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Modified Atmosphere Storage of Avocados: Effects on Storage life and Fruit Quality

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Abstract

Modified atmosphere packaging depleted in O_2 and enriched in CO_2 used in conjunction with refrigeration may provide an effective means of retarding deterioration, maintaining quality and extending the postharvest life of avocados. Mature preclimacteric avocados (cv. Fuerte) were packaged in a range of plastic films and stored at temperatures of 4, 7 and 10°C. The treated fruits along with the controls were ripened at 20±0.5°C and the relative humidity of 90-95%. Optimum storage duration, fruit injury and weight loss were determined during storage and ripening of fruits. In packs sealed with the micro-pores film MY-15, the O_2 concentration decreased to 4.0-6.5% and the CO_2 increased to 6.5-11.0% during storage. Fruits sealed in polyethylene packs were stored well up to 28 days at 4°C and 35 days at 7°C without chilling injury whereas the air stored fruits showed chilling injury after 21 and 28 days of storage at both temperatures, respectively. Modified atmosphere plays a significant role in retaining vitamin C, total sugars, oil, pH and flesh firmness of the fruit during storage. Modified atmospheres tended to cause an increase in the amount of palmitic and palmitoleic acids and decrease in the percentage of oleic, linoleic and linolenic acids. Among the tested films, low density polyethylene and micro-perforated film MY-15 and MD-15 were found to be suitable in extending the shelf life of avocados at low temperatures. Best results were obtained using micro-perforated film MY-15 and the fruits stored well for six weeks in modified atmospheric conditions with 4.8% O_2 + 8.4% CO_2 at 7°C. Commercial application of these packaging techniques would help to maintain the quality of avocados throughout the distribution and marketing chain.

Key words: Avocados, Fruit Quality, Micro-Perforation, Modified Atmosphere Storage, Shelf Life

Introduction

The avocado (*Persea americana* Mill.) belongs to the family *Lauraceae* and is one of the major fruit crops in the world. It is native to Central America but is grown in tropical and sub-tropical regions of the world. The demand for this fruit has increased recently as a result of (i) increased consumer awareness of the fruit's dietary value and uses (ii) improved fruit quality resulting from the implementation of maturity standards and improved storage and transportation facilities (Naiman and Hyman, 2007). The fruit has a markedly higher fat content than most other fruits, mostly mono-unsaturated fat. It is used as the base for the Mexican dip known as guacamole and also used in the preparation of chocolate syrup, ice-cream, milk-shakes and other dessert drinks. Avocados are mainly grown in the central high lands of Sri Lanka most often as seedlings growing among crop plants estates and in back gardens. Avocado is a favourite article of the diet in Sri Lanka and mainly consumed in the form of fresh fruit. There is immense potential to export avocado from Sri Lanka to UK and European markets, though limitations exist in technology and infrastructure.

Avocados are consumed only when ripened to the soft stage but they are picked and transported when the fruit is mature but still firm. The application of refrigeration is a method commonly used to increase the shelf life of fruits and vegetables. However, avocados and many other tropical fruits sustain physiological disturbances and chilling injury when exposed to low storage temperatures (Nagalingam, 1994). Under these circumstances, modified atmosphere (MA) packaging depleted in O_2 and enriched in CO_2 used either in conjunction with refrigeration or at ambient temperatures may provide an effective means of retarding deterioration, maintaining quality and extending the postharvest life of avocados. Therefore, a study was undertaken to investigate the application of modified atmosphere packaging to extend the shelf life of avocados without causing physiological disorders and decay. The work also describes the effect of modified atmosphere storage on the quality attributes of avocados.

Materials and Methods

Mature avocados (*Persea americana* cv. Fuerte) were obtained from a commercial horticultural grower in Kandy. Fruits were picked at optimum maturity and placed in card board boxes containing a single tray to hold 16-20 fruits. A range of packaging films were screened to identify the optimum degree of atmosphere modification to retard the ripening of avocados without affecting the quality. The tested film along with their gas and water vapour transmission rates are given in Table 1.

