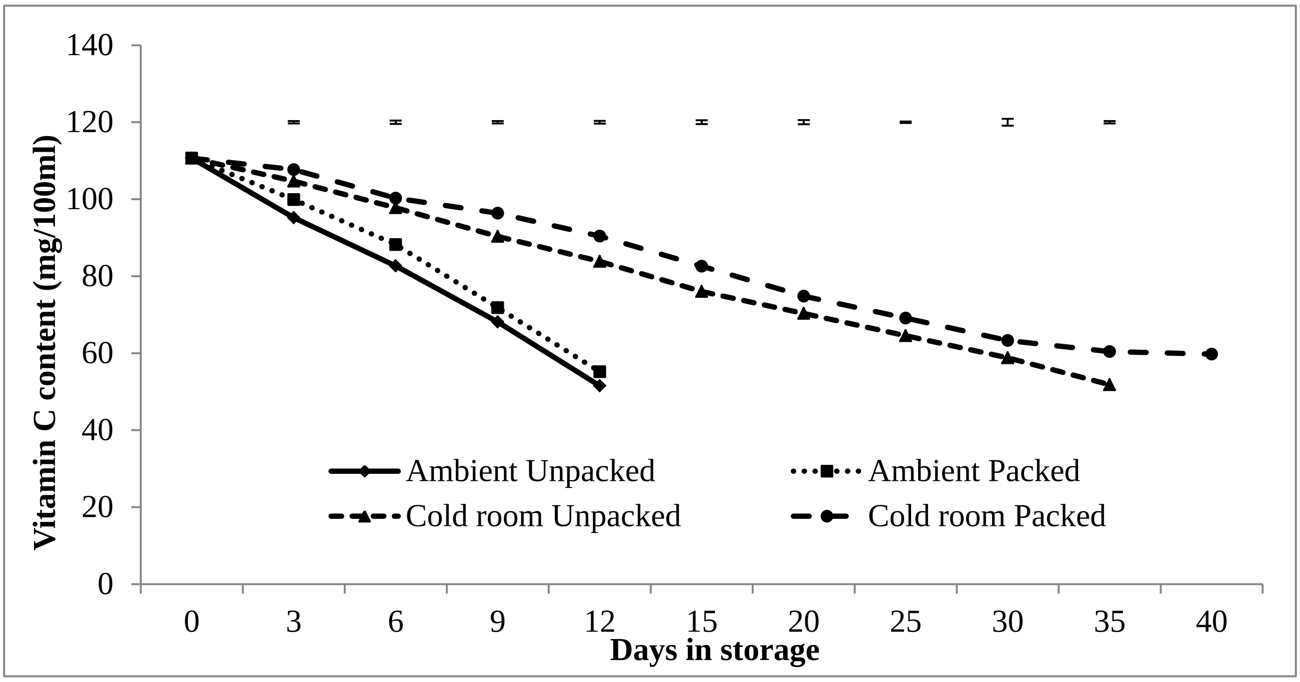

Figure 6. Vitamin C pattern in 'Apple' mango variety stored either in the cold room or at ambient room conditions with (packed) or without (unpacked) Active bags® MAP. Top bars represent least significant difference (LSD) of the means (p=0.05)

3.6 Changes in Soluble Sugars

Change in soluble sugars (glucose, sucrose and fructose) was slowed down by cold storage and MAP. Glucose content increased gradually as ripening progressed but was slowed by cold storage (Table 1). In fruits stored at ambient room conditions, glucose content increased from the initial 1.7 mg/100mL to 4.8 mg/100mL at the end of storage on day 12 compared to 4.9 mg/100mL in cold-stored fruits 23 days later.

Table 1. Change in glucose content (mg/100mL) in 'Apple' mango fruits stored either in the Coolbot cold room or at ambient room conditions with (packed) or without (unpacked) Active bags® MAP

Storage condition	Packing option	DAYS IN STORAGE										
		0	3	6	9	12	15	20	25	30	35	40
Ambient	Unpacked	1.7a	2.5a	3.1a	4.1a	4.8a						
Ambient	Packed	1.7a	2.4b	3.0a	4.1a	4.8a						
Cold room	Unpacked	1.7a	2.1c	2.5b	2.8b	3.2b	3.5a	3.7a	3.9a	4.3a	4.9a	
Cold room	Packed	1.7a	1.9d	2.3c	2.7b	3.1b	3.3b	3.5b	3.8a	4.1b	4.8b	4.8
	Mean	1.7	2.2	2.8	3.4	3.9	3.4	3.6	3.9	4.2	4.8	4.8
	LSD		0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.5	

Means within each column followed by different letters differ significantly at (p<0.05)

4. Discussion

Low temperatures (optimum for the commodity in storage) has been reported to slow down metabolic processes associated with ripening and senescence of fruits (Katsoulas et. al. 2001). On the other hand modified atmosphere packaging (MAP) results in altered gaseous composition and increased relative humidity around the packed produce which have been found to be effective in delaying ripening and deteriorative processes in fruits (Karaçay and Ayhan, 2009). This study was premised on the hypothesis that a combination of cold storage and MAP would have additive effect thereby resulting in better quality preservation and longer shelf life of mango fruits. This hypothesis was affirmed in the positive as evidenced by the results presented.

