Effect of Film Thickness on Postharvest Ripening and Quality Characteristics of Tomato *(Lycopersicon esculentum* L.) Fruit Under Modified Atmosphere Packaging

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ABSTRACT

Two different gauges, (0.04mm and 0.08mm) of low density polyethylene (LDPE) films were tested for their effectiveness in controlling ripening and quality of tomato *(Lycopersicon esculentum* L. cv. Cal J) fruit during modified atmosphere packaging (MAP) under ambient conditions of 60 to 65% relative humidity and 26 ± 1°C. Control fruits were stored under similar ambient conditions. Fruits stored in polymeric bags remained green for the 12 days of the experiment and had lower percent weight loss compared to the control fruit. Film thickness had a significant effect ($p<0.05$) on degradation of chlorophyll, physical colour development, synthesis of lycopene and modified atmosphere development while it had little effect on weight loss and extent of fruit spoilage. Carbon dioxide concentration in the 0.08mm LDPE bags was twice that in 0.04mm bags while oxygen concentration was lower in the 0.08mm bags. MAP delayed the increase in ascorbic acid that is associated with ripening. Fruits in 0.08mm bags had slightly lower ascorbic acid content and total titratable acidity (TTA) than those in the 0.04mm bags. MAP itself had no effect on total solids content. Upon transfer to normal atmosphere, fruits previou' ly held in MAP ripened normally with the changes for fruits previously in 0.08mm bags being slower. These results indicate that when all other parameters are held constant, a thicker film is more effective in retarding ripening processes and extending fruit shelf life, thereby facilitating handling and reducing waste.

KEY WORDS: Low density polyethylene, *Lycopersicon esculentum* L., Modified atmosphere packaging, Tomato fruit.

1.0 INTRODUCTION

Tomato fruits are one of the major crops involved in rural-urban trade in Kenya, and are among the most perishable during retail marketing. The deterioration of tomato fruits following harvest is influenced by many factors including stage of ripeness, pre-packaging treatment and packaging material (Geeson *et al.,* 1985). Delaying tomato fruit ripening is desirable during distribution and for short-term storage before marketing. Commercially, tomatoes intended for distant markets are usually harvested at mature green or breaker stages so that fruits can endure the rigors of handling while maximizing shelf life (Gong and Corey, 1994). Most of the work done on postharvest handling of tomatoes has been done in the developed countries where emphasis has been laid on low temperature effects on the fruit quality (Mathooko, 2002). It is plausible that this emphasis has been due to availability of cooling facilities in these countries. However, an inexpensive way to delay fruit ripening is the use of modified atmosphere packaging (MAP), where fruits are sealed in semipermeabble plastic packages that enable the development of a beneficial gas atmosphere created and maintained by interaction of fruit respiration and gas diffusion through the packaging film (Gong and Corey, 1994). Although a lot of work has been done on MAP, it has mainly been in combination with low temperature. Information on real rather than simulated tropical conditions seems to be lacking. Moreover, tomato fruit being sensitive to chilling temperature can only be stored safely at above 12°C to ensure freedom from chilling injury, good colour and flavour profile (Artes and Escriche, 1994).

In most developing countries tomatoes are grown in the peri-urban areas of the city. Farmers are faced with high postharvest losses due to tomatoes being highly perishable and seasonal. At peak harvest the farmers are forced to sell off their produce at very low prices or risk losing the lot due to spoilage. Farmers and traders could benefit from reduced losses by using appropriate low cost technologies such as MAP. Plastic films can slow down respiration and ethylene production thus reducing deterioration (Mathooko, 1996). Modified atmosphere results from the consumption of oxygen and the production of carbon dioxide through respiration leading to the delay of climacteric rise in respiration of the fruit. In addition the plastic film maintains high relative humidity and reduces water loss. The benefits of MAP are derived through its effects on various biochemical and physiological processes (Kader, 1986). Indeed MAP has become a common method for packaging and displaying fresh produce in many developing countries. However, it is common to find plastic films of various gauges being used for same commodity without due regard of its effect on quality. In Kenya, it has been observed that produce are sealed in packaging films of insufficient permeability which may result in development of undesirable fermentation reactions due to low oxygen concentration (Abe *et al.,* 1996). There has been no report on how the film thickness will affect ripening and hence quality of many fruits including tomatoes. Loss in quality and limited shelf life are major problems faced in the marketing of fresh tomatoes. An ideal storage should, therefore, increase the shelf life of tomatoes without causing notable loss of quality.

An appropriate MAP for unripe tomatoes delays changes in color, acidity, soluble solids concentration and firmness (Nakhasi, *et al.,* 1991). In addition, fruit kept in plastic film benefit from reduced weight loss due to maintenance of a high relative humidity (Mathooko *et al.,* 1993; Shirazi and Cameron, 1992). Although optimum quality of tomato is attained through vine ripening, ripe tomato fruits are perishable and very liable to transport damage that consequently leads to loss of quality and waste (Nakhasi *et al.,* 1991). This is especially so in developing countries due to poor postharvest handling systems and transportation of fruits and vegetables over rough roads and uneven surfaces.

