Effect of Modified Atmosphere Packaging on Microbiological, Physiological and Chemical Qualities of Stored Carrot

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Abstract

Optimum packaging film for carrots should lead to low condensation, but preventing moisture loss, and maintain optimum gas composition during the storage period. In this study, carrots were packaged in polypropylene (PP) and low density polyethylene (LDPE) films and stored at 0°C and ambient temperature (15-25°C). After 7 days of 0°C storage headspace O_2, CO_2 and N_2 concentrations were 11.85%, 13.38%, and 6.69% for PP films and 3.39%, 3.24% and 4.77% for LDPE films. On the other hand, after 7 days of ambient temperature storage O_2, CO_2 and N_2 concentrations were 6.78%, 28.31%, and 16.15% for PP films and 6.41%, 5.19% and 5.28% for LDPE films. The higher the CO_2 content of the headspace the more the sucrose content decreased while the glucose and fructose content changed slower. A general decrease of the sugars (sucrose, glucose and fructose) was observed for all samples packaged in PP. The free sugars in carrots were observed to decrease at a slower rate for packaging in LDPE. Based on these results, it was concluded that LDPE film allowed lower respiration rates and is preferred to the PP material. The number of total aerobic microorganisms was higher in packages stored under ambient conditions than in those stored at 0°C temperature. The lowest counts were observed in the least permeable packaging film (PP) up to day 14. The total number of populations of coliform was higher with PP and LDPE films stored under ambient conditions as compared to those stored at O°C. Packaging films with relatively higher permeability to O_2 and CO_2 are preferred for maintaining normal respiration of carrots without the occurrence of secondary decomposition during storage. Modified atmosphere packaging combined with low temperature storage of carrots (about 1°C) reduces both biological and biochemical activities resulting in improved keeping quality.

Key words/phrases: Modified atmosphere packaging, polypropylene, low density polyethylene

Introduction

The shelf life of harvested fresh fruit and vegetables depends on the interaction between genetic and physiological status, the postharvest physicochemical environment and spoilage organisms (Lizada, 1994). Various changes occur during extended shelf life of fresh vegetables and fruit. The primary causes of quality deterioration are therefore due to microbiological growth, physiological deterioration and biochemical changes, which lead to undesired colour changes, off-flavor and firmness loss. The composition of storage gases, environmental condition and product factors are the major factors that control the biological and b`chemical activities (Zagory and Kader, 1988). Extension of shelf life of vegetables can be achieved by minimizing the rate of respiration and biochemical activities, as these are associated with senescence of vegetables and fruit. There are various methods for retarding respiration and biochemical activities during storage, the more successful method being modified atmosphere packaging (MAP) (Zagory and Kader 1988, and Kader et al 1989). Modified atmosphere packaging involves the use of polymeric film with a specific permeability to O_2, CO_2 and water vapor. Depletion of O_2 and elevation of CO_2 within the package can be achieved passively by respiration or actively by flushing a desired mixture of gases into the package (Zagory and Kader 1988, Ballantyne *et al.*, 1988). In the first instance, the level of gas composition achieved depends on the permeability of the packaging film, and the rate of respiration of the vegetable materials. Lowering the storage temperature together with modified atmosphere packaging of vegetables and fruit may reduce both physiological and biochemical activities. Different types of packaging films used in MAP of vegetables have different permeability to O_2, CO_2 and water vapor. Therefore, packaging film should be evaluated for use of vegetables and fruit packaging and conditions of storage in order to have an insight into the possibility of using films for specific vegetables under a given storage condition. Modified atmosphere packaging of intact vegetables and fruit should also be evaluated with specific refrigeration conditions. In developing countries, the mechanical refrigeration systems are expensive for utilization by retailers, wholesalers distributors and transporters. High economic losses, decreased shelf life, difficulties to distribute products over longer distances and overall poor quality of perishable products are some of the severe postharvest problems (Wolde, 1991; Farber, 1991). As a result, populations of many developing countries suffer of chronic vitamin A deficiency (Wolde-Gebriel, 1993; Haidar and Demisse, 1999). Evaporative cooling (low-cost) may be one option for future application in developing countries (Rama *et al.*, 1990; Gopalakrishna *et al.*, 1991; Rama and Narasimham, 1991, Christenbury *et al.*, 1995; Mekonnen, 1996; Dzivama *et. al.*, 1999). In terms of cooling output, evaporative cooling is more efficient than mechanical refrigeration (Thompson and Kasmire, 1981). The temperatures attained by adiabatic cooling processes are close to those recommended for storage of low temperature-sensitive produces (Roy and Pal, 1994). However, in these countries, the post production handlers are using packaging materials without sufficient technical knowledge of the properties of the films and the physiology of plant products. For carrots, it was shown that higher temperature and lower relative humidity increases sprouting and reduce quality without affecting decay when stored in open air (Berg and Lentz, 1966). It was also shown that more permeable gas pathways and temperature compensation are needed for effective modified atmosphere systems (Exama *et. al.*, 1993). However, information is lacking regarding gas permeability of packaging films, temperature effects, microbiological quality and chemical changes during MAP storage and need investigation before combining MAP with the low-cost evaporative cooling.

