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Role of silicone membrane in increasing the shelf-life and quality of tomatoes during storage

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The silicone membrane makes use of the ability of polymer to permit selective passage of gases at different rates according to their physical and chemical properties. The product stored maintains its own atmosphere by the combined effects of respiration process of the commodity and the diffusion rate through the membrane. The mean shelf-life of 80 days was observed when the tomatoes were stored at 5% CO_2 under low temperature (10±2°C; 85% RH) whereas the mean shelf-life of 67 days was recorded at 5% CO_2 under ambient condition (30±3°C; 60% RH). Among the interactions between the storage condition and varieties, the highest shelf-life of 88 days was observed in 'PKM-1' variety stored at low temperature and shelf-life of 71 days was observed at ambient condition at 5% CO_2. The quality parameters were not affected by silicone membrane storage and was on par with the naturally ripened tomatoes.

Keywords: Controlled atmosphere, Low temperature, Modified atmosphere, Shelf-life, Silicone membrane, Tomatoes

India is the second largest producer of vegetables in the world and accounts for about 15% of the world's production of vegetables. The current production level is over 80.26 million mt and the total area under vegetable cultivation is around 6.2 million ha, which accounts for 9.3% of world's vegetable production. Though India has reached new heights in the production of vegetables, the availability are still far behind when compared to other major vegetable producing countries, one of the reasons being, lack of proper post-harvest technologies. Recent survey shows that in India, annually about 50% of the total fruits and vegetables produced, amounting to more than 4500 million US dollars being lost due to poor post-harvest practices (Anon 1997). According to Indian Council of Medical Research (ICMR), per capita requirement of vegetable in India is 285 g/day, against the per capita availability of 145 g/day (Fageria et al 2003). The vegetable requirement in India is 185 and 220 million mt, during 2010 and 2020, respectively (Pandey and Singh 2004). Tomato *(Lycopersicon esculentum)* production was 7.48 million mt from 0.46 million ha (Anon 2004). The estimated overall post-harvest distribution system losses in tomato varied from 19.4 to 26.9%, including 10.1% loss at farm level (Madan et al 1993).

Low temperature with regular atmosphere (RA), low temperature with regular atmosphere and high RH atmosphere (HRA) and low temperature with high RH and modified / controlled atmosphere (MA/CA) storage are the common methods used to maintain the quality of freshly harvested produce. Modified atmosphere storage is one of the methods for extending shelf-life of the perishable and semi-perishable products by altering the relative proportion of atmospheric gases that surround the product (Day 1992). Proper control of temperature, RH and storage gas composition can maintain the product quality for longer periods than refrigeration and high RH alone (Raghavan and Gariepy 1984).

Silicone membrane technique is a controlled ventilation system that regulates gas levels of storage environment by relying on selective gas permeation (Raghavan et al 1982, Gariepy et al 1984). The membrane makes use of the ability of polymer to permit selective passage of gases at different rates according to their physical and chemical properties. The membrane is characterized by its gas diffusion rate and its selectivity. It is the gas permeability of membrane combined with respiratory activity of product that permits enrichment of CO_2 and depletion of O_2 inside the storage unit (O'Connor et al 1992, Exama et al 1993).

The main advantages of silicone membrane system are lower operating cost due to fewer controls and less maintenance during operation, lower refrigeration cost attributable to lower respiratory activity, membrane's high permeability to ethylene and low permeability to water vapour. With this background an effort was made to extend the shelf-life of a few selected varieties of tomatoes by using silicone membrane.

Materials and methods

Sample preparation: Tomatoes (varieties 'Co-1', 'Co-3' and 'PKM-1') were harvested at mature green stages (USDA 1976) and packaged within 4-6 h after harvest. The damaged / spoiled fruits were removed and uniform size fruits were used. The tomatoes were washed to remove the soil and other foreign materials. The surface of the fruit was treated with chlorine (100 ppm).

Storage condition: One hundred tomato fruits of same size at mature green stage (USDA 1976) were selected at random from each variety. The fruits were kept in ambient condition (30±3°C; 60% RH). The loss of moisture was estimated by difference in weight and the spoilage was determined by visual scoring. Time taken for 35% spoilage was noted and expressed as number of shelf-life days (Madan et al 1993). The quality parameters were analysed at weekly interval as suggested by USDA (1976). One hundred fruits of same size at mature green stage (USDA 1976) were stored at low temperature (10±2°C with 85% RH).