Mathooko, (2002) reported that MAP could be used to extend storage life of tomatoes at ambient temperature. The MAP has been demonstrated to be an economical and effective way to delay fruit ripening and extend shelf life of tomatoes (Geeson *et al.,* 1985; Nakhasi *et al.,* 1991). It is important to determine the influence of film thickness since the nature and thickness of the barrier material and how it interacts with temperature and the presence of water will determine its permeability and hence the degree of atmosphere modification. For MAP design to achieve and maintain the desired levels of these gases, it is necessary to select appropriate combination of film composition and thickness, film surface area and fruit weight (Gong and Corey, 1994).

Since development of a modified atmosphere within the polymeric film extends the storage life of fruits and vegetables by reduction of ethylene production and respiration (Kader, 1986; Kader *et al.,* 1989; Mathooko *et al.,* 1993), MAP may provide a cheap means for the storage of fruits and vegetables and serve as an alternative to fungicides in extending their shelf life.

In this study the influence of film thickness on ripening and quality characteristics in tomato fruit and gas composition within the polymeric bags used in the MAP was investigated. The quality and ripening characteristics were determined with respect to weight loss, total titratable acidity, total soluble solids, ascorbic acid content, chlorophyll degradation, lycopene synthesis and physical colour development.

2.0 MATERIALS AND METHODS

Plant Material and Treatments

Freshly harvested mature green tomato (*Lycopersicon esculentum* L. cv. Cal J) fruits were purchased from a supplier in Thika market, Kenya. Prior arrangements had been made to ensure that not more than 24 hours had elapsed since harvesting. The tomatoes were carefully selected with respect to absence of defects and uniformity in terms of size, shape and degree of maturity. The tomatoes were then taken immediately to the laboratory at Jomo Kenyatta University of Agriculture and Technology, Kenya. The tomatoes were washed with tap water, treated with a solution of sodium hypochlorite (120 ppm chlorine) and mopped gently with tissue. The purpose of this treatment was to inhibit microbiological activity that would occur due to accumulation of a microlayer of moisture on the fruit surface. The fruits were divided into three batches and three replications for each of the treatments. One batch was used as control (stored on a laboratory bench in normal air to simulate retail conditions), the other batch was packaged and sealed in 0.04mm low density polyethylene (LDPE) bags and the third batch was packaged in 0.08mm bags (Packaging Industries Ltd., Nairobi, Kenya). Each batch consisted of 90 fruits, that is, in the MAP treatment each bag contained five fruits. A surface area to fruit weight ratio of 1.05 cm^2/g was used. All treatments were conducted at room temperature (26 ± 1°C) simulating retail marketing. The samples were monitored at two-days intervals during 12 days of storage for weight loss, colour change, chlorophyll content, lycopene content, total soluble solids content, ascorbic acid content and total titratable acidity as well as concentrations of oxygen, ethylene and carbon dioxide in the polymeric films. Samples were for chemical analyses were selected form each treatment at random. For measurement of weight loss and monitoring of gases, the same samples were used throughout the experimental period. After 12 days, the fruits under MAP were transferred to normal air for four days and monitored for ripening and quality characteristics.

Weight loss determination

The weight of three sets of tomatoes each for the control and packaged produce was determined initially and on at a two-day interval until the end of the experiment. The weight was determined using a desktop weighing balance (Libror Model EB-4000H, Shimadzu Corporation, Kyoto, Japan) which can measure to an accuracy of 0.001g. The same batches of tomatoes in each treatment were used for weight loss determination throughout the experiment. The percent weight loss was determined using the following formula: % weight loss = (initial weight − weight at a given time) ÷ (initial weight) × 100. Fruits were also evaluated for visual appearance and spoilage with respect to shriveling and incidences of decay and mold growth.

Determination of pigments

Lycopene and total chlorophyll contents were determined as described by Sozzi *et al.*, (1996). Due to lack of uniformity in ripening, the tomato tissue (excluding the seeds) was cut into small pieces and mixed to obtain a homogenous mixture. Two grams of the mixed tissue was homogenized in 10 ml of acetone while covering the tube with aluminum foil to prevent light-induced oxidation of lycopene. The supernatant after standing the tubes for 10 minutes was decanted and the pellet was macerated again with another 10 ml of acetone until the residue was white. The combined mixtures were finally extracted in a shaker at 140 rpm for 30 minutes. The acetone extract was centrifuged at 12,000 × *g* for 15 minutes and made upto 20 ml. Lycopene and chlorophyll contents were determined by measuring absorbance at 503nm and 664nm, respectively using a Shimadzu UV-visible spectrophotometer (Model UV-1600, Shimadzu Corporation, Kyoto, Japan) and expressed as µg per gramme fresh weight. The wavelength of 503nm for lycopene is the best because influence of carotenoids (473 m) is negligible (Beerh and Siddappa, 1959). Physical colour measurements were done using a Minolta color difference meter (Minolta Co. Ltd., Osaka, Japan, model CR-300) standardised against a white background. The colour was expressed based on hue ($\tan^{-1}b^*/a^*$), L and chroma $(a^{*2}+b^{*2})^{0.5}$. 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, L is an indication of the colour lightness, that is, colour intensity changing from white to black and chroma describes the intensity of a fundamental colour with respect to the amount of white light in the background (McGuire, 1992; Boakye and Mittal, 1996).

