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Effect of Modified Atmosphere Packaging on the Shelf Life and Postharvest Quality of Purple Passion Fruit (*Passiflora edulis* Sims)

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Abstract

Passion fruit *(Passiflora edulis* Sims) being highly perishable is susceptible to rapid water loss after harvest leading to diminished quality. This study evaluated the efficacy of activebag® which is a new modified atmosphere packaging (MAP) product in the Kenyan market. Fruits harvested at 60-65 and 75-80 days after anthesis were either packaged in activebag® or ordinary polyethene bags and allowed to ripen under ambient room conditions. MAP maintained the quality of fruits harvested at both stages of maturity and prolonged their shelf life by at least 14 days compared to the unpackaged controls. Packaging significantly slowed weight loss, which was lower at 7% compared to the unpackaged controls that lost up to 26% of the weight. Both MAP packages reduced ethylene production and respiration rate and slowed other physicochemical changes associated with passion fruit ripening. Although the ordinary polythene bag packaging prolonged the fruits' shelf life compared to unpackaged control, their positive effect was negated by high incidence of rotting evident after 14 days of storage. These results indicate that use of activebag® can prolong the shelf life by maintaining quality attributes and external appearance of purple passion fruits and hence extend their marketing period.

INTRODUCTION

Water loss after harvest results in wilting and shriveling and is one of the major causes of postharvest losses in perishable produce. Water loss from the fruits not only leads to loss of saleable weight but also aggravates deterioration as it triggers stress ethylene production and reduces the aesthetic value of the fruits as they shrivel (Siddiqui and Dhua, 2009). Therefore, the use of appropriate postharvest technologies such as low temperature storage, controlled atmosphere storage and modified atmosphere packaging is critical in maintaining fresh fruit turgidity and quality during postharvest storage (Beaudry, 1999). However, the use of these technologies depends on several factors including efficacy and relative value of the commodity. Use of MAP is ideal for postharvest handling of fresh produce in developing countries since it does not require any sophisticated equipment and the level of gases do not need to be continually monitored and adjusted to maintain optimal

concentration. An equilibrium state is achieved depending on the commodity's respiration rate, storage temperature, and type of film used in respect to its thickness and permeability to oxygen, carbon dioxide and water vapor (Kader et al., 1999; Rahaman and Bishop, 2013).

Modified atmosphere packaging has been reported to delay physical, physiological, and biochemical changes associated with fruit ripening (Sandhya, 2010). The altered atmosphere retards physiological processes such as respiration and ethylene biosynthesis. MAP significantly reduces weight loss because the polymeric films used in MAP hinder water vapor diffusion and as a result, the internal atmosphere package becomes saturated with water vapor pressure. This condition reduces transpiration of the tissues and the resultant weight loss. Several studies show that changes in most of the physicochemical parameters associated with ripening such as total soluble solids, total titratable acidity, peel color, sugars and ascorbic acid are delayed in fruits under MAP conditions (Mathooko, 2003, Baraza, 2013).

Recently, widespread and commercial application of MAP has become possible because of the development of polyfilms, which can be lined with ethylene, oxygen and carbon dioxide absorbers and anti-microbial compounds to improve their efficacy. Activebag® is one of such newly developed MAP product by Polybag International limited (PBI), designed with unique characteristics suited for different commodities.

Purple passion fruit (*Passiflora edulis* Sims) has been grown in Kenya for many years due to the unique flavor of its juicy pulp, and still has great commercial potential since demand for both fresh fruit and processed juice is on the rise (HCDA, 2012). In 2011, passion fruit contributed about US$ 30 million of the domestic value of the fruit subsector in Kenya. However, one of the challenges in the passion fruit value chain is the short shelf life of the fruit, which leads to shriveling and wilting and contributes to postharvest losses estimated at up to 50% (HCDA, 2008). These postharvest losses are not only a waste of food, but they also represent a similar waste of human effort, farm inputs, investments, and scarce resources. There is little information available on the mitigation of these losses using cost effective technologies such as MAP, including the quality and storage behavior of passion fruit under these MAP conditions. Therefore, the objective of this study was to investigate the efficacy of activebag®, a specific MAP product on the shelf life and postharvest quality of purple passion fruits.

