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FOOD PACKAGING AND SHELF LIFE

Shelf-life enhancement of green bell pepper (*Capsicum annuum* L.) under active modified atmosphere storage

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ABSTRACT

The effect of modified atmosphere packaging (MAP) along with moisture absorbent was assessed for maintaining quality attributes and extending shelf life of green bell pepper (*Capsicum annuum* L.) in bulk packages. Under active packaging the quality of capsicum were based on MAP using permeable polymeric films and sachets of silica gel crystals as moisture absorbents. Pre-designed polypropylene film (38 μm) packages were used for storage study under MAP at 8 ± 1 °C temperature. The in-pack O_2 and CO_2 composition and respiration rate in the package headspace was monitored during storage in all the treatments. A modified atmosphere of 4.5% O_2, 7.8% CO_2 and 4.7% O_2, 7.5% CO_2 were achieved in the MA packages with and without moisture absorbent, respectively. The active packaging significantly reduced the respiration rate of fruit in the package. These packaged fruits were compared with non-packaged samples, which served as control stored at both ambient conditions (CS) and control at refrigerated temperature (CR). The quality of capsicums was assessed by physiological weight loss, color (L^*, h^* and C^*) values, firmness, ascorbic acid, decay and marketability. The shelf life of bell pepper was extended to 49 days in active packages, 42 days with MA packages, as compared to 21 days with CR packages and 7 days with CS. Above all, by placing silica crystals sachets in the head space with moisture absorbing ability, could further extend the shelf life of capsicum 7 days in addition to modified atmosphere packaging alone with 97% fruit marketability.

1. Introduction

Green bell pepper (*Capsicum annuum* L.) is an annual herbaceous vegetable crop which belongs to the family *Solanaceae*. It is one of the most popular and high valued crops worldwide and specially grown in tropical and subtropical parts of the world (Lim, Kang, Cho, Gross, & Woolf, 2007), and is commonly known as capsicum (Mahadu & Ranganna, 2010). It is produced throughout the world for fresh market consumption. Its consumption is growing popularity mainly due to its availability in wide variety of colors, shapes and sizes and its characteristics flavor (Couey, 1989; Frank, Nelson, Simonne, Behe, & Simonne, 2001; Lucier and Lin, 2001). Pepper is rich in vitamins, especially A and C, and is low in calories (Howard, Smith, Wangner, Villalion, & Burns, 1994).

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Bell pepper is a highly perishable vegetable and needs appropriate handling and adequate care to maintain shelf-life and quality. Alleviation of water stress is the main factor extending postharvest life of bell pepper sealed in plastic film (Ben-Yehoshua, Shapiro, Chen, & Lurie, 1983; Lurie, Shapiro, & Ben-Yehoshua, 1986; Pandey and Goswami, 2012). However, excessive relative humidity (RH) and consequent water condensation may increase the risk of fruit decay (Polderdijk, Boerrigter, Wilkinson, Meijer, & Janssens, 1993). The storage life of capsicum significantly reduces if the control of moisture levels within the package is inadequate. The development of elevated relative humidity inside a package due to respiration of products or use of materials having low permeability to water vapor can cause condensation, which can then lead to reduced quality and safety of the produce due to microbial proliferation (Scully & Horsham, 2006).

The storage life of pepper fruit is limited by pathological deterioration (Ceponis, Cappellini, & Lightner, 1987), rapid water loss during prolonged storage (Diaz-Perez, Muy-Rangel, & Mascorro, 2007), and susceptibility to chilling injury (Paull, 1990). The most common decay microorganisms are Botrytis (gray mold), Alternaria, and soft rots of fungal and bacterial origin. Botrytis can grow even at the recommended pepper storage temperatures. High levels of CO_2 (> 10%) can control Botrytis, but it may damages peppers. The presence of Alternaria black rot on the stem end is a symptom of chilling injury. Bacterial soft rot is caused by several bacteria which attack damaged tissue. Soft rots can occur on washed or hydro-cooled peppers, where water sanitation was inadequate. A RH of 60–70% is desirable (Gonzalez-Aguilar & Tiznado, 1993; Wang, 1977).

Peppers are subject to chilling injury when stored below 7 °C and to accelerated ripening and bacterial soft rot when stored above 13 °C. Storage at 5 °C reduces water loss and ripening, but after 2 weeks chilling injury will appear and is associated with severe pitting, weight loss, calyx darkening and decay development (Lim et al., 2007; Mercado, Quesada, Valpuerta, Reid, & Cantwell, 1995). Some pepper cultivars can be sensitive to chilling if stored at 7 °C (45 °F), so a good storage temperature range should be 7–13 °C (Gonzalez-Aguilar, 2004).