Monitoring of gas composition

The concentrations of oxygen, carbon dioxide and ethylene within each of the bags were monitored during storage by gas chromatography. Samples of internal gas in the bagswere withdrawn through a self-sealing silicon stopper affixed on the surface of the bags using a 1-ml hypodermic gas-tight syringe. To determine the concentrations of carbon dioxide and oxygen the gas sample was injected into a gas chromatograph (Shimadzu GC 8, Shimadzu Corporation, Kyoto, Japan,), equipped with a thermal conductivity detector and, Porapak Q and molecular sieve columns, respectively. Helium was used as the carrier gas. Ethylene concentration was determined by injecting the gas sample into a gas chromatograph (Shimadzu GC 9A, Shimadzu Corporation, Kyoto, Japan), equipped with a flame ionization detector and an activated alumina column (Mathooko *et al.*, 1993).

Determination of total titratable acidity (TTA) and total soluble solids (TSS) content

Three fruits from each treatment were analyzed for TTA and TSS content. The core containing the seeds was removed and the fruits were pureed in a blender. The pureed samples were filtered to remove fibres. TTA was determined by titrating 5 ml sample with 0.1 N NaOH to pH 8.1.The acidity is expressed as percent citric acid, the predominant organic acid in tomato fruit. TSS content was determined by refractometry using an Atago N1 refractometer and expressed as °Brix. This represents not only the soluble sugar content but also organic acids and minor constituents in the sap that contribute to the refractive index (Davies and Hobson, 1981).

Determination of ascorbic acid content

Ascorbic acid content in the fruit pericarp tissue was determined by visual titration of extract with 2,6-dichlorophenolindophenol solution according to AOAC methods (1984).

The experiments were repeated twice at different times and only representative data is presented. The data were subjected to the Duncan's multiple range test where applicable.

3.0 RESULTS AND DISCUSSION

Weight loss and visual appearance

Modified atmosphere packaging reduced weight loss drastically compared to the control treatment (Fig. 1). Weight loss was also slightly influenced by the film thickness. Weight loss in fruits packaged in 0.04mm bags was only slightly higher than that for fruits packaged in 0.08mm polymeric films.

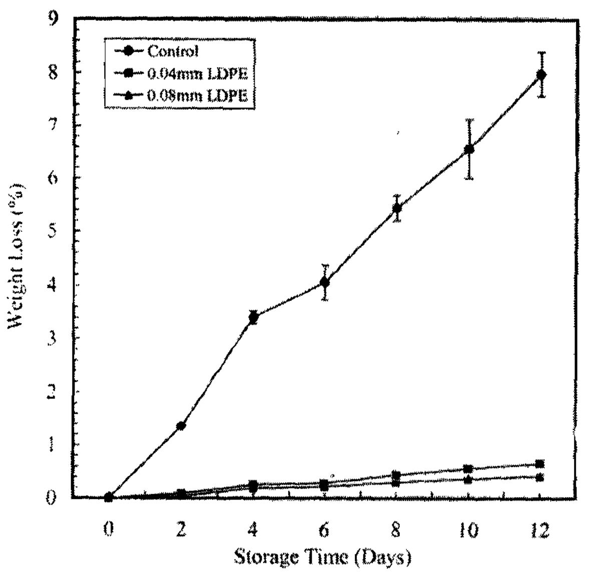

Figure 1. Effects modified atmosphere packaging and film thickness on weight loss in tomato fruit during ripening. Fruits were transferred from MAP to ambient conditions of relative humidity, air and temperature after day 12. Vertical bars represent SE of the mean of three replications.

The weight loss was associated mainly to loss of moisture. In general, weight loss progressively increased with storage time and was almost linear for all treatments as earlier reported (Mathooko, 2002). The respective regression equations and correlations were: control, $y = 1.3007x - 1.0843$ and $r^2 = 0.9906$; 0.04mm LDPE, $y = 0.1111x - 0.1171$ and $r^2 = 0.9916$ and 0.08mm LDPE, $y = 0.0725x - 0.07$ and $r^2 = 0.9773$. The loss of moisture results in a reduction in the fresh weight of harvested product, which when sold on a weight basis and translates into loss in value. Generally, the loss of only 5-10% moisture renders a wide range of products including tomato fruits unsalable (Kays, 1991).

It has previously been shown that MAP reduces weight loss in various commodities including tomato (Nakhasi *et al.*, 1991; Mathooko, 2002). Weight loss from fruits when film barriers are used is directly related to the water vapour transmission rates (WVTR) of the material which is independent of carbon dioxide and oxygen permeability (Smith *et al.*, 1987). Meir *et al.*, (1995) observed that MAP reduced water loss in bell pepper by 40-50%. In grapefruit, film thickness ranging from 0.02mm to 0.04mm had little effect on weight loss (Purvis, 1983). Water loss of fresh tomato fruits is primarily due to transpiration and respiration. The reduced weight loss by fruits held under MAP is most likely due to the high relative humidity (RH) maintained and reduced rate of respiration inside the polyethylene bags. Bhowmik and Pan (1992) observed that high RH under controlled atmosphere (CA) considerably reduced weight loss in tomato fruits. The control fruits were unattractive due to formation of wrinkles on the surface. According to Artes and Escriche (1994) and Bhowmik and Pan (1992), formation of wrinkles leads to loss of brightness in colour. Materials with low WVTRs such as the 0.08mm LDPE can lead to problems due to high relative humidity conditions in the package atmosphere, increasing the risk of pathological disorders (Geeson *et al.*, 1985) as a result of the moisture which was observed to condense on the surface of the fruits. The reduced weight loss in the fruits held in 0.08 mm bags could be related to limited permeability of water vapour through the film, thereby resulting in establishment of equilibrium RH.