The modified atmosphere (MA) packs consisted of pre-formed bags test films. Each pack contained 290±10g of avocados giving similar ratio between weight of the fruits and the area of the permeable film and the volume of free space of 750 cm^3 within the MA packs. Fruits were placed in constant temperatures of 4, 7 and 10±0.5°C. The concentration of O_2 and CO_2 in MA packs from each holding temperatures were monitored daily. Packs from holding temperatures were removed from storage at weekly interval and ripened at 20±0.5°C and the relative humidity of 90-95%. Optimum storage duration at each holding temperatures was determined.

Table 1: Composition; thickness, gas permeabilities and water vapour transmission rates (WVTR) of packing films used

Film	Composition	Thickness (μ)	Gas permeability (cm^3/ m^2 day bar) O_2	CO_2	WVTR(g/ m^2 day)
A	Control- Perforated polyvinylchloride:SM60	15	Inf.	Inf.	
B	Polyolefin (BB4L)	60	20	31	1.0
C	Microporous poly propylene: MY-15	15	3500	8500	7.0
D	Low density polyethylene (LDPE)	40	5426	14240	4.0
E	Laminate of 20μ Nylon+ 60μ LDPE	85	64	224	1.6
F	Microporous poly propylene: MY-15	15	9500	31,000	24.0
G	Polypropylene-oriented	20	39	49	3.0
H	Microporous polupropylene:MD-15	15	7500	21000	19.0

Gas permeability rates were measured with Lyssy Manometric Gas Permeability Tester at 20°C

The Fruit injury was examined when they were ripe. In pack gas compositions were analyzed by Servomex instruments, infra red for CO_2 and magnetodynamic cell for O_2. Physico-chemical properties of the fruits packed in the films were evaluated at different ripening stages.

The vitamin C content was titrimetrically determined using 2,6-dichlorophenol indophenol dye. The total sugar content of the avocados was determined using the recommended AOAC (2006) method. The oil content was determined by Soxhlet extracting method. The pH was measured using a pH meter (model – Beckman SS-3) with glass electrode. The fatty acid composition was analyzed using Gas Liquid Chromatography. The flesh firmness measurement was carried out using Stevens Compression Response Analyzer. On each assessment day, the fruits were weighed and the weight loss during storage and ripening was determined.

The design for this experiment was a Completely Randomized Design (CRD). Data were examined by analysis of variance (ANOVA) using statistical analysis system (SAS) computer package and means were separated using Duncan's multiple range test (DMRT) at 95% confident level.

Results and Discussion

The equilibrium oxygen and carbon dioxide concentrations at 4, 7 and 10°C in the passive modified atmosphere packs of avocados sealed with each of the experimental films are shown in Table 2. On each day, the pattern of atmosphere development in packs of fruits from each storage regime was similar. The concentration of CO_2 increased and that of O_2 decreased during the first few days at all temperatures, the changes were more pronounced at 10°C than at 4°C. The pack atmosphere resulted a state of equilibrium after 3-4 days and little or no further changes in concentration of O_2 and CO_2 were detected (Figure 1). Similar pattern of atmosphere changes were observed by other workers with tomatoes (Geeson *et al.*, 1992), apple (Smith *et al.*, 1998) and other fruits and vegetables.

In control packs, the concentration of O_2 remained >20.0% and the CO_2 concentration <0.1% whereas in packs sealed with the micro-porous film MY-15, the O_2 concentration decreased to 4-6.5% and that of CO_2 increased to 6.5-11.0% during storage. In general, the highest concentrations of CO_2 and the lowest concentrations of O_2 were found in packs sealed with low permeable films. Fruits sealed with low permeable films such as polyolefin, polypropylene and a laminate of 20μ Nylon + 60μ low density polyethylene have been found to contain over modified atmosphere of 20-48% CO_2 and 0-3% O_2. These films are not sufficiently permeable for avocados and present a major problem in devising effective MA packaging system. The high respiration rate of avocado (156-162 ml CO_2 / Kg-hr at 10°C) together with low gas permeability of these packaging materials are responsible for the rapid depletion of O_2 and accumulation of CO_2 in MA packs. Fruits packaged in these films showed early signs of injury varied from small spots to brown discolouration in the rind and mesocarp.