Modified atmosphere packaging (MAP) along with low temperature storage extends the shelf life of fresh produce packaged in polymeric films through interaction of the natural process of respiration of produce with the restricted gas exchange across the package. Peppers derive a slight benefit from CA storage (Brackett, 1990; Rodov, Ben-Yehoshua, Fierman, & Fang, 1995; Saltveit, 1997). Low O_2 atmospheres (2–5% for bell and 3–5% for chili) retard ripening and respiration during transit and storage, and have a slight benefit on quality. At 10 °C, high CO_2 (>5%) can cause calyx discoloration, skin pitting, discoloration and softening in both bell and chili peppers. A 3% O_2 + 5% CO_2 atmosphere is more beneficial for red than green peppers stored at 5–10 °C for 3–4 weeks. Before processing, chili peppers can be stored under 3–5% O_2 + 15–20% CO_2 for up to 3 weeks at 5 °C (41 °F) without appreciable chilling injury or quality loss. Water-loss from fresh produce can occur as a result of evaporation from the product followed by permeation through the package material when the package material does not provide an adequate water-vapor barrier (Kader, Zagory, & Kerbel, 1989; Meir, Rozenberger, & Aharon, 1993). Janssens (1993) recommended 90–95% relative humidity at 8 °C for an optimal balance between decay and dehydration for container transportation of bell pepper in controlled atmosphere.

A possible solution to control humidity would be to use desiccants. Soaking up moisture by using various absorbers or desiccants is very effective in maintaining food quality and extending shelf life by inhibiting microbial growth and moisture related degradation of texture and flavor (Rodrigues & Han, 2003; Rooney, 2005). Several researchers have studied the use of desiccants but most of these were based on a trial-and-error approach (Mahajan, Rodrigues, Motel, & Leonhard, 2008). Various agents such as sorbitol, xylitol, NaCl, KCl, $CaCl_2$ and silica gel have been used to control in-package relative humidity for different fresh fruits and vegetables (Anantheswaran, Beelman, & Roy, 1996; Ben-Yehoshua, Rodov, Fishman, & Peretz, 1998; Evelo and Horst, 1996; Rodov et al., 1995; Roy, Anantheswaran, & Beelman, 1995; Shirazi & Cameron, 1992; Song, Lee, & Yam, 2001; Villaescusa & Gil, 2003). Ben-Yehoshua et al. (1983) used 5 g of $CaCl_2$ per fruit to control relative humidity between 80% and 88% in packages containing bell pepper, whereas (Chinnan and Yang, 1989) used $CaCl_2$ in tomato packages.

Probably the best-known internal package moisture absorbers are conventional silica gels, which can absorb up to 50% of their own weight in water (De Jong et al., 2005). The use of moisture absorber sachets using silica gel/crystal is a common practice (Rooney, 1995). This approach allows food packers or even householders to decrease the water condensation on the surface of foods by reducing in-pack RH. This can be done by placing one or more moisture absorbents between two layers of water permeable plastic or in headspace in the form of sachets (Labuza & Breene, 1989; Rooney, 1995). Moisture absorbents protect sensitive products against water and humidity. They absorb moisture that enters or remains in a package. Silica gels are useful to maintain dry conditions within packages of dry foods, down to below 0.2 water activity (Rooney, 1995). Moisture-scavenging systems based on desiccation are evolving to control the moisture by maintaining a specific relative humidity inside the package by absorbing or releasing the moisture (Hutton, 2003). In the present investigations, the post-harvest shelf life and quality indices of mature green bell pepper was evaluated under modified atmosphere packaging with sachets of silica crystal as moisture absorbent.

2. Materials and methods

2.1. Fruit material

Bell pepper (cv. *Swarna*) fruits of uniform size, without defects or diseases were hand-picked at their commercial maturity (firm and bright green) during the month of June from PFDC farm of Central Institute of Agricultural Engineering, Bhopal, India and transferred to packaging laboratory immediately. They were visually inspected for freedom from defects and blemishes and non-uniform, damaged, poor quality peppers were removed. Peppers were disinfected with sodium hypochlorite (100 ppm) solution in water at room temperature (25 °C) for 5 min. The washed fruits were air-dried at ambient temperature for 30 min to remove surface moisture before the experiment began. The adopted hygiene rules and low storage temperatures are consisted with the food safety regulations (Gil, Allende, & Selma, 2011; Gonzaléz-Aguilar, Ayala-Zavala, Ruiz-Cruz, Acedo-Félix, & Diaz-Cinco, 2004).