The objective of this investigation was therefore to evaluate the performance of packaging films, low-density polyethylene (LDPE) and polypropylene (PP), on the quality of carrots during storage. Physiological, microbiological and chemical changes were determined during modified atmosphere storage at 0°C as well as at ambient conditions (15-25°C) in order to plan future studies on the use of MAP with low cost adiabatic cooling.

Material and Methods

Sample preparation, packaging and storage conditions

Ten kilograms fresh, carrots were obtained from a fresh market in Bloemfomtien, South Africa and stored at 0°C and under ambient temperature (15-25°C) after packaging. Carrot samples were washed with cold tap water and the surface dried with paper towel before packaging. The washed and surface dried carrots were packaged into two types of packaging film i.e. polypropylene (PP) and low density polyethylene (LDPE) in two replications. The packages were heat-sealed immediately after filling. Two packages from each of PP and LDPE films were stored both at 0°C and ambient conditions (15-25°C). The cold room was maintained at 0°C temperature with a relative humidity varying from 80 – 90% during the storage period of 14 days.

Gas sampling and analysis

Microatmosphere gas analysis was performed at 0, 7 and 14 days during the storage period. Gas samples were taken using a 5 ml. pressure lock syringe (precision Sampling Crop, Baton Rojge, Lausiana). At each sampling date, two packages from each storage condition were tested separately. Carbon dioxide, O_2 and N_2 gas concentrations in the headspace of packages were analyzed by gas chromatography (GC). The gas chromatograph (Varian 3300) was equipped with a Porapak Q 1.2 m X 2.3 mm stainless steel column, with thermal conductivity detection at 200 mAmp and using hydrogen gas as carrier at 19.5 ml. min^{-1} for CO_2 determination. For analysis of N_2 and O_2, a 0.8m Molsieve column was used, with thermal conductivity detection operated at 200 mAmp and hydrogen gas as carrier at 12.5 ml. min^{-1}. The GC oven temperature was set at 45°C for both analyses. The opening made by the needle during gas sampling was immediately sealed with drawing tape, to avoid leaks of gas from the packages.

Microbiological analysis

Half the portions (three carrots) were cut aseptically into pieces with sterile knives. Samples of 25 g were blended with 225 ml 0.1% peptone water (pH 7.0) in a stomacher for 3 minutes. The slurries were serially diluted in 9 ml 0.1% peptone water. To determine populations of total aerobic microorganisms (APC), duplicate samples were plated on plate count agar (PCA, Difico, and pH 7.0) and incubated at 30°C for 2 days. Similarly, to determine populations of coliform and *E. coli*, duplicate samples were plated on Violet Red Bile Agar with MUG (Difico) and incubated at 37°C for 1 day. The presence of *E. coli* was detected with an UV light at 366 nm. In all the cases pour plate methods were used. The mean log10 of viable counts from two duplicate plates were noted.

Sugar analysis

Free sugars (sucrose, glucose and fructose) were determined by the method of Riaz and Bushway (1996). Briefly, a 50 g carrot sample was homogenized for approximately 2 minutes. Sugars were extracted by placing a 10 g aliquot in a 100 ml beaker and stirring for 1 minute with 50 ml of 95% ethanol. The samples were shaken and kept at room temperature overnight. Aliquots of 5 ml were placed in vials and centrifuged for 5 minutes 3000 x g (Beckman, Microfuge E) before analysis by high performance liquid chromatography (HPLC). HPLC was carried out on a Waters system (501 pump), Biorad Aminex Colmn (7.8 mm X 300 mm) with a differential refractive index detector (R401) operated at 42°C and a mobile phase of de-ionized water at a flow speed of 0.6 ml. min^{-1} and temperature of 85°C.