Avocados packaged in low density polyethylene did not show over modification of in pack atmosphere and stored well for 28 days at 4°C without chilling injury whereas air stored fruits showed chilling injury symptoms after 21 days of storage at the same temperature. Scott and Chaplin (1998) reported that the avocados stored in polyethylene bags between 4-7°C for eight weeks showed no chilling injury whereas fruits stored in air were seriously affected by chilling.

Table 2: Fruit injury, weight loss and storage life of Fuerte avocados stored at 4º, 7º and 10ºC in MA packs for 4 weeks and softened in air at 20ºC

Film	Storage temperature (ºC)	Equilibrium gas concentration % O_2	% CO_2	*Fruit injury	Weight loss (%)	Storagelife(weeks)
A	4	20.8	0.3	1.4	5.02	3
	7	20.8	0.3	0.4	5.32	4
	10	20.8	0.3	-	-	3
B	4	1.0-1.4	38.1-39.5	2.8	3.56	1
	7	0.6-1.0	41.1-42.5	3.0	3.72	‹1
	10	0-0.8	44.2-48.0	3.0	4.10	‹1
C	4	5.6-6.2	6.5-7.5	0.2	4.50	5
	7	4.1-5.5	7.6-9.0	0	5.06	6
	10	4.0-5.1	8.8-11.0	0	6.40	4
D	4	8.0-8.8	4.8-5.6	0.4	4.12	4
	7	7.2-8.1	5.4-6.7	0	4.45	5
	10	6.0-6.9	6.3-7.7	0	6.22	4
E	4	2.2-3.0	20.6-21.4	2.2	3.84	1
	7	1.8-2.7	25.8-27.4	2.6	4.42	‹1
	10	0.8-2.0	29.7-31.9	2.8	5.21	‹1
F	4	16.2-17.6	2.0-2.8	1.2	4.80	3
	7	13.9-15.4	2.2-3.4	0.2	5.24	4
	10	12.2-14.8	2.8-4.2	-	-	3
G	4	1.8-2.6	22.0-23.6	2.4	3.62	1
	7	1.0-2.4	28.6-29.6	2.8	4.40	‹1
	10	0.4-1.6	31.0-33.8	3.0	5.10	‹1
H	4	9.7-11.2	3.8-4.6	0.4	4.74	4
	7	8.6-10.5	4.9-5.7	0	5.21	5
	10	7.2-8.7	5.9-7.0	0	6.80	4

*Fruit injury: 0-None; 1-Slight, ‹30% discoloured area; 2-Moderate, 31-70% discoloured area and 3-Severe, ›71% discoloured area.

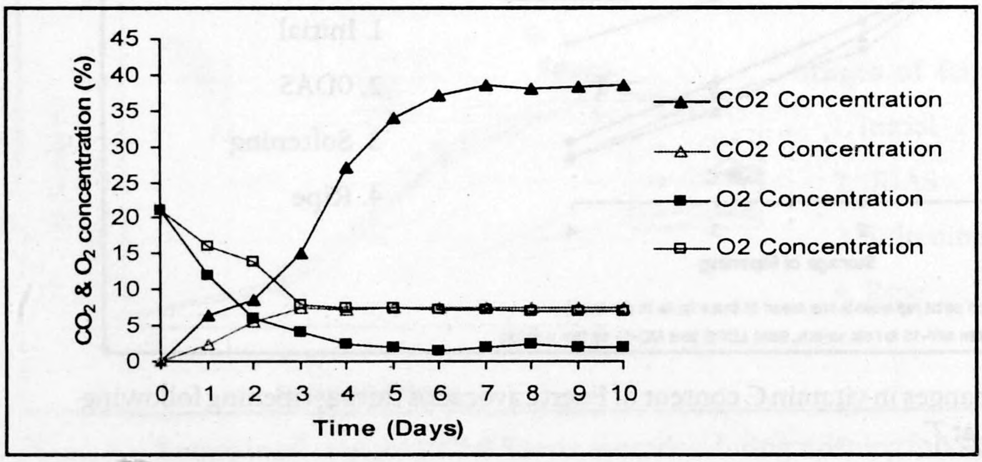

Figure 1: Changes in concentrations of O_2 and CO_2 within packs of avocados sealed with polyolefin -BB4L (solid) symbols and microporous MY-15 (hollow symbols) films at 4°C