2.2. *Design of packaging system*

Active modified atmosphere packages (AMAP) were designed based on the respiration rates of the products, film parameters and environment factors. The respiration rate of pepper fruits was determined as per the method adopted by Singh, Giri, Kulkarni, and Ahirwar (2012). Film parameters such as water vapor transmission rate (WVTR), oxygen transmission rate (O_2TR) and carbon dioxide transmission rate (CO_2TR) of the films were measured using a Water Vapor Transmission Rate Analyzer (Model: TSY-W3-3, Labthink, China) as per ISO 15106-3 standards, and Gas permeability tester (Labthink, Model BTY-B2P, China) as per ISO 5636, SJT 1071.9 standards, respectively. Based on design calculations (Singh, Kumar, & Singh, 2011) perforated polypropylene (PP) film was selected for bulk packaging of capsicum (10 kg). The detail of packaging design is summarized in Table 1. Based on design calculations and by comparing the values of required permeability of designed film with those of commercially available films, a best suitable film (nearest to the design calculations) for extending the shelf life and maintaining the quality of capsicum was 38 μm thick polypropylene (PP) with ten perforations of 0.3 mm made using a needle, and was selected for bulk (10 kg) active packaging of capsicum along with modified atmosphere (MA) at 8 ± 1 °C. Gas permeance through pores were calculated using standard formulas (Techavises & Hikida, 2008). The designed film was provided by Systec Packaging, Ludhiana, India.

2.2.1. *Moisture absorbent*

Silica gel crystals of 5–8 mesh size (supplied by Otto Chemie Pvt. Ltd., Mumbai, India) were used as moisture absorption agent for control of moisture inside MA package. The sachets were prepared @ 9 g of dry silica crystals per kg of packed fruits by filling pure silica crystals in woven polyester cloth with high permeability (Rooney, 1995). The weight of each sachet was 90 ± 2 g and the maximum water vapor absorption capacity of the dried silica gels was 35% of their own weight at a relative humidity of 90% (Fig. 1).

2.2.2. *Active packaging with modified atmosphere storage*

Pre-cooled fruit samples were exposed to UV light treatment for 5 min for surface disinfestations and were packaged in 38 μm thick PP flexible packages containing about 10 kg fruit. A pre-designed silica crystal sachet was tied along with package seal with silicon thread in the headspace of the packages for active MAP study of fruits. The bags were air-tight sealed with and without moisture absorbents. The treatment bags were immediately shifted and were stored in dark at 8 ± 1 °C and 95% relative humidity (RH) in environmental control chamber (Remi Laboratory Instruments, India) and analyzed at every 7th day interval until the end of the shelf life. By the end of the experiments, the fruit packages were immerged in water to

Table 1 – Design parameters for modified atmosphere packaging of capsicum.

Package parameters	Package properties	Unit	Value
Produce parameters	Unit weight of fruit	g	250 ± 10
	Weight of the sample in package	kg	10
	Density	kg/m^3	253 ± 5
	Respiration rate (RR) at 8 °C and 95% RH	ml-CO_2/kg-h	21
	Void volume	lit	7.2
Packaging film parameters	Type of film	Polypropylene	–
	Thickness of film	μm	38
	Area of packaging film	m^2	0.39
	Headspace	%	10
	Atmospheric O_2	Volume-%	20.9
	Atmospheric CO_2	Volume-%	0.03
	Desired oxygen (O_2) level in the package	Volume-%	3
	Desired carbon-dioxide (CO_2) level in the package	Volume-%	5
	Available gas permeability of film		
	O_2 permeance	cc (STP)/m^2-	2521.2
	CO_2 permeance	day-bar	8511.0
	Required permeability of film		
	OTR	cc (STP)/m^2-	44,847.2
	CTR	day-bar	238,463.7
	Activation energy (O_2)	kcal/mol	11.48
	Activation energy (CO_2)	kcal/mol	9.09
	WVTR	g/m^2-day-bar	120
	Number of perforations	Number	10
	Size (diameter) of perforations	mm	0.3
Environmental factor	Storage temperature	°C	8 ± 1
	RH	%	90–95

STP: 1.013 bar, 23 °C.

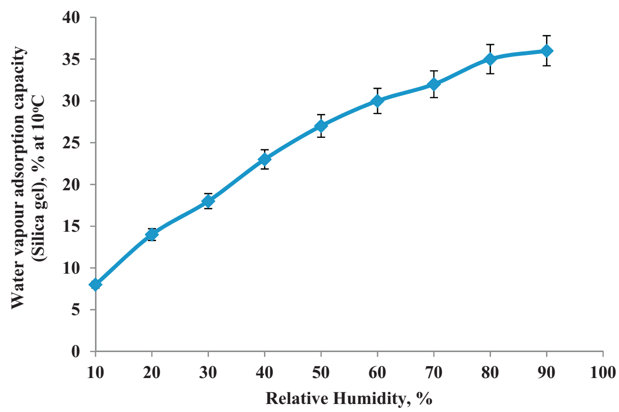

Fig. 1 – Water vapor sorption isotherm of silica gel at 10 °C temperature and different relative humidities.

test for probable leakage, to evaluate the free volume inside the package and disposed off safely.