2. Materials and Methods
2.1. Materials

Purple passion fruits were harvested from a commercial farm in Moiben location, Uasin Gishu County. The orchard is located in a high potential area at altitude of 2100M above sea level. The total annual rainfall ranges between 1300-1600 mm with annual temperature of approximately $18^{o}C$. The experiment was conducted during the July-September 2011 period. The fruits were harvested at two stages of maturity based on the peel color and classified as stage 2 and 3 maturity stages. Stage 2 fruits were harvested at 60-65 Days after anthesis (DAA) with the peel colour at 50-75% purple in color while stage 3 fruits were harvested at 75-80 DAA with the peel color being full purple. The harvested fruits were packed in cushioned crates, covered with wet paper towels to prevent water loss, and immediately transported within 12 hours to the Postharvest laboratory, Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, Nairobi.

2.2. Sample preparation
The uniform fruits free from injury and blemish were cleaned, dried, and selected

for the study. Fruits in each maturity stage were randomly batched into three and packaged with either activebag®, ordinary bag or left unpackaged to act as the controls. All the fruits were left to undergo normal ripening at ambient room conditions. Six fruits from each treatment combination were randomly sampled for evaluation of percentage cumulative weight loss, rate of respiration and ethylene production. Three fruits were randomly sampled at 3-day interval for the determination of other ripening related physicochemical parameters including color, total soluble solids, total titratable acidity and quality attributes including soluble sugars, ascorbic acid, and beta carotene.

2.3. Analysis of physical and physiological parameters

Rate of respiration and ethylene production were determined using gas chromatographs (Models GC-8A and GC-9A, Shimadzu Corp., Kyoto, Japan fitted with thermal conductivity and flame ionization detector respectively). Cumulative weight loss was determined using a digital balance (Model Libror AEG-220, Shimadzu Corp. Kyoto, Japan). The color of peel was determined using a NF-333-Color spectrophotometer (Nippon Denshoku Industries, Japan). The data obtained were the CIELAB color coordinates system, L*, a* and b*; where L* represents the perceived lightness, a* and b* indicate the change in hue from red to green and from yellow to blue, respectively. The hue-angle (h°) were calculated using trigonometric calculation h°=tan-1(b*/a*) (CIE, 1986).

Total soluble solids (TSS) content was determined using a Digital refractometer (Model PAL-1, Atago, Tokyo, Japan) and expressed as °Brix. Total titratable acidity (TTA) was determined by titration with 0.1N NaOH in the presence of phenolphthalein indicator and expressed as

% citric acid, the predominant organic acid in passion fruit. Ascorbic acid was determined using the AOAC (1996). The β-carotene content was determined by modified chromatographic procedure (Heionen, 1990) using High Performance Liquid Chromatography (Model LC-10AS, Shimadzu Corp., Kyoto, Japan).
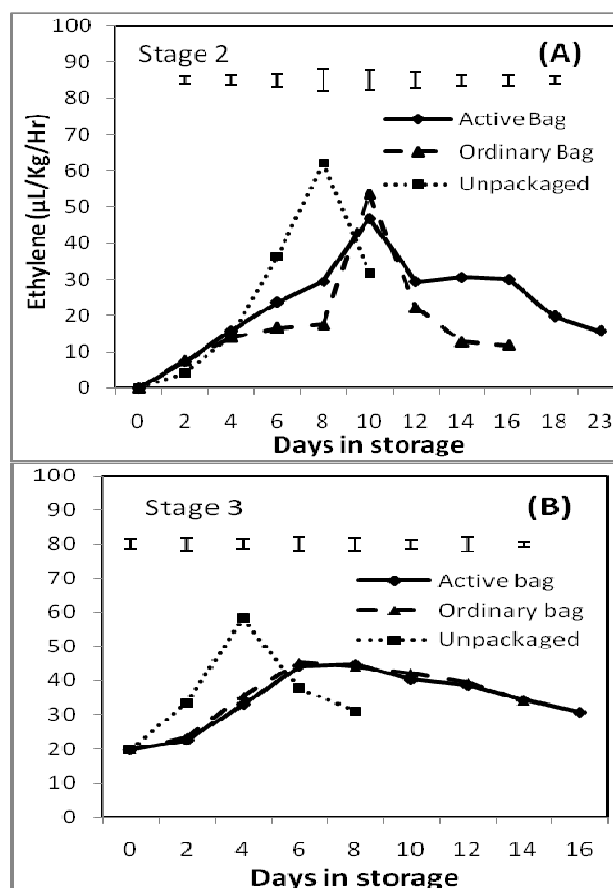

Figure1: Ethylene evolution patternof Purple passion fruit harvested at two stages of maturity; 50-75% (stage 2) and full purple (stage 3) and packaged in ordinary polythene bags or activebag® or left unpackaged (control). Top bars represent least significant difference (LSD) of the means (p=0.05).