Fruits stored in micro-porous film MY-15, an atmosphere containing 4.1-6.2% O_2 + 6.5-9.0% CO_2 developed at 4°C and 7°C and was more effective than any other combinations for reducing chilling injury. The fruits stored well upto five and six weeks at 4°C and 7°C, respectively and did not show any chilling injury symptoms. Reeder and Hatton (1994) reported that 'Lula' avocados were stored less than three weeks in air and eight weeks in controlled atmosphere of 2% O_2 + 10% CO_2 at 7°C. Among the film tested, low density polyethylene and micro perforated films MY-15 and MD-15 were found to be suitable for extending the postharvest life of avocados at low temperatures. Best results were achieved using micro-perforated film MY-15 and the fruits were stored well for 6 weeks in MA packs of 4.8% O_2 + 8.4% CO_2 at 7°C.

Vitamin C content of avocados was found to be affected by storage temperature, duration and atmospheric composition. The vitamin C content of control fruits falls during ripening at 20°C from 15.4 mg/100g in the unripe fruit to 14.1 mg/100g to the ripe pulp (Figure 2) due to oxidative deterioration of vitamin C. Wills and Tirmazi (1982) stated that the vitamin C content of ripening avocados (cv. Fuerte) dropped from 11.4 to 3.2 mg/100g in nine days at 20°C. In this study, all the samples showed loss of vitamin C during storage and ripening of avocados. There was no significant difference ($P>0.05$) in vitamin C content of MA stored ripe fruits upto optimum storage (six weeks in film MY-15 and five weeks in films LDPE and MD-15). However, avocados stored at 7°C for four weeks in MA of 4.8% O_2 + 8.4% CO_2 and air packs, followed by ripening at 20°C lost 11.7 and 15.6% of its vitamin C respectively. This may be due to increased oxygen concentration in air packs which accelerates the oxidative breakdown of vitamin C. This finding is in agreement with Saito *et al.*, (2000) that vitamin C content of carambola fruits held in an atmosphere containing 1-6% O_2 retained 45--55% of its original concentration whereas it was found to be adversely affected at ambient atmosphere.

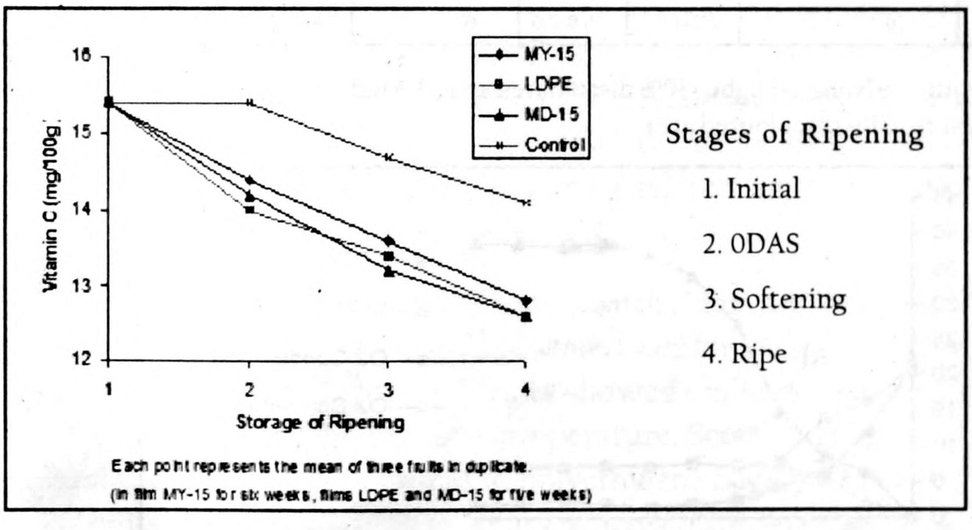

Figure 2: Changes in vitamin C content of Fuerte avocados during ripening following MA storage at 7°