2.2.3. Control experiments

In another experiments, fruit lots were filled in 38 μm thick PP polymeric flexible packets containing about 10 kg fruits and kept open for control storage (CS) in ambient conditions at mean day temperature of 27 °C and 72% relative humidity as well as in refrigerated conditions (CR) at 8 ± 1 °C and 95 ± 3% relative humidity. Fruits were evaluated for various quality parameters on every day 7 during storage as discussed under Section 2.4.

2.3. *Measurement of in-pack gaseous composition and respiration rate*

The in-pack gaseous composition of O_2 and CO_2 were analyzed in all MA packages during storage using a portable headspace gas analyzer (Model GS3M, Systech Instruments Ltd., UK). The apparatus uses an electrochemical and an infrared sensor to evaluate the headspace gas concentration and express in percent. The gas analyzer was calibrated with reference gases and the sensor probe was inserted in the headspace of polymeric package and sensor signals were converted to gas concentration values of O_2 and CO_2, which were directly read on the digital display panel. The respiration rate (RR) of fruits in terms of CO_2 liberated (ml/kg-h) were determined in all treatment packages during storage as per the method adopted by Singh, Kumar, and Kulkarni (2012).

2.4. *Evaluation of shelf life quality*

Loss of firmness is one of the main factors limiting quality and the post-harvest shelf-life of fruit and vegetables (Barth, Kerbel, Perry, & Schmidt, 1993). Fruit firmness was analyzed by measuring the maximum compression force using Texture Analyzer Stable Micro Systems, Model TA.XT.*plus* (Surrey, UK), fitted with a stainless steel compression plate (length 15 cm, circular dia. 7.5 cm) using a 50 N load cell. Texture analysis was done on 3 fruits per replication with each fruits compressed on the side at the equatorial region. The data were recorded in triplicate and the mean values were expressed as kgf.

Color development of fruit (skin) was measured at harvesting and during storage using a colorimeter (chroma-meter) (Miniscan XE plus, Hunter associates, USA) appropriately calibrated with a standard white tile (UE certificated) with the following parameters: $X = 83.47$, $Y = 84.43$, $Z = 95.16$ with illuminant $C/2°$ (light source used for the day lighting), according to CIE L^*, a^*, b^* scale. The a^* measures the degree of redness ($+a^*$) and greenness ($-a^*$) while the b^* the degree of yellowness ($+b^*$) and blueness ($-b^*$). The measured a* and b^* values were used to estimate chroma values, $C^* = (a^*2 + b^*2)0.5$ and hue angle degrees $h^* = \arctan{-1}(b^*/a^*)$. The hue angle values greater than 90° correspond to intense green color while values close to 90° indicate yellow color. Chroma defines the color intensity or purity of the hue. Values close to 0 correspond to neutral colors and values close to 60 to bright colors (Mcguire, 1992). Depending on the sampling scheme and accuracy, the L^*, a*, b^*, h^* or C^* values can provide a satisfactory color description (Manolopoulou, Xanthopoulos, Douros, & Lambrinos, 2010). The color of the fruit was measured on every 7th days of storage, the '*L*', and '*a*' values were recorded as an average of 15 measurements.

Physiological loss in weight was determined by weighing all samples with a laboratory level weighing scale (Model CT-35K2, Contech Instruments Ltd., India) having least count ±2 g at the beginning and end of the storage period. The difference between the two values was considered as weight loss and expressed in percentage:

$$\text{PLW}\,(\%) = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

2.4.1. Ascorbic acid content

Pepper is an excellent source of ascorbic acid that very with maturity, genotype and processing. Ascorbic acid was determined using the 2,6-dichlorophenolindophenol method (AOAC, 1990) and expressed in mg per 100 g of the initial fruit mass as well as per unit weight of dry matter. Measurements were taken at the beginning and on every 7th days of storage to assess the variability in ascorbic acid content with storage. Measurements of the ascorbic acid were carried out in all packaging treatment, as an average of 3 measurements.

2.4.2. Decay and marketability

Percentage of decay was obtained from the number of fruit that showed signs of decay over the initial number of fruit. The cumulative decay during storage period was recorded and expressed as a percentage. The percent samples excluding decay after end of the storage period represent marketability.

2.5. *Statistical analysis*

The experimental data were analyzed using GLM procedure available in SAS (SAS Institute India Pvt. Ltd.) available at CIAE, Bhopal. Completely Randomized Design (CRD) was used in the experiment. The experimental design is presented in Table 2. The significance of different methods, their pair wise comparison and estimations of coefficients were carried out. The pair wise comparison was performed using Tukey's Studentized Range (HSD) Test.

Table 2 – Experimental design for the study.