2.4. Statistical Analysis

All the parameters were expressed as mean ± standard error, which were computed for sextuplicate determinations for weight loss, respiration, and ethylene parameter

and triplicate for the other parameters. Data were analyzed by analysis of variance, using statistical procedures Genstat statistical package 18 and means separated by Least Significant Difference (LSD) at P = 0.05.
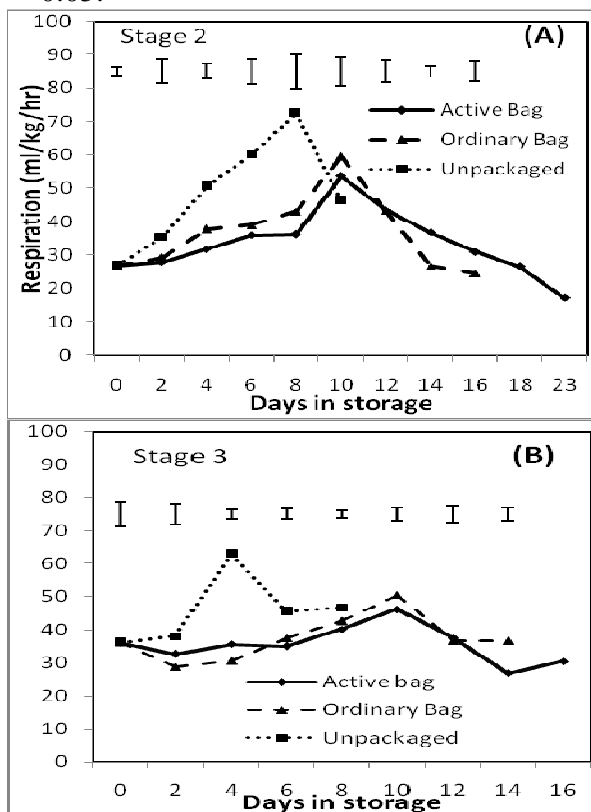

followed by a decline until the end of storage period. The end of storage occurred on the 10th day in unpackaged control which was 6 and 13 days earlier compared to fruits packaged in ordinary bag and activebag® respectively. Overall, unpackaged control produced relatively higher ethylene levels compared to the packaged fruits. The significantly reduced peaks (46 and 52µL/Kg/Hr) in activebag® and ordinary bag packaged fruits occurred 2 days later compared to the unpackaged control. Similarly, in fruits harvested at stage 3, both forms of MAP significantly reduced ethylene evolution rate throughout storage but no definite peaks were observed. However, in the unpackaged fruits, ethylene evolution followed the climacteric pattern increasing gradually to a peak level (58µL/Kg/Hr) on day 4 of storage and thereafter decreased until the end of storage.

Figure 2: Respiration pattern of Purple passion fruit harvested at two stages of maturity; 50-75% (stage 2) and full purple (stage 3) and packaged in ordinary polythene bags or activebag® or left unpackaged (control). Top bars represents least significant difference (LSD) of the means (p=0.05).