There is need, however, to investigate how long the fruits can be stored without noticeable pathological disorders as a result of high RH. Fruits held under ambient conditions spoilt faster and by the end of the experiment about 75% had spoilt compared to about 2% for those in the 0.04mm bags. Sensory evaluation of the fruits under MAP indicated that the fruits were firmer (data not shown) than the control by virtual of being at different stages of ripeness an this is an advantage in handling as there will be less mechanical damage during transportation and postharvest handling. This was due to delay in ripening and any other associated biochemical process that may induce textural changes in the fruits. Ben-Arie and Zutkhi (1992) reported that film thickness has profound effect on spoilage of persimmon whereby fruits held in 0.06mm bags spoilt faster than those stored in 0.08mm bags. At the end of the 12 days, the control fruits were overripe and the skin had started wrinkling due to moisture loss. The tomatoes in the thin gauge (0.04mm) had started to ripen whereas the ones in a thick bag (0.08mm) had only a slight change in colour. Only one tomato in the 0.04mm bags had mould growth at the end of the experimental period probably due to invisible injury sustained before the start of the experiment, which could have been aggravated by moisture condensation within the bags and on the surface of the fruits as observed in the study.

Gas composition

The changes in the concentrations of oxygen and carbon dioxide in the respective polymeric bags are shown in Figs. 2 and 3, respectively.

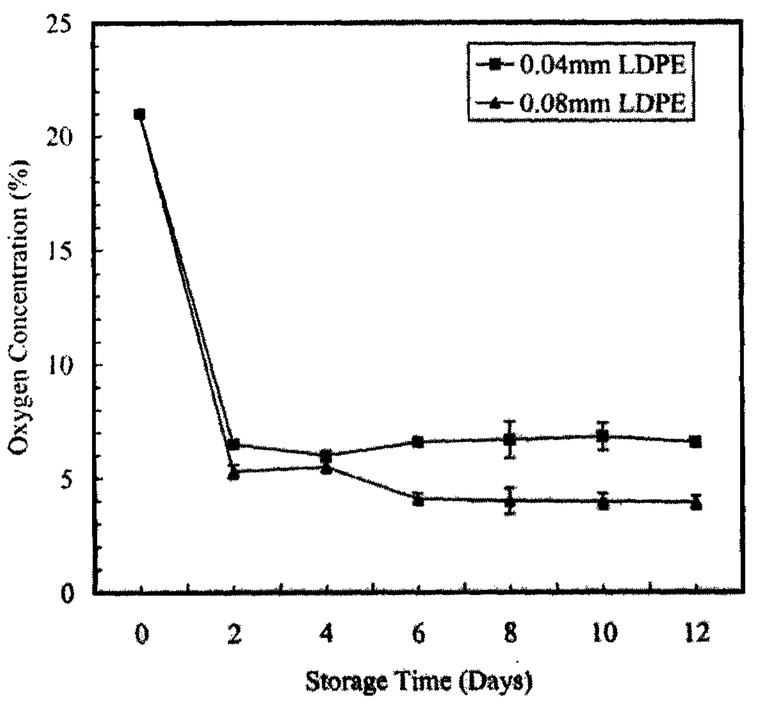

Figure 2. Effects of modified atmosphere packaging and film thickness on oxygen concentration in the polymeric films. Vertical bars represent SE of the mean of three replications.

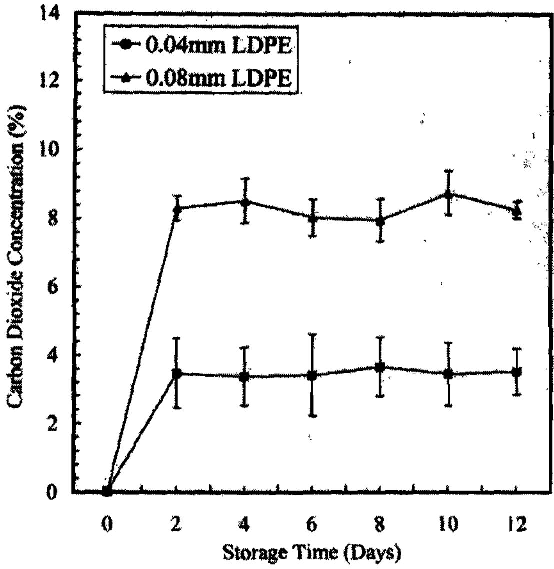

Figure 3. Effects of modified atmosphere packaging and film thickness on carbon dioxide concentration in the polymeric films. Vertical bars represent SE of the mean of three replications.