Statistical Analysis

The experimental design was a factorial type with Randomized complete block design (RCBD) with storage conditions, packaging materials and quality parameters as factors. Gas composition and sugar content were subjected to analysis of variance (ANOVA) and Duncan's Multiple Range Test at value 1% was used to determine the significant differences among means of sugars. For viability counts the standard deviation of each observation from the mean was calculated.

Results and Discussion

General Observation

During the two-weeks storage period, sprouting was a serious problem associated with LDPE carrot packages while occurrence of condensation and mold was observed in PP carrot packages when stored at 0°C and ambient conditions. Modified atmosphere storage, when combined with higher storage

Fig. 1. Changes in O_2 content (%) in packages of carrots in PP (•) and LDPE (▲) at 0°C and PP (♦) and LDPE (x) at ambient temperature (15-25°C). C.V.(=0.1728) gives average coefficient of variation (n = 2 over two storage time).

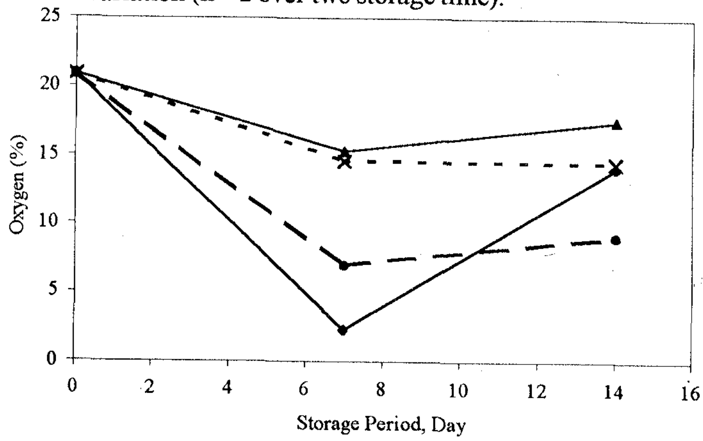


Fig. 2. Changes in CO_2 content (%) in packages of carrots in PP (•) and LDPE (▲) at 0°C and PP (♦) and LDPE (x) at ambient temperature (15-25°C). C.V.(=0.2511) gives average coefficient of variation (n = 2 over two storage time).

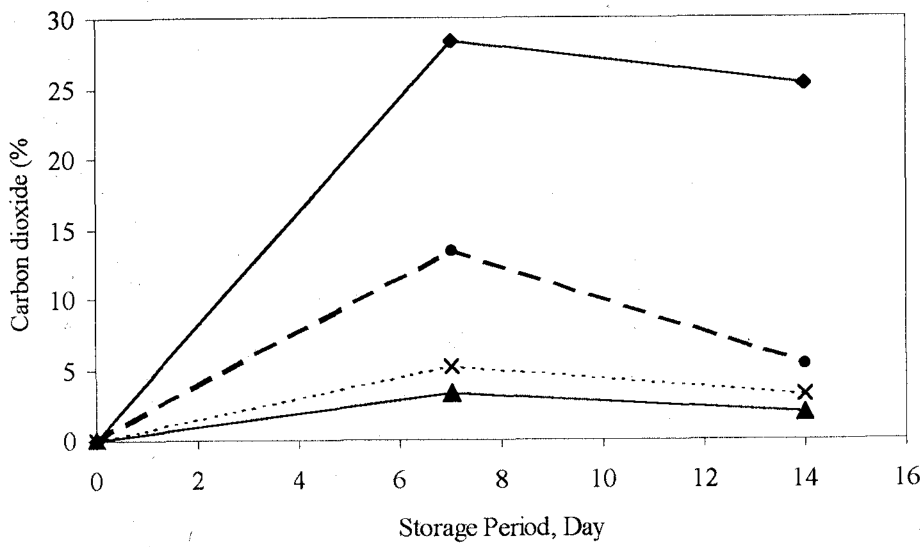
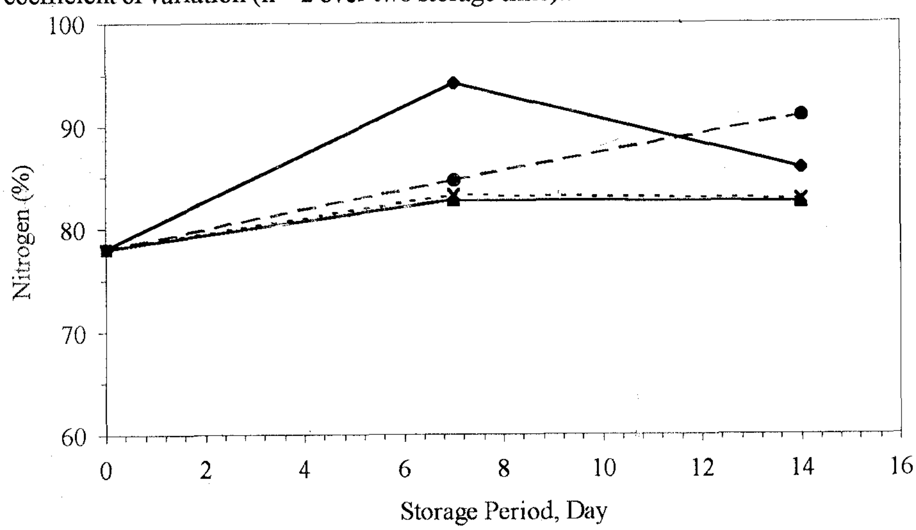