The rate of all the ripening-related changes including respiration, physiological weight loss, softening, color changes, ethylene evolution (results not presented) was significantly slowed down under cold storage and further when cold storage was combined with MAP. In addition, the results of this study confirm the importance of proper temperature management to realize the potential benefits of MAP. At ambient room conditions, there were no benefits of MAP on the packed mangoes. A break in the cold chain during postharvest handling of packaged fruits can result in negative effects. A rise in temperature leads to increased respiration which could deplete the in-pack oxygen below the recommended levels. If the oxygen levels fall far below the critical level for the product, anaerobic respiration sets in, resulting in off-flavours that render the product unmarketable (Good Fruit and Vegetables Magazine, 2011). It is reported that the rate of metabolic processes such as respiration increase 2 to 3 fold with every 10^0C increase in temperature (Kitinoja, 2013). This was confirmed in the present study as significantly higher respiration rate (1 - 2 fold) was reported in fruits stored at ambient room conditions compared to cold-stored fruits. Although respiration was also slowed down by MAP, its effect was more pronounced under cold storage. The role of MAP in lowering respiration rate is attributed to low O_2 levels in the package. Oxygen is essential for oxidative metabolic processes such as respiration and therefore storage conditions that curtail O_2 supply to the commodities disfavors such processes (Mohammed and Brecht, 2002). In most climacteric fruits, the rate of respiratory activity is known to be indicative of other ripening-related changes such as cumulative weight loss, color changes and softening.

The difference between the rate of physiological weight loss at ambient versus and cold storage was highly significant. At the end of storage at ambient room conditions, unpacked fruits had lost 6.5% of the initial weight compared to just 1% for packed and cold stored fruits - this is more than six fold difference. Modified atmosphere packaging creates a high relative humidity environment around the produce which results in a low vapor pressure deficit (VPD) thereby slowing down physiological water loss from the fruits. Cold storage in combination with MAP results in an additive effect on VPD further reducing water loss from stored produce.

The observed reduction in flesh and peel firmness could be attributed to reduced activity of enzymes involved in the degradation of the cell wall and breakdown of insoluble protopectins to more simple soluble pectins. Jarimopas and Kitthawee (2007) reported reduced activity of fruit softening enzymes including polygalacturonase, pectin methylesterase, pectatelyase and endo-β-1, 4-glucanase at low temperature. Colour change in mango fruits is attributed to breakdown of chlorophyll as new pigments (mainly carotenoids) are synthesized (Ueda, 2000). The delayed colour changes in cold-stored mango fruits could be attributed to the suppressed activity of enzymes involved chlorophyll breakdown and the synthesis of carotenoids due to low temperatures.

Reduction in vitamin C was slowed down under cold storage and even further when cold storage was combined with MAP which disfavors the oxidative destruction of vitamin C during storage (Appiah et al. 2011; Githiga et al. 2014). The slowed reduction in vitamin C also correlated with reduced physiological weight loss associated with transpirational water loss. Vitamin C is a water-soluble vitamin and its loss during storage is positively correlated with physiological water loss. Therefore measures aimed at reducing water loss (cold storage and MAP) also serve to slow down vitamin C loss (Ambuko et al, 2017).

The observed gradual increase in sugars (glucose, fructose and glucose) as ripening progressed is attributed to the breakdown of stored carbohydrates into simple sugars as fruits respire (Kundan et al. 2010). The significantly low sugar level in cold-stored packed fruits is attributed to the low rate of respiration at the low storage temperatures and MAP and reduced activity of the enzymes associated with breakdown of stored carbohydrates into simple sugars. Reduced accumulation of sugars under cold storage and MAP has been previously reported in other fruits including mangoes (Githiga et al. 2014) passion (Yumbya et al. 2014) and loquats (Amoros et al. 2008).

In conclusion, the results confirm the beneficial and additive effects of cold storage (using the Coolbot™ technology) and modified atmosphere packaging. The two technologies together resulted in a longer shelf (40 days) of mango fruits compared to 12 days under ambient room conditions with or without MAP. It is noteworthy that MAP at ambient room conditions resulted in no beneficial effects because the fruits were discarded at the same time as unpacked fruits (day 12). This reiterates the importance of cold storage and overall proper cold chain management to realize the benefits of MAP.

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