The pattern of atmosphere development within the packages included an initial period of rapid change followed by a semi-equilibrium (steady state) of the concentrations of oxygen and carbon dioxide. Other researchers (Nakhasi *et al.*, 1991; Mathooko *et al.*, 1993) have previously reported this trend. During MAP treatment, the O_2 and CO_2 levels in air packed plastic bags decreased and increased respectively, thereby creating a microclimate in the package (Mathooko *et al.*, 1993). It has been shown that within 24 hr after package sealing the levels of O_2 and CO_2 in the package reach a steady state and remain constant thereafter, as long as the storage environment does not change in terms of temperature and relative humidity (Forney *et al.*, 1989). The concentration of carbon dioxide in the 0.04mm and 0.08mm bags increased to about 3.7% and 8.2%, respectively while oxygen concentration decreased to about 7% and 5%, respectively. This is related to the differences in the permeabilities of the films. Ben-Arie and Zutkhi (1992) observed that in persimmons held under MAP, oxygen concentration was higher in 0.06mm bags than in the 0.08mm bags while the converse was true for carbon dioxide. The steepness of the oxygen gradient between the external and internal atmospheres affects the flux of oxygen into the bags so that a steady level can be maintained (Ben-Arie and Zutkhi, 1992). The limited permeability of carbon dioxide out of the 0.08mm bags and the limited permeability of oxygen into the bag result in high and low level of the gases, respectively. A steady state is thereafter established as a result of inhibition of respiration by the accumulated carbon dioxide. The permeability of plastic films to water vapor and oxygen is related to the thickness of the film (Purvis, 1983). The low oxygen concentration generally encountered in the bags may encourage anaerobic respiration during prolonged storage resulting in accumulation of ethanol and off-flavour development (Ben-Ariè and Zutkhi, 1992). At the present time, the key to successful commercial MAP of fresh produce is to use packaging film of correct permeability so as to establish optimal equilibrium modified atmosphere (EMAs) of typically 3-10% oxygen and 3-10% carbon dioxide (Day, 1996). Film thickness among other factors will affect its permeability and, therefore, there is need to establish the exact permeability. Currently we are investigating WVTR and gas permeability of the films under different storage conditions in an attempt to develop appropriate models.

Ethylene concentration increased rapidly within the first two days and only increased slightly thereafter (Fig. 4).

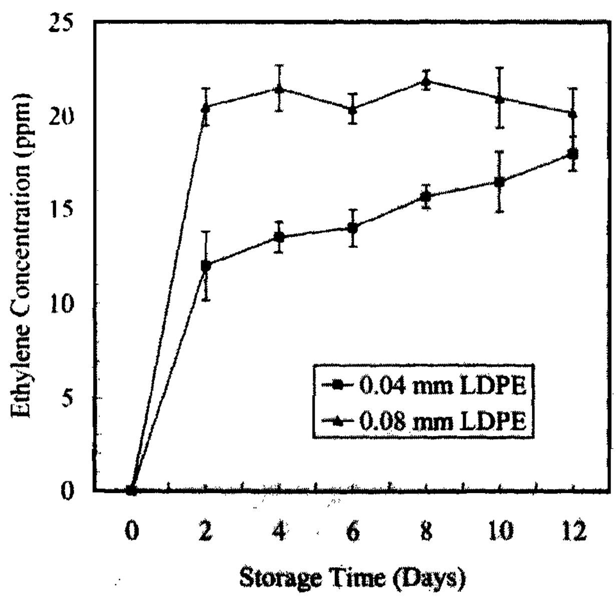

Figure 4. Effects of modified atmosphere packaging and film thickness on ethylene concentration in the polymeric films. Vertical bars represent SE of the mean of three replications.

The ethylene concentration was higher in the 0.08mm bags than in the 0.04mm bags. The initial increase in ethylene concentration was due to increased ethylene production and the levels maintained thereafter were due to differences in the permeability of the films. The slight increase in the concentration of ethylene in the 0.04mm bags after two days may indicate that the level of carbon dioxide in the bag was not adequate enough to completely inhibit ethylene production and hence the rate of ethylene production was higher that its diffusion out of the bag. On the other hand, the high levels of ethylene in the 0.08mm bags within the same period could have been due to lack of inhibition of ethylene production by the initially low concentration of carbon dioxide in the bags and, limited permeability of ethylene out of the bag. Although ethylene is known as the ripening hormone and, therefore, would have been expected to accelerate ripening in fruits in 0.08mm bags, its action was inhibited by the high levels of carbon dioxide which is a known inhibitor of ethylene action (Mathooko, 1996). Low O_2 concentration has also been shown to inhibit ripening in many fruits (Kader and Zagory, 1989). Indeed, elevated CO_2 and low O_2 concentrations have been shown to have synergistic effect in regulating many physiological and biochemical reactions including ripening (Kader and Zagory, 1989; Mathooko, 1996). However, successful MAP must maintain near optimum O_2 and CO_2 levels to attain the beneficial effects of MA without exceeding the limits of tolerance which may increase the risk of physiological disorders and other detrimental effects. It should be noted that O_2 concentrations below 8% have significant effect on fruit ripening and elevated levels of CO_2 (>1%) also retard ripening. In fact their effects are additive (Kader and Zagory, 1989; Mathooko, 1996). It is, therefore, clear that the levels of O_2 (about 6% and 4% in 0.04mm LDPE and 0.08mm LDPE, respectively) and CO_2 (about 3% and 8% in 0.04mm LDPE and 0.08mm LDPE, respectively) observed in the current study are able to inhibit tomato fruit ripening.