Fig. 3. Changes in N_2 content (%) in packages of carrots in PP (•) and LDPE (▲) at 0°C and PP (♦) and LDPE (x) at ambient temperature (15-25°C). C.V.(=0.037) gives average coefficient of variation (n = 2 over two storage time)..



temperature increased sprouting of carrots. Berg and Lentz (1966) reported similar results for carrots stored in an air tight plywood material and in open air. As compared to carrots packaged in LDPE films, a marked increase in mould growth and rotting was observed in PP packaged carrots when stored under ambient conditions.

Gas composition

For LDPE and PP films, O_2 level was highly significant ($P < 0.05$) factor. On the other hand, highly significant differences were found among type of packaging on CO_2 composition ($P < 0.001$). As regards N_2 composition, there was no difference ($P < 0.05$). The effect of temperature on CO_2 level was highly significant ($P < 0.001$).

The changes in O_2 and CO_2 concentration in carrot packages sealed with PP and LDPE films are shown in **Fig. 1** and **2** respectively. A rapid decrease in O_2 and an increase in CO_2 concentration were observed after 7 days in all packages. The changes in O_2 and CO_2 concentration were less for carrots stored in LDPE packages compared to the changes in PP packs (**Fig. 1** and **2**) after 7 days to 14 days. Nitrogen concentration changes faster in packages sealed with PP films than in LDPE films (**Fig. 3**). The lowest O_2 and highest CO_2 concentrations were found in carrot packages sealed in the least permeable films and vice-versa. A study on the modified atmosphere packaging of fresh, "ready-to-use," grated carrots demonstrated similar trends, howevere, these results can not directly be extrapolated to whole carrots, as grated material has a higher metabolism (Carlin *et al.*, 1990). After 7 days of 0°C storage, headspace O_2, CO_2 and N_2 concentrations were 11.85%, 13.38%, and 6.69% for PP films and 3.39%, 3.24% and 4.77% for LDPE films respectively. After 7 days of ambient temperature storage the microenvironment O_2, CO_2 and N_2 concentrations were 6.78%, 28.31%, and 16.15% for PP films and 6.41%, 5.19% and 5.28% for LDPE films respectively. A sharp decrease in O_2 concentration was observed in PP films during the 7 days of storage (**Fig. 1**). The CO_2 concentration increased sharply and the atmosphere compositions seems equilibrated in carrot packages sealed with PP films thereafter. The change in O_2 and CO_2 concentration was found to be slower in packages of carrots sealed in LDPE films. A sharp increase in CO_2 and decrease in O_2 levels

Table 1. Changes in content of total free sugar, sucrose, glucose and fructose carrots packaged in PP and LDPE films and stored at 0°C and ambient temperature (15-25°C).