	A: Treatment	MAP (modified atmospheric package)	3 replications each
		AMAP (active MAP)	
Factors		CS (control ambient storage without packaging)	
		CR (control refrigerated without packaging)	
	B: Storage period (DOS)	0–7 weeks	–
Interactions	A	Treatment	4
	B	Storage period	7
	A × B	Treatment × Storage period	84
Constants	RH	95% (Cont.)	–
	Storage temperature	8 ± 1 °C (Cont.)	–
		To examine effect on quality indices for enhanced shelf life as	
RR	In-pack gas composition	PLW, color, texture, ascorbic acid,	Decay and marketability

3. Results and discussion

3.1. *In-pack gaseous composition*

In pack gaseous composition in terms of O_2 depletion and CO_2 evolution during the storage of fresh whole peppers in different packaging system at 8 ± 1 °C temperature is showed in Fig. 2. It was observed that, by the end of day 7, a rapid decline in O_2 and subsequently rapid increase in CO_2 evolution set-in both the AMAP and MAP treatments and then maintained steady state thereafter. The range for steady state headspace gas composition in AMAP package varied between 20.9% and 4.2% for O_2 and 0.03% and 7.8% for CO_2. Whereas, the range for steady state headspace gas composition in MAP package varied between 20.9% and 4.7% for O_2 and 0.03% and 5.6% for CO_2. In AMAP sample, the O_2 gas depletion and CO_2 gas evolution was 4.45% and 9.85%, respectively between start of steady state condition by day 7 and by the end of storage period (day 49). Similarly, in MAP samples, the O_2 gas depletion and CO_2 gas evolution was 6.38% and 9.8%, respectively between start of steady-state condition by day 7 and by the end of storage period (day 49). The headspace gas composition was found to be non-significant at 5% level of significance ($p \leq 0.05$) and unaffected by type of packaging system and duration of storage. At 8 ± 1 °C, the respiratory activity consumed O_2 by the end of day 7 of storage although at the end of the storage no tissue injuries or off flavors were detected. Similar trend of O_2 depletion and CO_2 evolution during MAP storage was reported by Singh, Giri, and Kulkarni (2013) for guava, Singh et al. (2012c) for mango, and Kaur, Rai, and Paul (2011) for spinach storage at low temperature.

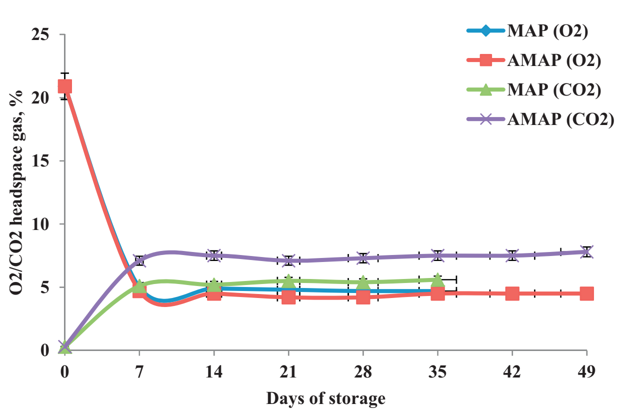

Fig. 2 – In pack gas composition in terms of O_2 depletion and CO_2 evolution in active MA package (AMAP) and modified atmospheric package (MAP) during storage at 8 ± 1 °C temperature.

The analysis of variance of O_2 level, CO_2 level of capsicums by different methods is presented in Table 3. The effect of storage period on O_2 and CO_2 level in packages were found to be significant at 1% level of significance. O_2 and CO_2 levels were significantly affected by methods of storage. Also R^2 and coefficient of variation (CV) for each parameter indicates goodness of fit of the model and coefficient of variation of the variable under study was found very low, respectively (Table 3). The pair wise comparisons and minimum significant difference (MSD) at $p = 0.05$ level of significance was carried out and found to be different over different methods of storage for O_2 and CO_2 levels (Table 4).

Table 3 – ANOVA of gas compositions (O_2/CO_2) levels and respiration rate of capsicums stored by MAP and AMAP.

Source	DF	*p*-Value		
		O_2	CO_2	RR
Model	8	<0.0001	<0.0001	<0.0001
Treatment	1	0.0031	0.0003	0.6704
DOS	7	<0.0001	<0.0001	<0.0001
Error	7			
Total	15			
R^2		0.99	0.97	0.98
CV		2.05	9.12	8.92
RMSE		0.13	0.51	1.92

Table 4 – Pair wise comparison of gas compositions (O_2/CO_2) levels and respiration rate of capsicums stored by MAP and AMAP.