3. Results
3.1. Ethylene Evolution

The rate of ethylene evolution increased with ripening in all the fruits harvested at both stages of maturity. The packaged fruits exhibited significantly low rate of ethylene evolution throughout the storage period. In stage 2 fruits, ethylene evolution followed a pattern typical of climacteric fruits with a gradual rise up to a peak level
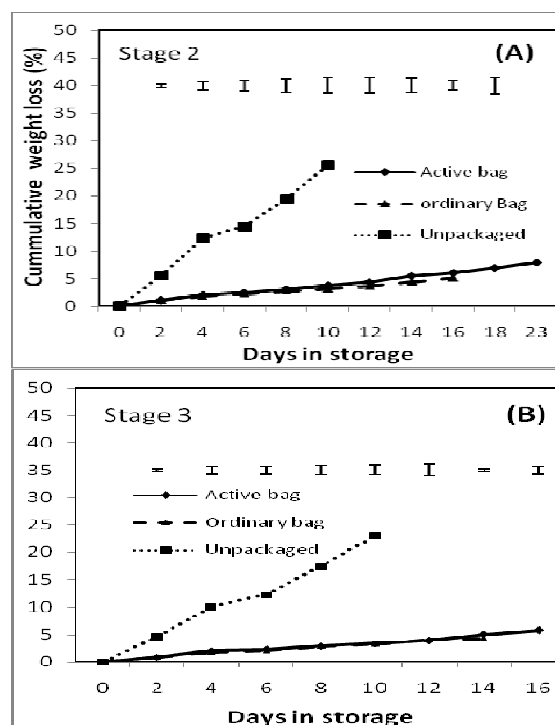

Figure 3: Changes in percentage cumulative weight loss of Purple passion fruit harvested at two stages of maturity; 50-75% (stage 2) and full purple (stage 3) and packaged in ordinary polythene bags

or activebag® or left unpackaged (control). Top bars represents least significant difference (LSD) of the means (p=0.05).

Figure 4: Changes in peel hue angle of Purple passion fruit harvested at two stages of maturity; 50-75% (stage 2) and full purple (stage 3) and packaged in ordinary polythene bags or activebag® or left unpackaged (control). Top bars represents least significant difference (LSD) of the means (p=0.05).
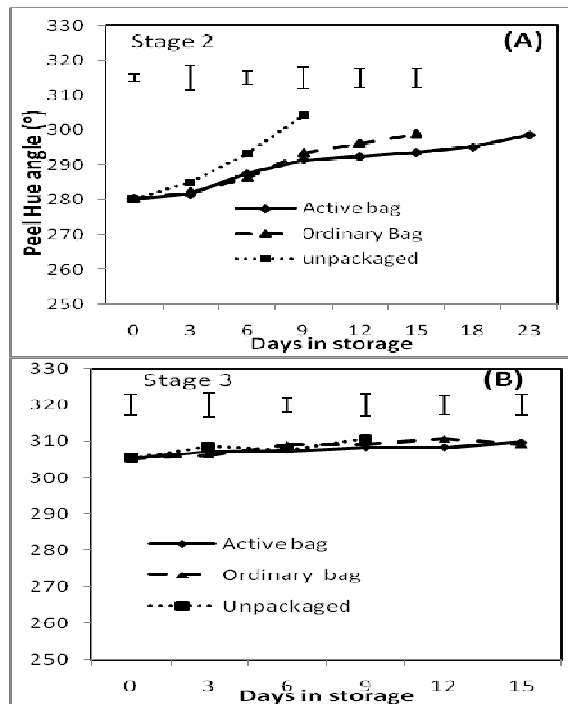
3.2. Respiration rate

In all the fruits, rate of respiration increased with storage time (Fig 2). Packaging (activebag® and ordinary bag) significantly (P< 0.05) reduced the rate of respiration in fruits harvested at both stages of maturity throughout storage. For fruits harvested at stage 3, the initial rate of respiration was higher (36ml/kg/hr) compared to that of stage 2 fruits (approximately 28ml/kg/hr). In stage 2 fruits, the delayed respiratory peak in packaged fruits was significantly smaller (53 and 59 ml/kg/hr) inactivebag®and