Packaging Film (storage temp. and days)	Sucrose (g/100g)	Glucose (g/100g)	Fructose (g/100g)	Total Free Sugar (g/100g)
At 0 day storage	2.69[a]	2.06[a]	1.62[b]	6.38[a]
PP (0C, 7 day storage)	2.20[b]	1.76[bc]	1.54[abc]	5.50[bc]
LDPE (0C, 7 day storage)	1.93[c]	1.97[b]	1.66[a]	5.56[bc]
PP (room, 7 day storage)	0.95[d]	0.91[d]	0.74[d]	5.21[c]
LDPE (room, 7 day storage)	2.26[b]	2.06[a]	1.47[c]	5.79[b]

SE = 0.09487, C.V. = 0.0518, EMS = 0.018 and LSD Value = 0.3994 at alpha = 0.010. [a, b, c, d] mean data from two packs pre treatment; mean separation by Duncan's Multiple Range Test at value 1%. Values not followed by the same letter are significantly different.

Fig. 4. Growth of total aerobic microorganisms in packages of carrots in PP (•) and LDPE (▲) at 0°C and PP (♦) and LDPE (x) at ambient temperature (15-25°C). Standard deviation is indicated (lower than symbol sizes were omitted).

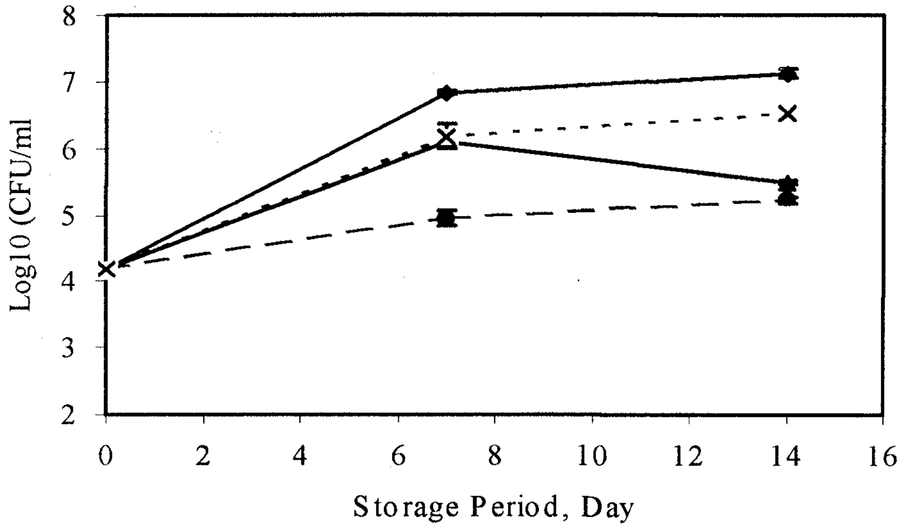
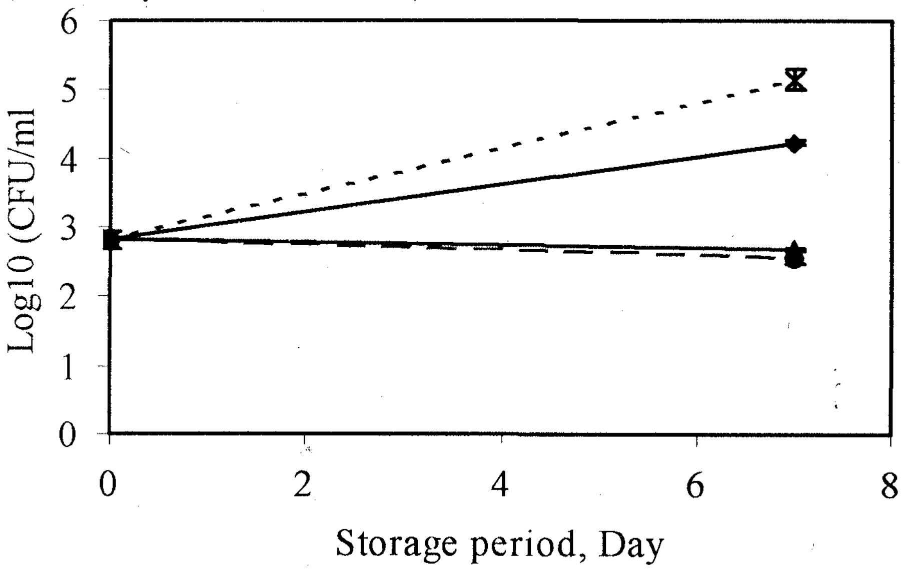


Fig. 5. Growth of coliform in packages of carrots in PP (•) and LDPE (▲) at 0°C and PP (♦) and LDPE (x) at ambient temperature (15-25°C). Standard deviation is indicated (lower than symbol sizes were omitted).



of the microenvironment of carrot packages in PP film may likely be associated with secondary decomposition.