There was a large drop in total sugar content of avocados during ripening. At harvest, total sugar content of the pulp was 2.69%. It decreased at a uniform rate throughout storage, reaching a minimum value at the edible ripe stage. Storage temperature, duration and atmospheric composition appeared to have great influence on sugar content of avocados. Storage at 10°C resulted in lower sugar content than storage at 4°C suggesting more sugar had been used as the substrate for energy metabolism at 10°C compared to 4°C. Comparable results were reported by Ahamed *et al.*, (2007) on sugar content during ripening of avocados.

Modified atmosphere did not produce any significant effect ($P>0.05$) on total sugar content of ripe avocados upto six weeks in film MY-15 and five weeks in films LDPE and MD-15. However, avocados kept in modified atmosphere had higher sugar content upon removal from the storage than those kept in air. Littlefield *et al.*, (1975) reported that sugar losses were smaller in apples and pears during storage at 1.7°C for six months in

2.5% O_2 + 1.5% CO_2 compared with the samples stored in air. In avocados, sugars are the major substrate for respiration and other metabolic processes during ripening. The higher content of sugars observed in avocados following MA storage is manly due to the reduced respiration rate under MA conditions.

The oil content of the fruit pulp was 14.3% at harvest. It increased during storage and ripening, reaching a maximum value of 20.1% at the edible ripe stage. Kikuta and Erickson (2007) demonstrated that there were slight increases in total lipid content during ripening of Fuerte avocados following storage at 5°C for 9 and 14 days. The oil content of MA stored avocados increased with the progressive ripening of the fruits (Figure 3). This could be due to synthesis of fatty substances during ripening. The present results confirm the previous findings of (Meir 1997). MA storage did not have any significant influence ($P>0.05$) in oil content of the ripe fruits and indicates that equilibrium gas concentrations in MA packs do not markedly affect the enzymes responsible for fat metabolism.

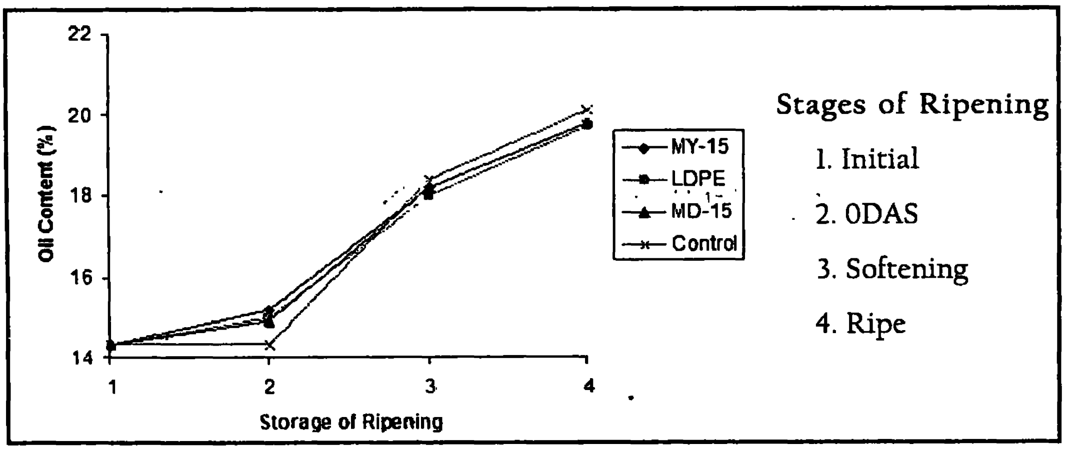

Figure 3: Changes in oil content (%) of Fuerte avocados during ripening following MA storage at 7°C

The reduction in pH of MA stored avocados was not significant ($P>0.05$) even though the pH of these fruits was lower than that of fruits held in air. The pH increased from 6.30 to 6.91, if the avocados were ripened immediately after harvest. This loss of acidity during ripening appears to result from the use of the acids as respiratory substrate via Tri Carboxylic Acid (TCA) cycle. When the fruits were placed in modified atmospheres, the pH decreased slowly below the initial level during storage and then increased with progressive ripening in air. Acidity in avocados is mainly due to their citric acid content. The initial increase in citric acid in the tissue during MA storage may result from incomplete utilization of acids in the TCA cycle (Goodenough and Thomas, 1981).