Total titratable acidity and total soluble solids

The changes in TTA during storage are shown in Table 1. TTA in the control fruits decreased as ripening progressed.

Table 1. Effect of film thickness on total titratable acidity (% citric acid) in tomato fruit under modified atmosphere packaging

	% Citric acid		
Storage time LDPE (Days)	**Control**	**0.04mm LDPE[y]**	**0.08mm**
0	0.43 ± 0.05[a]	0.43 ± 0.05[a]	0.43 ± 0.05[a]
2	0.37 ± 0.07[a]	0.40 ± 0.08[a]	0.43 ± 0.03[a]
4	0.33 ± 0.05[a]	0.37 ± 0.01[a]	0.40 ± 0.04[a]
6	0.30 ± 0.02[a]	0.36 ± 0.06[a]	0.39 ± 0.01[a]
8	0.27 ± 0.05[a]	0.32 ± 0.04[ab]	0.35 ± 0.03[b]
10	0.24 ± 0.04[a]	0.29 ± 0.01[ab]	0.32 ± 0.04[b]
12	0.22 ± 0.01[a]	0.28 ± 0.01[ab]	0.31 ± 0.02[b]
16	0.20 ± 0.03[a]	0.22 ± 0.05[a]	0.25 ± 0.05[a]

Results are mean±SE of triplicate determinations, [y] LDPE – Low Density Polyethylene ,

[z] - After day 12 the fruits where removed from MAP and stored in normal air.

Means in a row followed by the same letter are not significantly different at the 5% level of significance.

However, MAP inhibited the decrease in TTA which is associated with ripening. The rate of decrease was, however, lower in fruits held in 0.08mm bags compared to those held in 0.04mm bags. The TTA decreased to levels slightly higher than the control four days after transfer of fruits from MAP to normal air. In tomato fruits at the breaker stage held under MAP and then transferred to air, TTA was still higher than in the control fruits (Nakhasi *et al.,* 1991). It has also been proposed that the lower TTA in fruits held at high RH as would be encountered under MAP is primarily due to their higher retention of water and, therefore, the concentration effect caused by water loss may be reflected in TTA values (Bhowmik and Pan, 1992). It seems, therefore, that MAP has a residual effect in controlling ripening-associated changes.

Although TSS content is expected to increase as fruits ripen, TSS content remained fairly constant in all the treatments (data not shown). This could be due inhibition of respiration since TSS has been reported to be closely related the rate of respiration. It has been reported that MAP has no effect on TSS content in tomato fruits treated at breaker stage of ripeness (Nakhasi *et al.,* 1991). The observation that MAP had little effect on TSS content is in good agreement with that of Nakhasi *et al.,* (1991) and Mathooko (2002) and supports the conclusion reached by Goodenough *et al.,* (1982) that MAP may not equally control all ripening processes. Yang and Chinnan (1987) reported that an appropriate MAP delays changes in TSS content among other parameters. In tomato fruits held under CA, TSS content remained low during storage probably due to suppression of respiration and delay in ripening, and then increased upon return to air (Bhowmik and Pan, 1992).

Changes in colour

Colour is the most visible ripening indicator, hence determination of colour development appears to be a logical factor in investigating modified atmosphere storage of tomatoes (Yang and Chinnan, 1988). The changes in chlorophyll content and lycopene content are shown in Figs. 5 and 6, respectively.

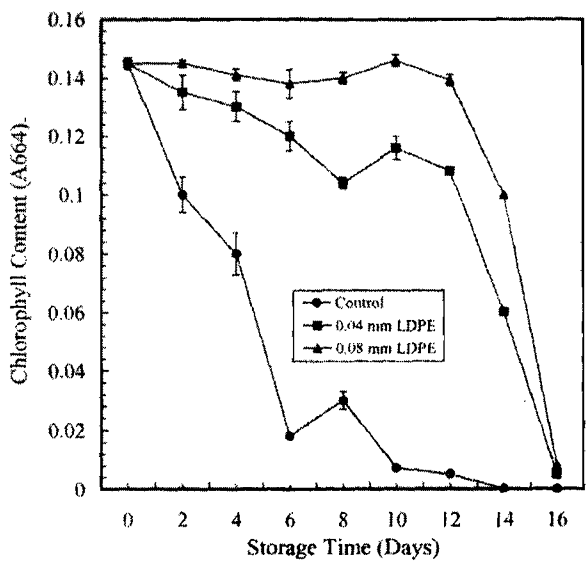

Figure 5. Effects of modified atmosphere packaging and film thickness on chlorophyll degradation in tomato fruit during ripening. Fruits were transferred from MAP to ambient conditions of relative humidity, air and temperature after day 12. Vertical bars represent SE of the mean of three replications.