Microbiological analysis

The change in total aerobic microorganisms is shown in **fig. 4**. The number of total aerobic microorganisms was higher in packages stored under ambient conditions than in those stored at 0°C. The lowest counts were observed in the least permeable packaging film (PP) up to day 14. The total number of populations of coliform on carrots was higher in both PP and LDPE films when stored under ambient conditions as compared to those stored at O°C (**Fig. 5**). Generally, the number of viable coliform was higher with carrots sealed in LDPE films over the 7 days of storage. Non of the plates has shown the precence of *E. coli* during the investigation.

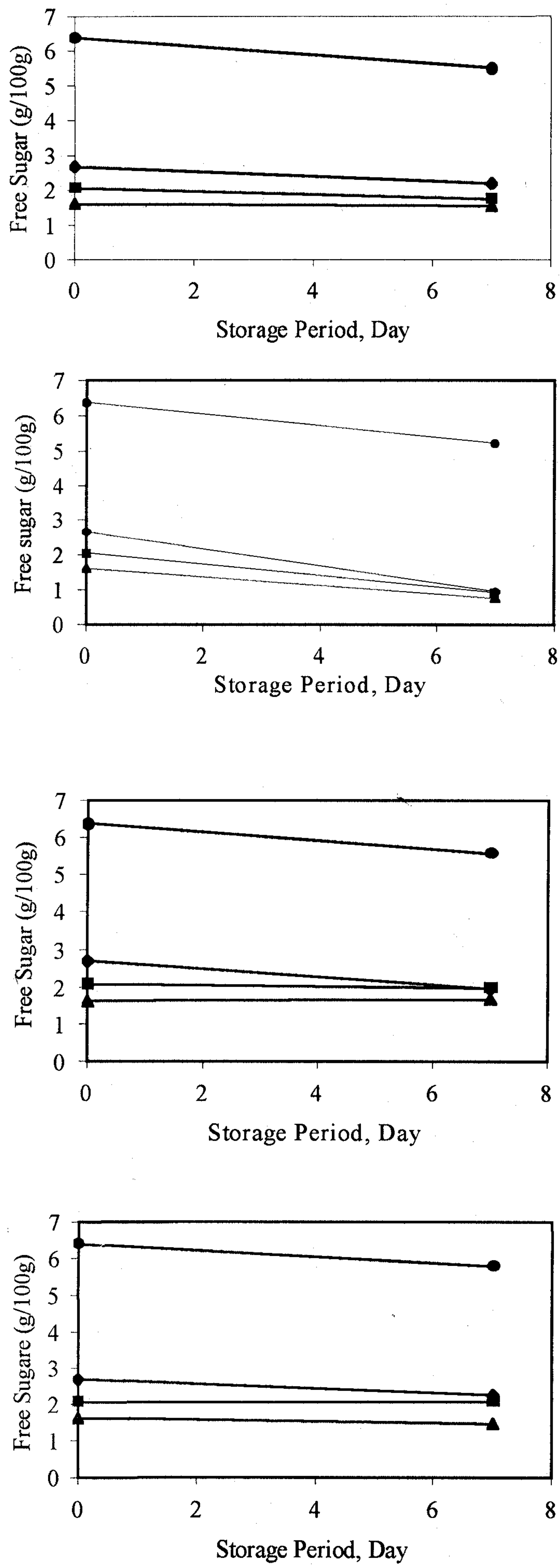
Sugar content

During storage, a general decrease of the sugars (sucrose, glucose and fructose) was observed for all samples packaged in PP and LDPE. The changes in total free sugar over 7 days of storage was found to be highest (1.17 g/100g tissue) for carrots packaged in PP and stored at ambient temperature (**Fig. 6 (b)**). The changes in total sugar for carrots packaged in PP and LDPE stored at 0°C was 0.88g/100g and 0.82 g/100g respectively. Storage at ambient conditions showed a sharper decrease in total free sugar of carrots packaged in PP (**Fig. 6 (b)**). These sugars in carrots were observed to decrease at a slower rate for packaging in LDPE (**Table 1**). No change in glucose content during the 7 days of storage was observed in LDPE stored at ambient temperature (**Fig. 6 (d)**). On the other hand, a slight decrease in sucrose was seen in packages sealed with LDPE film and stored at ambient temperature. The change in sugar content of carrots packaged with PP film followed the same pattern (**Fig. 6 (a)** and **(b)**). The greatest decrease in all free sugar content was observed in carrots packaged in PP films. The reason for these may be due to reduced respiration as a result of a depletion of headspace O_2 (**Fig.1**) and a consequent increase in CO_2 level (**Fig.2**). shortly after packaging. Sprouting was a serious problem with LDPE packaged carrots stored under ambient temperature and humidity, and could be an explanation of the small decrease in free sugars shown in **Fig. 6 (d)**. Starch may be transformed into sugars, particularly sucrose, glucose, and fructose, during the storage period and is largely dependent upon the storage temperature of vegetables which is ambient temperature in this case (Eskin *et. al.*, 1971).

The results show a relationship between CO_2 content in the headspace and the sugar content of packaged carrots. The higher the CO_2 content of the headspace the more the sucrose content decreased while the glucose and fructose content changed slower. The higher the CO_2 concentration was in carrot packaged in PP and stored at ambient temperature, the lower the total free sugar at the end of the 7 days storage period.