Modified atmosphere at ambient temperature: Impervious HDPE bottles of 1000 ml capacity were used for storage. The lids of the bottles were cut open to different diameters to fix the silicone membrane which consisted of fine nylon fabric (52 to 54 g/m^2) covered with a thin and uniform layer (about 90 microns; 80 g/m^2) of silicone rubber compound: dimethyl - polysiloxane of different surface area to maintain the desired CO_2 concentration as described by Raghavan et al (1982).

$$A = \frac{R_x * M}{K_x * X} \qquad \text{---(1)}$$

where, A=surface area of silicone membrane, m^2; M=mass of stored product, kg; X=desired CO_2 partial pressure difference across membrane, atm; R_x=respiration rate of tomato under MA, L CO_2 kg/m^2/ d; Kx=permeability of silicone membrane to CO_2, L d/m^2/ atm

The openings were covered with silicone membrane to maintain concentration of CO_2 at 2, 4, 5, 6, 8, 10 and 12% inside the container by regulating the surface area of silicone membrane exposed to the atmosphere as given in equation 1. Permeability characteristic of silicone membrane was found to be 23.9 x 10^{-14} mol/m/s/pa for CO_2, 3.8 x 10^{-14} mol/m/s/pa for O_2 and 1.7 x 10^{-14} mol/m/s/pa for N_2. Neoprene rubber sheet (1.5 mm thickness) was placed on the lid of impervious HDPE bottles to ensure complete air tightness. Surface sterilized fruits weighing approximately 500 g were stored in bottle along with ethylene absorbent sachets (10 g). Lid joint of the bottles was covered with a gum tape to avoid gas exchange. Bottle was stored at ambient condition (30±3°C and 60% RH). The CO_2, O_2 and N_2 composition were analysed using gas chromatography (NUCON make). Each treatment was replicated 4 times.

Modified atmosphere at low temperature: The fruits were stored at low temperature of 10±2°C and 85% RH with ethylene absorbent in an impervious HDPE plastic container of 1000 ml capacity. The composition of gas was analysed using gas chromatography.

Qualitative characteristics of fruit: The qualitative analyses of fruits were carried out at weekly interval. The skin and flesh thickness were measured using screw gauge with least count of 0.01 mm. The firmness of the fruit was measured using penetrometer. The pH was analysed using digital pH meter (Systolic digital pH meter). Acidity, ascorbic acid and β-carotene contents were analysed as per AOAC (1990). Lycopene content was analysed as per the method suggested by Adsule and Ambadan (1979). Reducing sugar, non-reducing sugar and total sugars were determined as per the procedure described by Ranganna (1986). The quality parameters were analysed at weekly interval during the storage period.

Statistical analysis: The data were analysed as Completely Randomized Design (CRD). Statistical significance was determined at $p < 0.05$ by ANOVA and the means were separated using Duncan's Multiple Range Test as per Panse and Sukhatme(1989). Each treatment was replicated 4 times.

Results and discussion

The correlations between the shelf-life and the quality parameters are shown in the Table 1. Skin and flesh thickness are considered as important traits in deciding the shelf-life. Fruit firmness also significantly influences the shelf-life (Madan et al 1993) skin and flesh thickness decreased as the ripening progressed. (Fig.1,2). Variation existed in the skin and flesh thickness of the fruits between varieties, days of storage and storage temperatures. Firmness is another important factor, which is closely associated with ripeness and shelf-life. The variation in the fruit firmness and the softening pattern are important factors, which determine the shipping ability and the post-harvest shelf-life of tomatoes. Firmness was highest (3.kg /mm^2) in 'PKM-1' variety on the day of harvest (Fig.3). The lowest firmness (1.64 kg /mm^2) was in 'Co-1' variety stored under MA at ambient temperature (28±3°C) on the day of storage.

Significant difference was observed in acidity and pH of fruit juice extracted from the fruits of different varieties, stored for different storage periods at differ-ent storage temperatures (Fig. 4, 5) Highest acidity of 0.56% was found on the 14th day and 21st day of storage in 'PKM-1' variety at ambient and low temperature storage, respectively. The corresponding pH values were 4.39 and 4.40, respectively (which were the lowest pH at the given storage conditions). The lowest acidity of 0.39% was recorded in 'Co-1' variety on 63rd day of storage under ambient condition with the pH value of 5.49 which was on par with the pH of low temperature stored 'Co-1' fruit on the 70th day of storage.