Methods	Mean		
	O_2	CO_2	RR
AMAP	6.50	6.51	21.33
MAP	6.80	4.78	21.79
MSD	0.16	0.61	2.51

3.2. *Respiration rate*

The RR in terms of CO_2 evolution for AMAP and MAP of the whole pepper was 45.5 and 49.1 ml CO_2/kg-h, respectively after 7 days of storage (Fig. 3). The RR of the samples in both the AMAP and MAP treatments decreased sharply and attained a value of 30.30 ml CO_2/kg-h and 32.40 ml CO_2/kg-h, respectively on day 14 probably due to the exhaustion of the necessary substrates and conversion of carbohydrates for retaining high RR. By the end of day 21, RR of both the AMAP and MAP samples declined by almost 6.6–7.6 ml of CO_2/kg-h during last week. A declining trend in both the samples was observed throughout the storage period. After passage of 21 days, up to the end of the respective storage period in both the AMAP (49 days) and MAP (42 days) samples the declined in RR (CO_2) were 16.95–39.3 ml of CO_2/kg-h, respectively. An overall decline in terms of RR of the whole peppers in AMAP samples was 14% by the end of 49 days of storage. However, an overall decline in RR was 19% for MAP sample by the end 42 days of storage period. Both the AMAP and MAP samples showed a similar trend of decrease RR during and by the end of storage period. The mean RR values for the pepper at 8 ± 1 °C were 21.336 mL-CO_2/kg-h and 21.796 mL-CO_2/kg-h for AMAP and MAP, respectively. Similar results were obtained by Saltveit (1997), Gonzaléz-Aguilar et al. (2004) and Jin-hua, Mao-run, Miao-miao, and Wei (2007) for respiration rate of bell peppers. The measured RR values followed similar trend to those reported by Kang and Lee (1997) for capsicum, Caleba, Mahajan, Oparaa, & Witthuhn (2012) for pomegranate; Manolopoulou et al. (2010) for cut fresh bell pepper, Singh, Kumar, and Singh (2012) for chickpea sprouts; Singh, Giri, et al. (2012) for mango.

The analysis of variance for respiration rates of capsicums in different treatments is presented in Table 3. The respiration rate (RR) of the MA packages with silica gel was slightly lower than those without the absorbent, may be due to less relative humidity levels in packages with silica gel crystals. Alferez, Agusti, and Zacarías (2003) found similar results of decreased respiration rate in oranges when the relative humidity was decreased from 90% to 45%. However, the values of respiration rates in these two packages differ non-significantly throughout the storage under MA conditions at 8 ± 1 °C as per the MSD value (Tables 3 and 4). The storage period has significant effect on RR at 1% level (Table 3).

3.3. *Physiological weight loss (PLW)*

Among all the packaging treatments, the control samples (CS and CR) showed significant increase in physiological weight loss. However, the PLW was very minimal in both the AMAP and MAP refrigerated samples during and by the end of the storage period with no visible formation of water drips and fogging in the AMAP packages. The use of silica crystals sachets under active packaging acted as anti-fogging and reduced water drips and moisture loss, and significantly reduces PLW by maintaining a suitable relative humidity level inside the package. The use of humidity-control technology reduces condensation inside packages of respiring and other high-water-content foods and eliminates water films on the food without further drying the food (Brody, Strupinsky, & Kline, 2001, chap. 5). A non-significant ($p \geq 0.05$) interaction was observed in both the AMAP and MAP refrigerated samples during and by the end of the storage period. In AMAP refrigerated samples, by the end of the storage (day 49), packaged produce lost 4.27% of its initial weight, whereas in MAP refrigerated samples PLW lost was 4.42% by the end of 42 days of storage (Fig. 4). However, in both the control samples (CS and CR) the PLW was 29.34% and 22.36% of its initial weight, which lies beyond the acceptable limit of 5% reported by Manolopoulou et al. (2010) for whole peppers under MAP storage.

The effect of different storage methods on PLW of capsicums was found to be significant at 1% level of significance (Tables 5 and 6). The statistical analysis indicates that period of storage has a lesser significant effect (5% level) on PLW compared to methods of storage (Table 5). The pair wise comparisons and minimum significant difference (MSD) at $p = 0.05$ level of significance for PLW was carried out and found to be different over different methods of storage (Table 6). It can be seen that significant difference existed between CS and CR and with AMAP and MAP. However no significant difference was observed between AMAP and MAP as per MSD.