Nine fatty acids were identified in avocado oil using Gas Liquid Chromatography techniques (Table 3). The major saturated fatty acid is palmitic whereas the main unsaturated fatty acid is oleic in ripe avocados. The O_2 and CO_2 concentrations in MA packs influence the amount of fatty acids present in avocado mesocarp.

Table 3: Fatty acid profile (% of total fatty acids) of ripe avocados after modified atmosphere storage for 5 weeks at 7°C

Fatty acids	Control 21%O_2 + 0.03% CO_2	MY-15 4.8%O_2 + 8.4% CO_2	LDPE 7.7%O_2 + 5.8% CO_2	MD-15 9.0%O_2 + 5.4% CO_2
Saturated (SFA)				
Myristic $C_{14:0}$	0.06±0.01	0.07±0.01	0.04±0.01	0.04±0.01
Palmitic $C_{16:0}$	13.7±0.17	15.7±0.21	15.1±0.19	14.7±0.20
Stearic $C_{18:0}$	0.60±0.04	0.64±0.05	0.61±0.02	0.62±0.04
Arachidic $C_{20:0}$	0.17±0.02	0.24±0.02	0.21±0.01	0.18±0.02
Mono Unsaturated (UFA)				
Palmitoleic $C_{16:1}$	3.8±0.14	6.4±0.17	5.9±0.16	5.7±0.12
Oleic $C_{18:1}$	70.0±0.52	67.4±0.41	68.1±0.47	68.5±0.49
Poly Unsaturated (UFA)				
Linoleic $C_{18:2}$	10.4±0.24	8.5±0.21	8.9±0.24	9.1±0.20
Linolenic $C_{18:3}$	1.0±0.07	0.76±0.06	0.85±0.09	0.89±0.07
Arachidonic $C_{20:4}$	0.27±0.02	0.29±0.03	0.29±0.02	0.27±0.02
UFA / SFA ratio	5.88	5.01	5.27	5.44

Values are means of three fruits in duplicate.
Values in parentheses are standard error.

Modified atmospheres low in O_2 and high in CO_2 tended to cause an increase in the amount of palmitic and palmitoleic acids and decrease in the percentage of oleic, linoleic and linolenic acids. This may be due to bio-oxidation of C_{18} (oleic, linoleic and linolenic) fatty acids to C_{16} (palmitic and palmitoleic) fatty acids. Comparable results were reported by Mazliak (1991) in which, storage of avocados in an atmosphere of 1.5% O_2 + 5-6% CO_2 resulted in an increase in palmitic and palmitoleic acid contents whereas storage in atmospheres composed of 16.0% O_2 + 4.5% CO_2 resulted in higher amounts of oleic, linoleic and linolenic acids.

The firmness of avocados is greatly influenced by the storage temperature and duration. The maximum compression load tends to decrease gradually as storage time increased and declined markedly with the onset of ripening. The most pronounced losses in firmness occurred when the fruits were removed from the storage and allowed to ripen (Figure 4). Avocado fruit ripens only after harvest and shows a rapid transition from a hard to a soft flesh consistency. Decrease in firmness of avocados during ripening was due to lessening the mechanical strength of cell walls and weakening the bounding matrices of cellular tissue during ripening. This change is intimately related to activity of cell wall degrading enzymes viz. *cellulase* and *pectinase* (Pesis *et al.*, 1998). Flesh firmness decreased as ripening progressed in both MA stored and control fruits. Modified atmosphere appeared to have a significant effect ($P>0.05$) in retaining firmness of avocados during storage. Fruits stored in 4.8% O_2 + 8.4% CO_2 treatments remained firmer than fruits in other treatments. The greater retention of firmness in MA storage as compared to air storage was consistent with the previous findings on Fuerte (Gerdes and Parrino, 1993) and other cultivars (Chaplin and Hawson, 1981).