The lowest ascorbic acid (16.5 mg/ 100 g) content was observed on the day of harvest in 'Co-1' variety and the highest value of 38.6 mg /100 g on the 77th

Table 1. Correlation studies between shelf-life and the quality parameters under modified atmosphere storage

Skin thickness, mm	- 0.85*
Flesh thickness, mm	- 0.96*
Firmness, kg/mm^2	- 0.94*
Acidity, %	- 0.89*
pH	0.85*
Ascorbic acid, %	0.97*
Reducing sugars, %	0.97*
Non-reducing sugars, %	-0.92*
Total soluble solids, %	0.98*
Total sugars, %	0.97*
Lycopene, mg/100g	0.93*
β-carotene, mg/100g	0.97*

* $p \leq 0.05$ (n = 4)

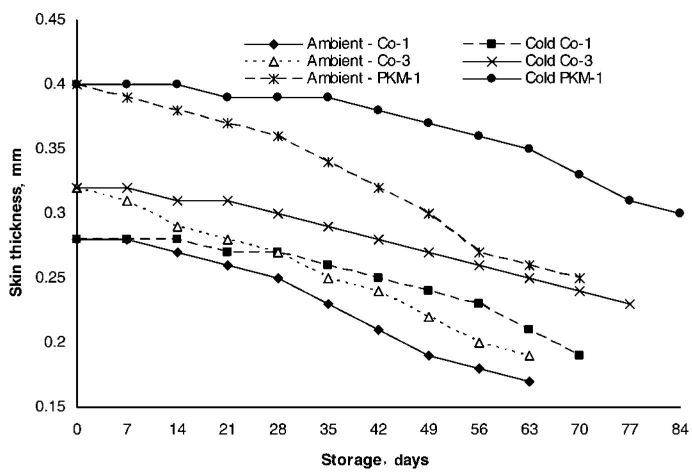

Fig. 1. Changes in skin thickness in different tomato varieties during storage (n=4)

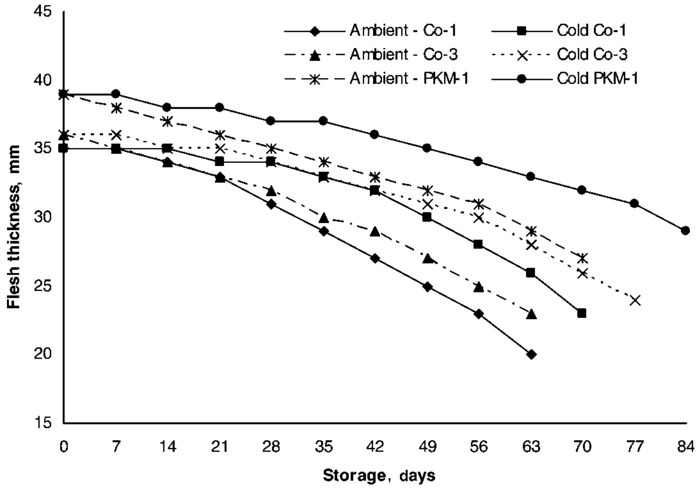

Fig. 2. Changes in flesh thickness in different tomato varieties during storage (n=4)

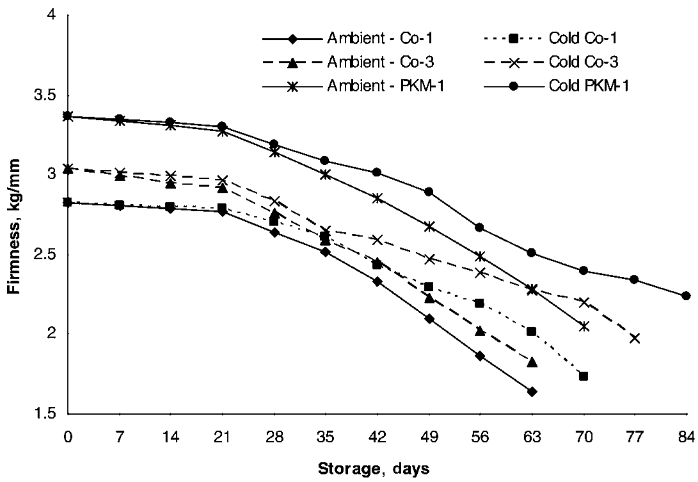

Fig. 3. Changes in firmness in different tomato varieties during storage (n=4)