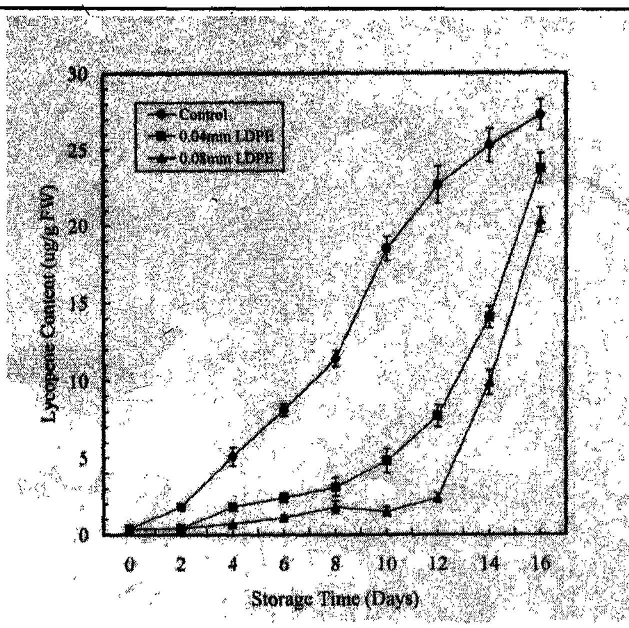

Figure 6. Effects of modified atmosphere packaging and film thickness on lycopene content in tomato fruit during ripening. Fruits were transferred from MAP to ambient conditions of relative humidity, air and temperature after day 12. Vertical bars represent SE of the mean of three replications.

The chlorophyll and lycopene contents in the control of fruits were significantly different ($p<0.05$, n = 3, ms = 16.2, df = 8 and $\chi^2 = 0.86$ for chlorophyll and n = 3, ms = 12.8, df = 8 and = χ^2 = 1.23 for lycopene) compared to those of fruits held under MAP. Chlorophyll content decreased in the control fruits as they ripened. However, chlorophyll degradation that is associated with ripening of tomato fruits was delayed by storage of fruits under MAP. The increase in lycopene content associated with tomato fruit ripening was also delayed by MAP probably due to inhibition of its synthesis. This implies that MAP decreased the metabolic processes responsible for both chlorophyll degradation and lycopene synthesis or any process that may facilitate unmasking of presumably preexisting lycopene. In all the treatments the decrease in chlorophyll content and increase in lycopene content was lower in fruits packaged in 0.08mm bags compared to those in 0.04mm bags albeit not significant. This effect could be due to the high concentration of carbon dioxide in the 0.08mm bags since carbon dioxide is known to inhibit chlorophyll degradation through its effect on the activity of chlorophyllase, the enzyme responsible for chlorophyll degradation.

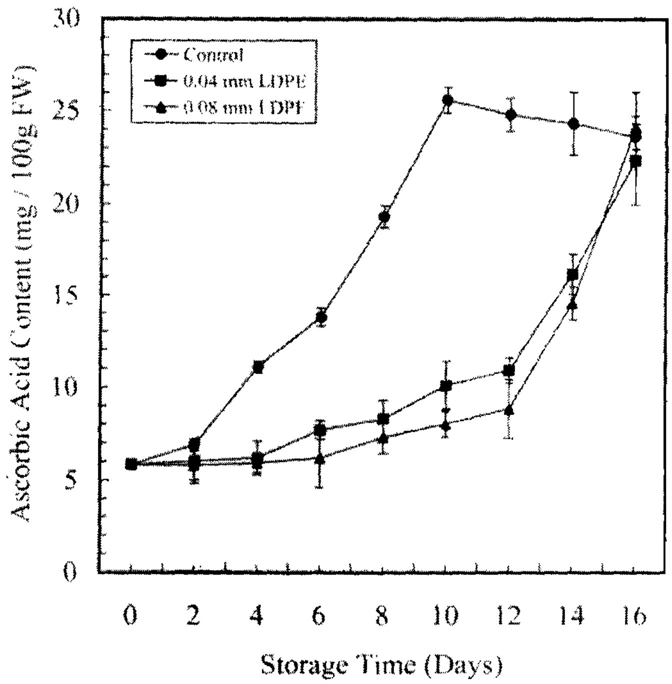

Figure 7. Effects of modified atmosphere packaging and film thickness on ascorbic acid content (mg/100 g fresh weight) in tomato fruit during ripening. Fruits were transferred from MAP to ambient conditions of relative humidity, air and temperature after day 12. Vertical bars represent SE of the mean of three replications.

Lycopene synthesis has a strong dependence on ethylene (Jeffrey *et al.,* 1984). This statement is supported by the observation that the thickness of the films had a strong effect on chlorophyll degradation than lycopene synthesis. However, it has been reported that the high concentration of ethylene in the polymeric bags does not negate the retarding effects of MA environment on tomato fruit ripening (Nakhasi *et al.,* 1991). The effect of MAP was reversed upon transfer of fruits to ambient conditions where colour developed normally. However, lycopene content did not reach the values observed in the control fruits. It has been reported that the delay in the ripening process upon transfer of tomatoes to normal air is associated with slow recovery of respiration to normal rate (Bhowmik and Pan, 1992). The increased carbon dioxide concentration counteracted the biological activity of ethylene in enhancing chlorophyll degradation. MAP also delayed decrease in L and hue values and increase in chroma (Table 2). During ripening of tomato fruits, L and hue values decrease while chroma value increases (Shewfelt *et al.,* 1988). Our observation, therefore, indicates that 0.08mm LDPE was more effective in delaying colour change associated with ripening than 0.04mm LDPE. Colour development is delayed by storing tomato fruits under CA (Bhowmik and Pan, 1992). MAP has also been shown to delay colour change in tomato fruits, although these treatments were in combination with low temperature storage (Yang and Chinnan, 1987; Nakhasi *et al.,* 1991). Gong and Corey (1994) showed that tomatoes under MAP kept for three weeks at 20°C without reaching the pink stage. Reduced respiration rates combined with reduced sensitivity to ethylene results in decreased chlorophyll degradation (Kader *et al.,* 1989). MAP has also been shown to delay chlorophyll degradation in green vegetables (Barth *et al.,* 1993).