ordinary bag respectively compared to unpackaged control (72ml/kg/hr). In stage 3, the unpackaged fruits had significantly higher rate of respiration with the significantly larger respiratory peak (62ml/Kg/Hr) occurring on the 4th day of storage compared to the smaller peaks, 46ml/Kg/Hr and 50ml/Kg/Hr respectively for activebag® and ordinary bag. The respiratory peaks were observed 2 days later in the packaged fruits.
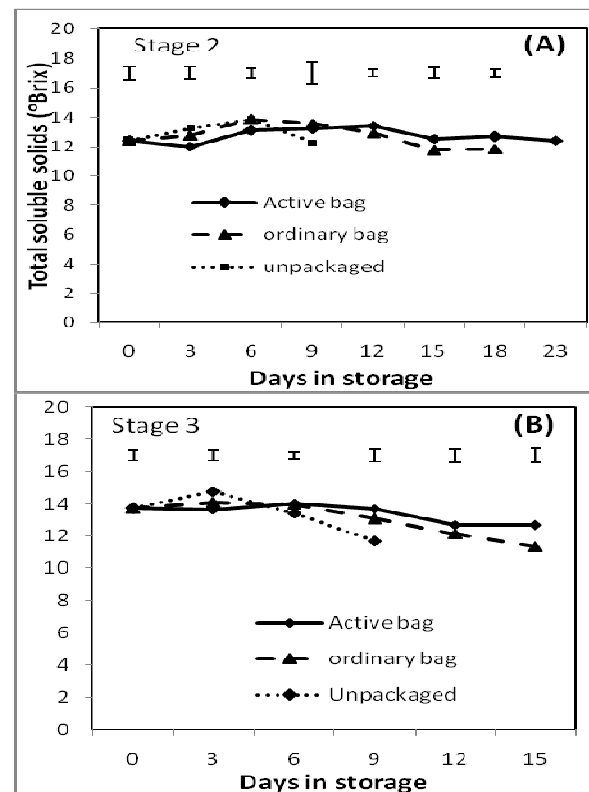

Figure 5: Changes in total soluble solids of Purple passion fruit harvested at two stages of maturity; 50-75% (stage 2) and full purple (stage 3) and packaged in ordinary polythene bags or activebag® or left unpackaged (control). Top bars represents least significant difference (LSD) of the means (p=0.05).

3.3. Percentage cumulative weight loss

As ripening progressed, all the fruits gradually lost weight (Fig. 3). For both stages of maturity, MAP (activebag®and ordinary bag) significantly slowed down

the rate of weight loss throughout the storage period. No significant difference was observed between the two forms of MAP which were both effective in slowing down rate of weight loss compared to the unpackaged control. In stage 2 fruits, the unpackaged control lost 26% of the initial weight at the end of storage (day 10) compared to 5.2 and 6.9% in fruits packaged with ordinary bag and activebag® 6 and 13 days later respectively. In fruits harvested at stage 3, the unpackaged fruits had lost 23% of the initial weight at the end of storage (day 8) compared to only 4.4% and 5.7% in ordinary bag and activebag® 6 and 8 days later respectively
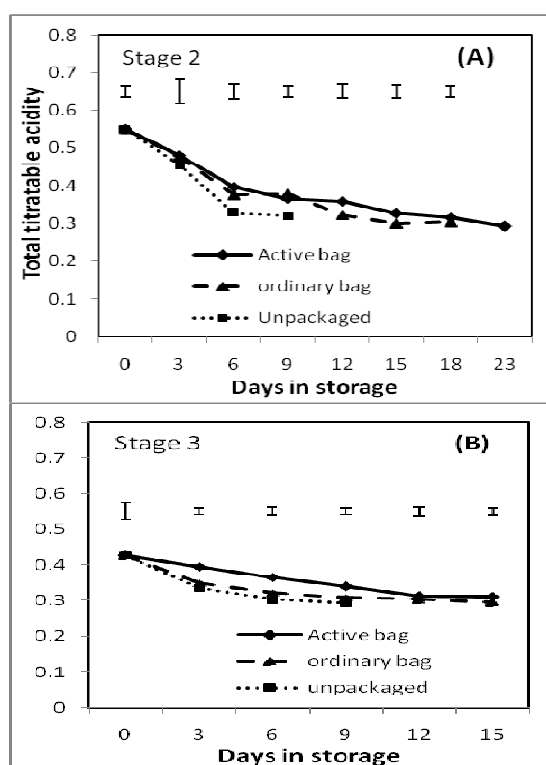

Figure 6: Changes in total titratable acidity of Purple passion fruit harvested at two stages of maturity; 50-75% (stage 2) and full purple (stage 3) and packaged in ordinary polythene bags

3.4. Peel color

Optical measurement is an attempt to express numerically that is seen by the human eye. Among the color attributes, hue describes a visual sensation according to which an area appears to be similar to one or proportions of two of the perceived colours, red, yellow, green, and blue and thus hue angle value is the actual perceived colour (JánosSchanda, 2007). Peel color measured by hue angle increased gradually with ripening in all the fruits as the color changed towards full or deeper purple (Fig. 4). Fruits harvested at stage 3 had significantly a higher initial hue angle (304°) which did not change much during storage, regardless of packaging or non-packaging. In stage 2 fruits, the initially lower hue angle (280°) increased gradually during storage, which increase was significantly slowed by MAP. At the end stage of unpackaged fruits (day 9) the hue angle was significantly (P=0.05) higher (304°) compared to the packaged fruits (298°) 6 and 14 days later in ordinary bag and activebag® respectively. For fruits harvested at stage 3, no significant packaging effect on peel color was observed throughout the storage period.