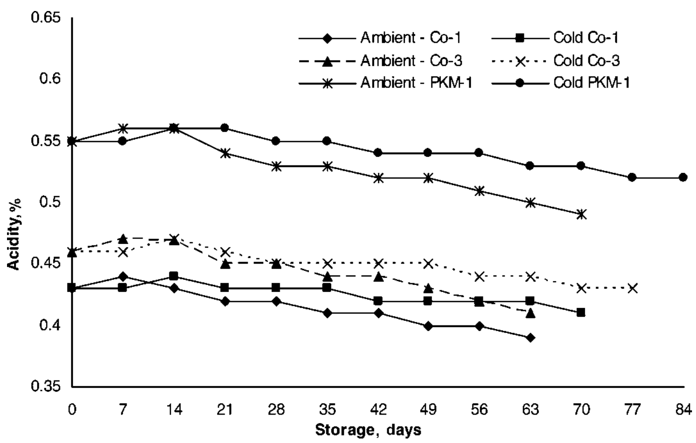

Fig. 4. Changes in acidity in different tomato varieties during storage (n=4)

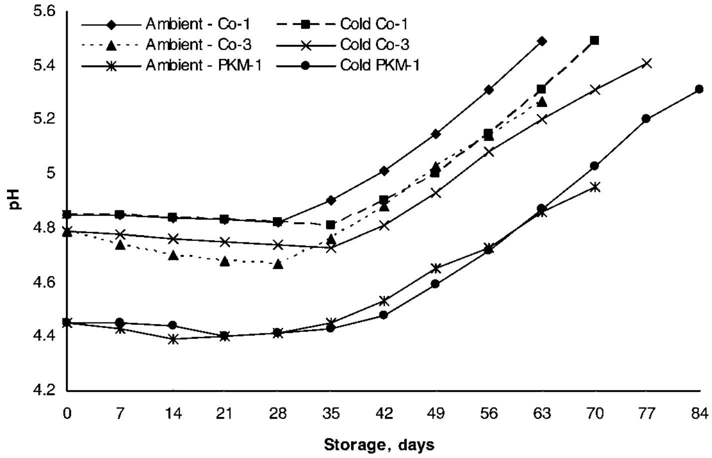

Fig. 5. Changes in pH in different tomato varieties during storage (n=4)

day of storage (from the initial value of 21.91) in 'Co-3' variety at the low temperature. (Fig.6). The total soluble solids (TSS) increased with increase in storage peroid in all the varieties at both storage temperatures (Fig.7). Highest TSS content (5.9%) was recorded in 'Co-3' variety on the 77th day of storage at low temperature, whereas the lowest TSS content (4.3%) was recorded in ' Co-1' on the day of harvest.

Reducing sugars was highest (5.7%) in 'Co-3' variety on the 77th day of storage under low temperature condition (from the initial content of 4.31%); and lowest of 3.4% was in 'Co-1' variety on the day of harvest (Fig. 8). Highest non-reducing sugar of 0.38% was recorded on the day of harvest in 'Co-1' and lower value of 0.18% in 'Co-3' variety on the 77th day of storage under low temperature (Fig.9). Highest total sugars (5.8%) was recorded in 'Co-3' variety on the 77th day under low storage (from the lowest total sugars of 4.61% on the day of harvest); total sugars was lowest (3.8%) in 'Co-1' variety on the day of harvest (Fig. 10).

The lycopene and β-carotene have a great role to play in the visual quality and thereby the marketability of the fruits stored. Both lycopene and β-carotene contents increased with increase in storage period, irrespective of the varieties and the storage temperatures (Fig.11, 12). The highest lycopene content of 11.1 mg/100g was recorded on the 63rd day of storage (from the initial value of 5.4 mg/100g) in 'Co-1' variety under ambient storage condition, whereas the lowest content of 3.2 mg/100 g was recorded in 'PKM-1' variety on the day of harvest. The highest β-carotene content of 261.8 mg/100 g was recorded in 'Co-1' variety on the 70th day of storage under low temperature storage (from the initial value of 179.6 mg /100 g) whereas the lowest (105.6 mg /100 g) was recorded in 'PKM-1' variety on the day of harvest.