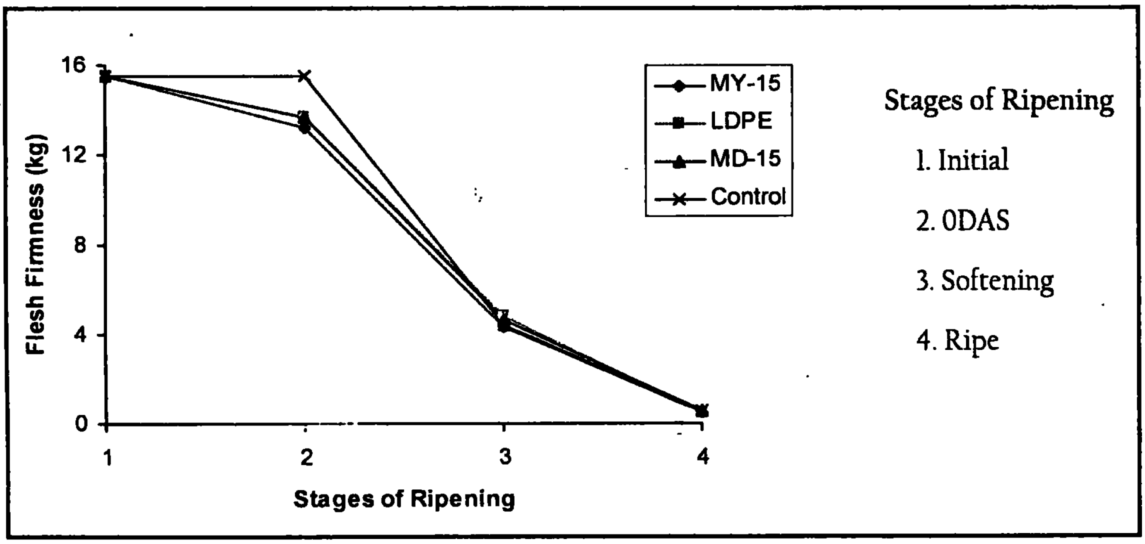

Figure 4: Changes in flesh firmness of Fuerte avocados during ripening following MA Storage at 7 °C

Each point represents the mean of three fruits in five determinations

(In filmMY-15 for six weeks, films LDPE and MD-15 for five weeks)

Fruits stored in MA packs with RH levels over 90% were firmer than fruits stored in air with only 70-80% of RH. Softening results from enzymatic dehydration of cell wall protopectin, mostly during ripening and senescence of the fruit. MA has a significant influence in retaining firmness of avocados during storage. This may be due to the reduced activity of cell wall degrading enzymes during MA storage.

The major factors limiting the storage of avocados at any of the temperatures used were the incidence and severity of chilling injury, over ripeness and the time required for fruit ripening at 20°C. Modified atmosphere packaging within the tolerance limits has been shown to be beneficial for avocado storage. The reduced level of O_2 and elevated level of CO_2 in the package suppresses respiration, thereby slowing down the ripening process. Therefore, the combination of refrigeration and modified atmosphere packaging produced a synergistic effect in terms of the shelf life extension of avocados.

Conclusion

The shorter shelf life of avocados has stimulated research to develop effective methods of extending storage life and preventing decay. Avocados are susceptible to chilling injury so that refrigeration cannot be used to full capacity but must be held close to 10°C at which aging, ripening and decay can soon cause destruction of stored fruits. Therefore, the use of modified atmosphere in combination with refrigeration further slow down the metabolic activities of fruits and thereby extend the storage life of fruits. This experiment indicated that the shelf life of avocados could be extended by six weeks by enclosing the fruits in the plastic films and storing it at 7°C. The quality attributes of the avocado fruits were maintained during storage and ripening. Commercial application of these packaging techniques would help to maintain the quality of avocados throughout the distribution and marketing chain.

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