3.5. Total soluble solids (TSS)

Total soluble solids (TSS) increased gradually in all the fruits as ripening progressed (Fig. 7). Packaging significantly (P= 0.05) reduced the rate of increase of TSS in fruits harvested at both stage 2 and 3. In the unpackaged fruits (stage 2), TSS increased rapidly from an initial 12.4^o brix peaking to 13.9^o brix on day 6 of storage and declined gradually until the end of storage (day 9). MAP packaged fruits maintained significantly low TSS levels until the end of storage. Similarly in fruits harvested at stage 3 which had higher initial TSS levels (13.7^o) compared to stage 2 fruits, MAP packaging (activebag® and ordinary bag) significantly reduced the rate of increase in

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TSS. In the unpackaged fruits, TSS increased rapidly to a peak level (14.8°brix) by 3rd day of storage before declining gradually to 11.7°brix at the end of storage (day 9). Although the two forms of packaging did not differ significantly, at the end of storage, fruits packaged in activebag® had slightly higher TSS levels compared to the unpackaged controls.

3.6. Total titratable acidity (TTA)

Levels of TTA decreased gradually with storage time in fruits harvested at both stages of maturity (Fig.8). Fruits harvested at stage 3 had significantly low initial levels of TTA (0.43% citric acid) compared to that of stage 2 fruits (0.55% citric acid). The two forms of packaging (activebag® and ordinary bag) significantly slowed down decrease in TTA levels throughout storage. In stage 2 fruits, the decrease in TTA levels occurred more rapidly in the unpackaged fruits throughout storage. A significant packaging effect was observed as from the 6th day where the packaged fruits maintained relatively high levels of TTA. In stage 3, fruits packaged with activebag® retained significantly high levels of TTA throughout storage compared to the unpackaged control and ordinary bag packaged fruits. At the end of the storage period (day 9), unpackaged fruits had relatively lower levels of TTA(0.29% citric acid)compared to 0.31% and 0.29% citric acid of activebag® and ordinary bag respectively, 6 days later.

3.7. Ascorbic acid

Levels of ascorbic acid decreased gradually with ripening in both the packaged and unpackaged fruits (Fig. 7). Packaging had a significant effect on ascorbic acid reduction rate with the packaged fruits maintaining relatively higher levels of the vitamin throughout storage in both stages of maturity. In stage 2 fruits, decrease in ascorbic acid progressed rapidly in unpackaged fruits from an initial of 42.9 mg/100ml to 29 mg/100ml at the end of storage (day 9). On the other hand, packaged fruits (activebag® and ordinary bag) retained significantly high levels of ascorbic acid throughout the storage period. At the end of storage period on the 18th and 23rd day for ordinary and activebag® packaging respectively, the packaged fruits had relatively higher ascorbic acid levels, 30 mg/100ml respectively. Similarly, in fruits harvested at stage 3, ascorbic acid decreased rapidly from the initial 40mg/100ml to 27mg/100ml in unpackaged controls. The decrease in ascorbic acid progressed less rapidly in packaged fruits, which retained relatively higher ascorbic acid levels (28mg/100ml) even at the end of storage 6 and 14 days later compared to the unpackaged control.

3.8Beta-Carotene

Beta carotene levels increased gradually as the fruits ripened, regardless of the packaging or stage of maturity (Fig. 18). Packaging effectively slowed down the rate of increase in beta carotene. The increase in beta carotene levels was more rapid in the unpackaged fruits compared to the packaged ones, for both stages of maturity. In stage 2 fruits beta carotene levels increased rapidly in unpackaged fruits from an initial of 1.1 mg/100ml to 3.1mg/100ml at the end of storage (day 9). In packaged fruits, the increase was less rapid and at the end stage, day 15 and 23 respectively for ordinary bag and activebag®, the beta carotene levels were relatively higher.In stage 3 fruits a similar trend as in stage 2 fruits was observed. For unpackaged fruits, beta carotene levels increased rapidly from an initial of 2.1mg/100ml to 3.3g/100ml at the end of storage (day 9). Although the two forms of packaging significantly (P=0.05) slowed down the increase in beta carotene, activebag® was the most effective in

delaying increases in beta carotene throughout the storage period.