In the present investigation, the longer shelf-life variety 'PKM-1' had higher skin and flesh thickness with higher firmness as compared to 'Co-1' and 'Co-3'. The qualitative characteristics also influenced the shelf-life of the fruits. Total pectic substances and alcohol insoluble solid contents were found to be strongly associated with greater cell wall thickness and consequently better firmness and storage life (Stevens and Kader 1979). Similar results have been reported for tomato fruits with lower TSS, reducing sugars, total sugars, pH, lycopene, β-carotene and higher acidity possessed higher shelf-life (Kopelovitch et al 1979, Davies and Hobson 1981, Tikoo 1987, Costa et al 1995). In the present study, 'PKM-1' variety possessed all the quality parameters as compared to 'Co-1' and 'Co-3' varieties, which could have led to its enhanced shelf-life.

It is seen from the Table 2 that irrespective of the varieties and temperatures, shelf-life increased with the increase in CO_2 concentration from 2 to 5% and further increase in CO_2 concentration up to 12% reduced the shelf-life. The highest mean shelf-life of 74 days was observed when the tomatoes were stored at 5% CO_2, whereas the lowest of 39 days was observed at 12% CO_2 concentration which was on par with the products stored at 2%CO_2(40 days). The mean shelf-life of 80 days was observed when the tomatoes

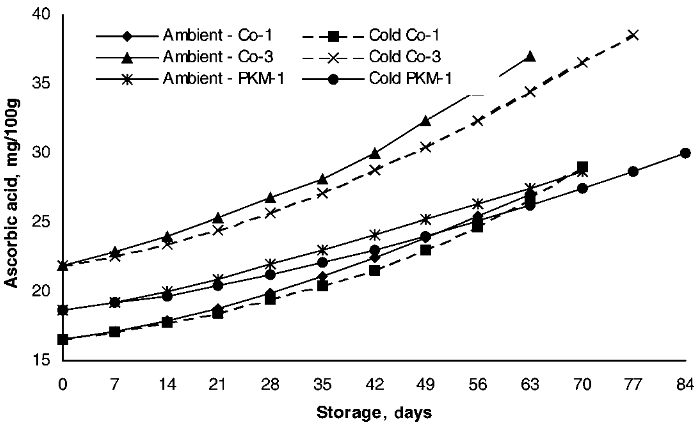

Fig. 6. Changes in ascorbic acid content in different tomato varieties during storage (n=4)

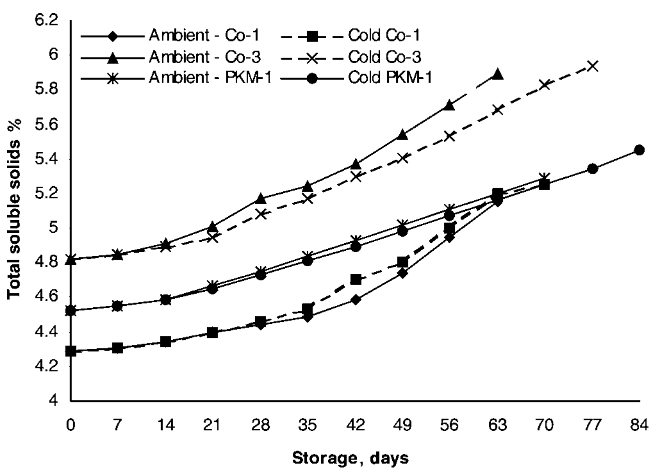

Fig. 7. Changes in on total soluble solids in different tomato varieties during storage (n=4)

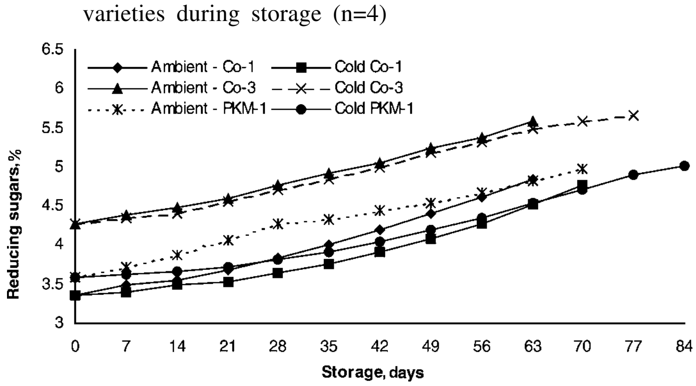

Fig. 8. Changes in reducing sugar content in different tomato varieties during storage (n=4)