3.4. *Ascorbic acid content*

The changes in ascorbic acid content in terms of fresh weight of capsicums and per unit weight of dry matters are depicted

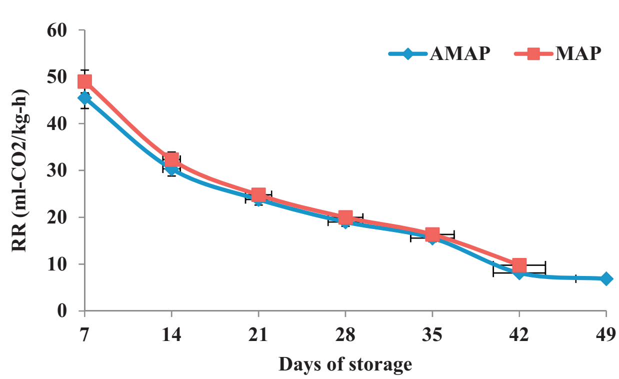

Fig. 3 – Respiration rate of capsicum in terms of CO_2 evolution in active MA package (AMAP) and modified atmospheric package (MAP) during storage at 8 ± 1 °C temperature.

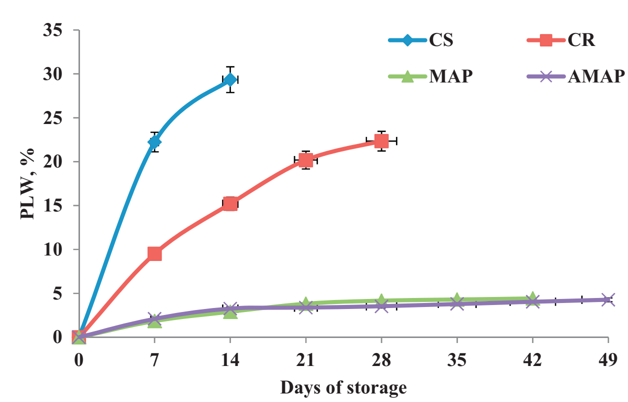

Fig. 4 – Physiological loss in weight (PLW) of capsicum fruits stored by different methods.

Table 5 – ANOVA of different physico-chemical parameters of capsicum stored by different methods.

Source	DF	p-Value					
		Firmness	PLW	Asc. acid	L	C	H
Model	10	0.0001	0.0015	0.0050	0.0029	0.0049	0.0331
Treatment	3	0.0072	0.0002	0.0003	0.0017	0.0002	0.0027
DOS	7	0.0001	0.0493	0.0353	0.0182	0.5018	0.5720
Error	14						
Total	24						
R^2		0.87	0.81	0.76	0.78	0.76	0.87
CV		21.76	69.11	3.21	6.69	5.15	7.36
RMSE		0.26	5.65	3.66	2.07	5.93	1.38

Table 6 – Pair wise comparison of different physico-chemical parameters of capsicum stored by different methods.

Methods	Mean					
	Firmness	PLW	Asc acid	L-value	Hue angle	Chroma
CS	0.74	21.70	122.97	26.40	97.95	15.74
CR	1.17	13.45	116.00	31.80	117.87	19.11
MAP	1.33	3.25	111.33	30.99	118.52	19.28
AMAP	1.39	3.05	110.42	32.75	118.36	19.58
MSD	0.32	6.83	4.55	2.52	7.18	1.74

in Figs. 5 and 6, respectively. In fresh green capsicum, initially the ascorbic acid content was (112.5 mg/100 g of initial mass). When expressed in terms of dry matter, the ascorbic acid content was found to decrease with time for all the cases. The loss was almost 70% of the initial value in case of control samples, where as both the packaged refrigerated samples (AMAP and MAP) retained ascorbic contents throughout the storage at 8 ± 1 °C (Figs. 5 and 6). In both the control samples (CS and CR), due to lack of proper packaging, excessive moisture loss was observed and resulted an increase in ascorbic content per 100 g of fruit weight (Fig. 5). These results agree with experiments on shelf-life of fresh-cut peppers under passive MAP by Senesi, Prinzivalli, Sala, and Gennari (2000) and González-Aguilar et al. (2004). The combined effect of low storage temperatures (0 and 5 °C) and MAP was beneficial in retaining the initial ascorbic acid reported by (Manolopoulou et al., 2010).

The statistical analysis indicates that ascorbic acid content of capsicums vary significantly over different methods of storage as well as period of storage. R^2 and coefficient of variation (CV) for ascorbic acid indicates goodness of fit of the model and coefficient of variation of the variable under study was found low. Table 6 indicates the pair wise comparisons and minimum significant difference (MSD) at $p = 0.05$ level of significance for ascorbic acid content. The values were found to be different over different methods of storage. MSD value in Table 6 indicates significant difference at 5% level between different method of storage except between AMAP and MAP.