Ascorbic acid content in tomato fruits increases with maturity and stage of ripening (Watada, 1987). Ascorbic acid is very labile and its retention is often followed when evaluating postharvest storage effects on nutritional quality in fruits and vegetables. In the control fruits, ascorbic acid content increased to a maximum and then started to decline (Fig. 7) while MAP delayed the increase in ascorbic acid content that is associated with ripening. Although ascorbic acid content in between fruits held in two films was not significantly different ($p<0.05$, $n = 3$, $ms = 17.6$, $df = 8$ and $\chi^2 = 0.35$) fruits in 0.08mm bags maintained slightly lower ascorbic acid content compared to those in 0.04mm bags indicating that it was more efficient in delaying ripening. It has been indicated that once fruits reach full ripe stage, ascorbic acid content starts to decline (Kays, 1991). Upon transfer of fruits from MAP to normal air, ascorbic acid content increased to almost the maximum observed for the control fruits.

This increase was in parallel with the increase in other parameters associated with ripening. Therefore, MAP could be an inexpensive way of preserving the nutritional quality of tomato fruits among other fruits and vegetables. It seems that MAP suppresses the synthesis of ascorbic acid but does not impair the fruit capability to synthesize the vitamin (Mathooko, 2002). Factors such as high RH as found in the polymeric films have been shown to affect ascorbic acid content (Watada, 1987).

Table 2. Effect of film thickness on physical colour characteristics of tomatoes under modified atmosphere packaging

Storage Time	Control			0.04mm LDPE[y]			0.08mm LDPE		
Days	L	Hue	Chroma	L	Hue	Chroma	L	Hue	Chroma
0	48.6 ± 3.5	130 ± 7	16.8 ± 2.5	47.2 ± 5.6	125 ± 11	18.4 ± 1.5	49.8 ± 0.05	136 ± 15.4	17.0 ± 15
2	45.3 ± 5.4	102 ± 12	17.2 ± 1.7	46.1 ± 4.3	118 ± 19	17.1 ± 2.3	49.4 ± 4.6	130 ± 14	17.1 ± 1.9
4	40.8 ± 5.7	87 ± 21	19.7 ± 3.5	46.0 ± 7.2	110 ± 23	19.4 ± 3.9	48.8 ± 6.4	128 ± 18	17.5 ± 2.1
6	37.2 ± 1.4	42 ± 4.8	23.8 ± 5.7	45.6 ± 10.5	108 ± 17	23.8 ± 1.9	48.2 ± 8.3	111 ± 23	18.0 ± 5.9
8	34.7 ± 3.4	33 ± 4	25.3 ± 7.2	45.3 ± 3.9	102 ± 12	24.9 ± 4.7	48.4 ± 6.8	107 ± 17	18.2 ± 3.6
10	30.3 ± 5.4	27.0 ± 1.7	29.8 ± 2.6	44.8 ± 4.1	99 ± 8	26.3 ± 1.8	47.8 ± 4.7	102 ± 18	18.8 ± 2.1
12[z]	28.0 ± 3.1	22.0 ± 2.8	31.2 ± 4.3	44.3 ± 2.7	93 ± 9	29.4 ± 3.2	47.4 ± 4.7	98 ± 12	19.2 ± 2.1
16	26.8 ± 4.5	19.0 ± 1.7	32.0 ± 4.2	30.9 ± 3.8	31 ± 2.6	33.8 ± 4.3	30.6 ± 2.4	34 ± 3	28.2 ± 4.1

The values are means ± SE of four determinations from different points of the fruit.

[y] – LDPE – Low Density Polyethylene

[z] - After day 12 the fruits where removed from MAP and stored in normal air.

CONCLUSIONS

In conclusion, it is clear that eliminating water loss through packaging holds greater potential for extending postharvest life of tomato fruits. Further study will, however, be required to optimize packaging conditions especially with respect to film permeability characteristics. There is, however, need for further research especially to investigate the effect of light by use of opaque bags since photosynthesis may interfere with establishment of the modified atmosphere, to evaluate internal colour development to check whether it correlates to the external colour characteristics, to run the experiment for a longer time to check the impact of the 0.08mm film on decay incidences. Further, there is need to evaluate the response of fruits at different stages of ripeness to MAP, optimum fruit to free volume ratio and establish the actual permeability rates of the various films to oxygen, water, vapour, carbon dioxide and ethylene. Implementation of MAP for tomato fruits in Kenya and other developing countries where refrigeration facilities are rare because it not only retards ripening processes and extend fruit shelf life, but because it is also relatively a very cheap technology.

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