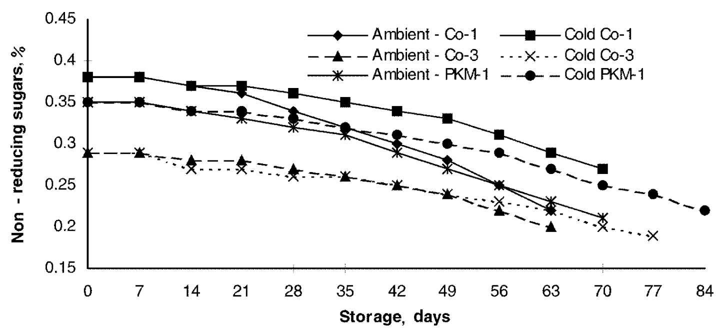

Fig. 9. Changes in non-reducing sugar content in different tomato varieties during storage (n=4)

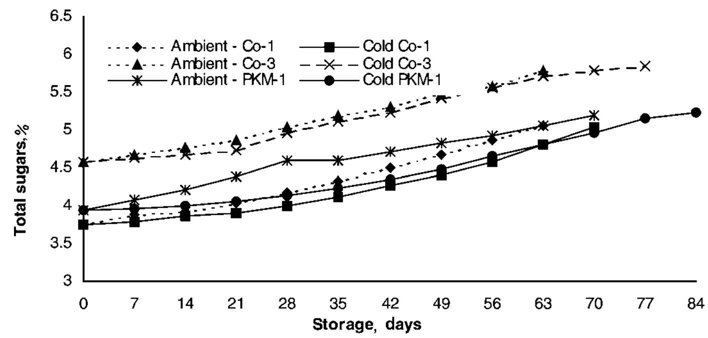

Fig. 10. Changes in total sugar content in different tomato varieties during storage (n=4)

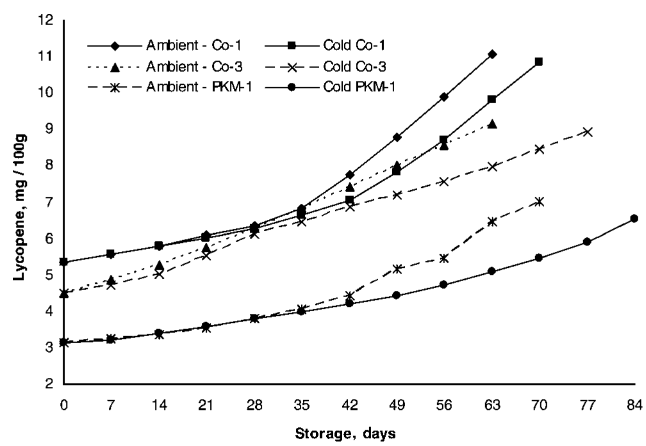

Fig. 11. Changes in lycopene content in different tomato varieties during storage (n=4)

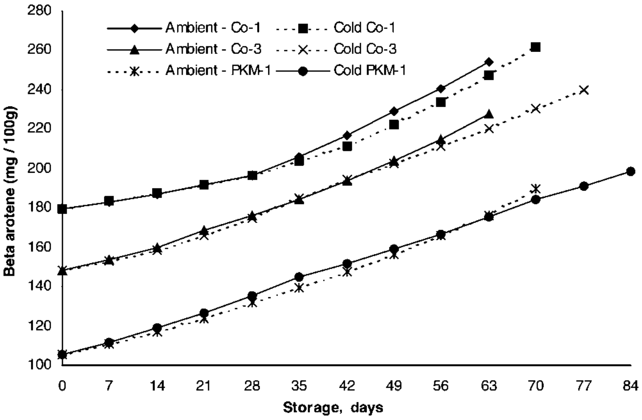

Fig. 12. Changes in β-carotene content in different tomato varieties during storage (n=4)

were stored at 5% CO_2 under low temperature (10±2°C with 85% RH) whereas the lowest shelf-life of 34 days was recorded at 12% CO_2 under ambient condition (30±3°C, 60% RH) (Table 2). Among interactions, for tomatoes stored at low temperature the highest shelf-life of 88 days was observed in 'PKM-1' variety at 5% CO_2 whereas the lowest shelf-life of 37 days was observed in 'Co-1' variety at 12% CO_2. For tomatoes stored at ambient condition the highest shelf-life of 71 days was observed in 'PKM-1' variety at 5 % CO_2 whereas the lowest shelf-life of 31 days was observed in 'Co-1' variety at 12 % CO_2. Comparison between the shelf life of the tomatoes stored under different temperatures revealed that the mean shelf-life was higher at the cold storage than at ambient condition. Similar results have been reported for tomato (Davies and Hobson 1981, Costa et al 1995).