4. Discussion

The high CO_2, low O_2 and high relative humidity conditions created by MAP have been reported to lead to reduction of fruit weight loss, respiration rate, ethylene production and sensitivity, as well as retard changes related to the ripening process, thus maintaining postharvest fruit quality (Diaz-Mula et al., 2011). In the present study, the observed reduction in ethylene evolution rate in packaged fruits is attributed to the modified gas composition (high CO_2 and low O_2). According to Artés et al. (2006), low levels of O_2 are known to inhibit 1-aminocyclopropane-1-carboxylic acid oxidase (ACO), one of the key enzymes regulating ethylene biosynthesis. Similarly, high CO_2 levels have been reported to inhibit ethylene biosynthesis and consequently retard fruit ripening and deterioration in several commodities. Previous reports also show that low O_2 and elevated CO_2 reduce tissue sensitivity to ethylene and hence reduced ethylene effects in MAP packaged fruits (Valero and Serrano, 2010). The MAP-mediated effects on ethylene production and action observed in the present study concur with observations previously reported in other commodities such as plums (Diaz-Mula et al., 2011), tomato (Mathooko, 2003), mangos (Githiga, 2012). Of the two MAP packages used in the present study, activebag® packaging was most effective in slowing down the increase in ethylene evolution rate in fruits from both stages of maturity. This could be attributed to the lining of activebag® with ethylene absorbers which are reported to remove ethylene from the package.

The relatively low rate of respiration coupled with delayed respiratory peak of up to 2 days observed in packaged fruits can be associated with the altered gas composition inside the MAP packages; increased CO_2 levels and decreased O_2 concentration. The altered gas commotion may leads to suppress the activity of enzyme related to respiration in fruits of MAP, whereas the activity of enzyme responsible for degradation of reserved food is higher in control fruits (Koley et al., 2009). The activebag® package was more effective in slowing respiratory activity compared to the ordinary polythene. This could be attributed to the permeability characteristics of the polymeric film which in turn favored gaseous exchange with the surrounding environment thereby creating an equilibrium modified atmosphere favorable for the packaged fruits. Delayed respiratory activity following MAP packaging has been reported in several fruits including banana (Athapol et al., 1993) and mango (Githiga, 2012).

The unpackaged fruits lost more weight (approximately 26% of initial weight) compared to only up to 7% in packaged fruits. The significantly reduced weight loss by MA packaging is attributed to the increased relative humidity around the fruits, leading to reduced transpiration rates as the packages served as barriers to water movement from within the package (Batu et al., 1996). In addition, MAP may have contributed to the lower weight loss observed due to reduced respiration rates which translated into slower breakdown of stored carbohydrates reserves. The MAP mediated retardation of cumulative weight loss has been reported in several commodities including table grape (Martínez-Romero et al., 2003), mango (Githiga, 2012), broccoli (Serrano et al., 2006), and sweet cherry (Serrano et al., 2005). Fruits harvested at advanced maturity (stage 3) lost less weight compared to stage 2 fruits and this could be attributed to the well developed waxy layer on the surface of the fruits harvested at advanced maturity (stage 3) which

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reduced the rate of moisture loss (Sass and Lanker, 1998).

Peel hue angle increased as the fruits ripened, changes that were significantly slowed by MAP. Previous studies in mango (Pesis et al., 2002), loquat (Amoros et al., 2008) and table grapes (Martinez-Romero et al., 2003b) have shown that color evolution associated with the ripening process is delayed in fruits stored under MAP conditions. The change in peel color is associated with chlorophyll degradation by chlorophyllase enzyme and synthesis of color pigments such as anthocyanins, which are responsible for the purple color (Blankenship and Dole, 2003). The positive effect of MAP on peel color could be indicative of decreased metabolic processes responsible for both chlorophyll degradation and carotenoids synthesis or other processes that facilitate unmasking of preexisting color pigments (Mathooko, 2003).The delayed color change could also be due to a delay in anthocyanins and carotenoids biosynthesis, as well as reduced activities of metabolic processes involved in their biosynthesis as reported by Artes et al. (2006). MAP has been reported to maintain colour of fruit such as mangos (Pesis et al., 2000; Githiga, 2012), loquat (Amoros et al., 2008)and peaches (Artes, 1998).