From the above results it appears that optimum packaging film for carrots would be a film, of which the permeability would result in very low moisture condensation, low moisture loss, and would maintain optimum gas composition during the storage period. The use of packaging films with microperforations or high permeability to oxygen could eliminate excessive low oxygen levels while maintaining high moisture contents. More permeable gas pathways and temperature compensation are desirable for modified atmosphere packaging systems to function effectively (Exama *et. al.*, 1993). Modified atmosphere packaging, when combined with low temperature storage of carrots (about 1°C) reduces both biological and biochemical activities resulting in the best product regarding aesthetic qualities.

Fig. 6. Changes in contents of sucrose (♦), glucose (■), fructose (▲) and total free sugars (•) of carrots packaged in PP and LDPE at 0°C (a and c respectively) and at ambient temperature (15-25°C) (b and d respectively).



(a) (b) (c) (d)

Conclusions

In this investigation it was found that optimum packaging film for carrots should lead to low condensation, but prevent moisture loss, and maintain optimum gas composition during the storage period. From headspace CO_2 and O_2 concentration data on packaged carrots it was concluded that LDPE film showed lower respiration rates and is preferred to the PP material. Lower respiration rate is associated with long storage life (Phan *et. al.*, 1975; Robinon *et. al.*, 1975; and Wills *et. al.*, 1981). Therefore, packaging films with relatively higher permeability to O_2 and CO_2 are preferred for maintaining normal respiration of carrots without the occurrence of secondary decomposition during storage. Modified atmosphere packaging combined with low temperature storage of carrots (about 1°C) reduces both biological and biochemical activities resulting in improved keeping quality.

The number of total aerobic microorganisms was higher in packages stored under ambient conditions than in those stored at 0°C temperature. The lowest counts were observed in the least permeable packaging film (PP) up to day 14. The total number of populations of coliform was higher with PP and LDPE films stored under ambient conditions as compared to those stored at O°C. The lease permeable packaging film (PP) performed well in keeping microbial population low during storage. However, high CO_2 concentration and low O_2 level associated with PP may most likely lead to secondary decomposition and anaerobic metabolism.

The results show a relationship between CO_2 content in the headspace and the sugar content of packaged carrots. The higher the CO_2 content of the headspace the more the sucrose content decreased while the glucose and fructose content changed slower. The higher the CO_2 concentration was in carrot packs in PP stored at ambient temperature, the lower the total free sugar at the end of the 7 days storage period.

For future work, more low-density films and packaging films with micro-perforations could be included when combining modified atmosphere packaging with less expensive adiabatic cooling processes for application in developing countries with hot climate.

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