High respiratory activity has been associated with short storage life and indicates the rate of deterioration in quality (Phan 1975). Modified atmosphere creates an environment, which reduces the metabolic activity of exposed product. It directly influences the rate of respiration by modifying or retarding the normal biochemical reactions that occur under normal atmosphere. Salisbury and Ross (1969) showed that the relative release of CO_2 decreased as the available O_2 decreased from its availability in air (21%) to approximately 3%. In this range of O_2 concentration, the Kreb's cycle is predominant energy generating system functioning in the organ and bulk of CO_2 is evolved from this system. In the presence of adequate O_2, release of CO_2 by glycolysis is minimal, but when O_2 becomes limiting factor, there is a rapid rise in CO_2 evolution, since the glycolytic system is no longer inhibited by O_2 and takes over the energy supplying function (Pasteur effect). This is the optimum storage condition which could have occurred at 5% CO_2 in the present investigation, thereby enhancing the shelf-life of tomatoes.

By the reduction of O_2 level below 10%, respiration rate also significantly gets reduced (Palma et al 1993). However, reduction of oxygen concentration below 2% or the tolerance limit of the commodity can lead to anaerobic respiration leading to the accumulation of aldehydes and ketones (Brady 1992). CO_2 levels above 10% causes off odour development and browning injury. In the present investigation, optimum level of CO_2 was 5%. Increase in the level of CO_2 reduced the shelf-life of the tomatoes irrespective of temperature and varieties. The reduced O_2 level could aggravate the injury. The effects of increased CO_2 and reduced O_2 were synergistic (Hochhaus and Wild 1993).

Table 2. Shelf-life (days) of tomatoes under modified atmosphere at two different conditions

CO_2,%	'Co-1'		'Co-3'		'PKM – 1'		Mean	
	A	C	A	C	A	C	A	C
0.03%*	8.0^{h}	17^{h}	8^{h}	17^{h}	10^{h}	20^{h}	9	18
2	34^{f}	41^{f}	36^{f}	44^{f}	39^{f}	48^{f}	36	44
4	56^{c}	65^{c}	58^{c}	69^{c}	62^{c}	79^{b}	59	71
5	63^{a}	73^{a}	67^{a}	79^{a}	71^{a}	88^{a}	67	80
6	60^{b}	68^{b}	63^{b}	71^{b}	67^{b}	77^{c}	63	72
8	48^{d}	53^{d}	50^{d}	56^{d}	51^{d}	59^{d}	50	56
10	37^{c}	43^{e}	41^{e}	48^{e}	46^{e}	54^{e}	41	49
12	31^{g}	37^{g}	34^{g}	41^{f}	40^{f}	49^{f}	34	41

CD (0.05) 1.51, SEd 0.76 (n = 4); * : Ambient
A= Storage at ambient condition (temperature 30±3°C; RH = 60%)
C= Storage at cold condition (temperature 10±2°C; RH = 85%)
Values bearing different superscripts in a column differ significantly ($p \leq 0.05$)

Conclusion

Silicone membrane makes use of ability of the polymer in it to permit the selective passage of gases at different rates according to their physical and chemical properties to obtain required modified atmospheric condition. The product stored maintains its own atmosphere by combined effects of respiration process of the commodity and diffusion rate of the various gaseous components through the membrane. The mean shelf-life of 80 days was observed when the tomatoes were stored at 5% CO_2 under low temperature (10±2°C and 85% RH) and 67 days under ambient conditions (30±3°C and 60% RH). Among the interactions between storage condition and varieties, the highest shelf-life of 88 days was observed in 'PKM-1' variety stored at low temperature at 5% CO_2 whereas the shelf-life was 71 days under ambient conditions for the same variety. The quality parameters were not affected by silicone membrane storage and were on par with the naturally ripened tomatoes. Hence, this technology can be used to increase the shelf-life and thereby reduce the post-harvest losses in tomatoes.

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