The observed increase in total soluble solids (TSS) during ripening is associated with the breakdown of stored carbohydrates during respiration into simple sugars (Siddiqui and Dhua, 2010). In the unpackaged fruits, TSS levels increased rapidly to peak levels on the 3rd and 6th day of storage in stage 2 and 3 respectively. This can be correlated with the high rate of respiration observed which may have led to the breakdown of the stored carbohydrates to yield respiratory substrates necessary to maintain the metabolic activities (Saranwong et al., 2003). Packaging significantly delayed increase in TSS and this could be

attributed to the suppression of metabolic activities (Mathooko, 2003). MAP significantly retarded the characteristic decrease in TTA associated with passion fruit ripening. The decrease in TTA with ripening in all the treatments is attributed to organic acids being used as respiratory substrates. The MAP effect (delayed TTA decrease) can be attributed to the fact that packaging decreased fruit metabolism, and hence loss of respiratory substrates such as citric acid (Girardi et al., 2005). This delay in TTA reduction by MAP has been previously reported in other fruits including plums (Diaz Mula, 2011), loquats (Amoros et al., 2004), peaches and nectarine (Akbudak, 2004).

Generally, MAP extended the shelf life of fruits harvested at stage 2 by 6 and 14 days in ordinary bag and activebag® respectively compared to the unpackaged control. In stage 3 fruits, packaging (ordinary bag and activebag®) prolonged the shelf life by 6 days compared to the unpackaged control. Activebag® packaging was most effective in fruits harvested at stage 2 as it prolonged the shelf life by 8 days longer compared to ordinary packaging. This advantage of the activebag® over the ordinary polythene bag could be attributed to better permeability characteristics of the former that may have better matched the passion fruit physiological characteristics. Additionally, according to the manufacturers, activebag® polymeric films are also lined with ethylene absorbers and antimicrobials compounds giving it an edge over the ordinary polythene, hence the better results observed.

Ascorbic acid levels decreased gradually in all the fruits with increase in storage time. The decrease in vitamin C was less rapid in the packaged fruits compared to the unpackaged controls. The decrease in the vitamin during ripening is partly due to degradation of ascorbic acid through

oxidation (Appiah et al., 2011). Higher retention of ascorbic acid observed in the packaged fruits may be as a result of reduced enzymatic oxidation at low O_2 and high CO_2 composition. In addition, being a water soluble vitamin, previous studies have shown that the loss in vitamin C correlated positively with that of water loss through transpiration (Valero and Serrano, 2010; Siddiqui et al., 2011). In this study, the cumulative weight loss was more rapid in unpackaged fruits and positively correlated with loss of vitamin C. Similar results have been reported in papaya (Sing and Rao, 2005) and mango (Githiga, 2012), which maintained high levels of ascorbic acid under MAP condition compared to the unpackaged control. The lower levels of beta carotene observed in the packaged fruits can be attributed to the slower progression of ripening compared to the unpackaged where higher beta carotene levels were observed. MAP interfering with the enzymes involved in the carotenoid biosynthetic pathway can explain this packaging effect (Artes et al., 2006).

5. Conclusion

 MAP was effective in prolonging shelf life of passion fruit while maintaining postharvest qualities. Although there is widespread use of MAP in perishable commodities especially by retail traders, the use is mainly limited to ordinary polyethene bags with very high incidences of rotting due to low permeability. Therefore, the use of activebag® is an ideal alternative product that is ideal in extending the marketing period of purple passion fruit by maintaining their quality attributes and external appearance. Fruits harvested at stage 2 were able to maintain their quality attributes under activebag® packaging of up to 23 days and is thus ideal for fruits targeted for distant markets. Fruits harvested at stage 3 were able to had

good keeping quality of up to 16 days which is suitable for nearby markets.

5. Acknowledgement

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