3.5. *Fruit firmness*

The firmness of fresh fruits was 1.97 kgf. A continuous decline in fruit firmness was observed in all the packaging treatments by the passage of storage period. Fruit firmness was significantly protected by both the AMAP and MAP samples by the end of day 49 and day 42, respectively. However, a steep and significant decline in fruit firmness was observed for both the control (CS and CR) samples by the end of day 14 and day 21

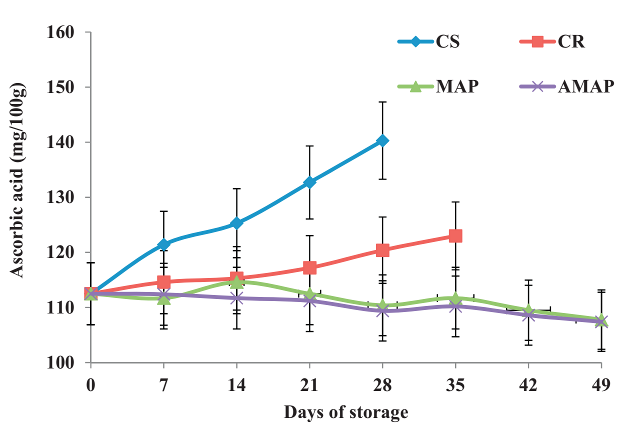

Fig. 5 – Variation in ascorbic acid content (mg/100 g) of capsicums stored by different methods.

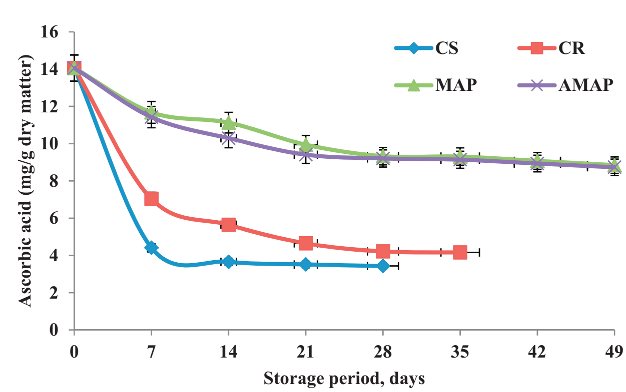

Fig. 6 – Variation in ascorbic acid content (mg/g d.m.) of capsicums stored by different methods.

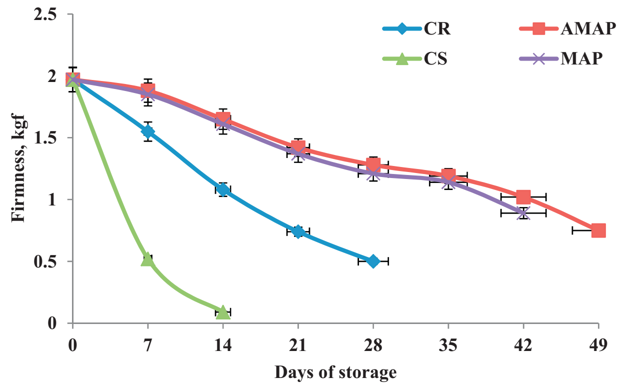

Fig. 7 – Variation in firmness values (kgf) with time of capsicum fruits stored by different methods.

respectively (Fig. 7). In AMAP and MAP refrigerated, fruit firmness finally settled at 0.75 and 0.89 kgf, respectively by the end of storage period of 42 and 49 days respectively. Non-treated fruits control (CS and CR) samples had about 95.43–74.61% reduction in firmness by the end of respective storage life in contrast to about 12.18–15.22% decline in both the refrigerated (AMAP and MAP) packages by the end of 49 days and 42 days of storage period. As expected, both refrigerated (AMAP and MAP) packages attained a similar trend in retention of fruit firmness throughout the storage period (Fig. 7). Modified atmospheric packaging significantly slowed down softening of capsicum fruit during storage which was consider the minimum requirement for commercially acceptability (Howard & Hernandez-Brenes, 1998).

Firmness values of capsicums were found to be significantly affected (at 1% level) both by methods and period of storage (Table 5). R^2 and coefficient of variation (CV) for each parameter indicates goodness of fit of the model and coefficient of variation of the variable under study was found low. The pair wise comparisons and minimum significant difference (MSD) at $p = 0.05$ level of significance indicate non-significant difference among CR, AMAP and MAP, whereas these method differs significantly with ambient stored control (CS) samples (Table 6).

3.6. *Color values*

The color parameters (L^*, C^* and h^*) of capsicum in different treatments are tabulated in Table 7. The lightness (L^*) of the fresh whole capsicum on the initial day was 34.3. The L^* values were significantly reduced in both CS and CR samples. Whereas, both the AMAP and MAP treatments observed very minimal L^* value and did not changed significantly by the end of day 49 and day 42, respectively. The initial chroma (C^*) value was 19.61 in fresh capsicum. The C^* values (intensity of green color) were significantly reduced to 35.21% in CS and 20.21% in CR treatments from initial value by the end of day 49 and day 42 of storage, respectively. However, AMAP and MAP treatment had non-significant in-between differences (Table 6). The AMAP samples exhibited the lowest, chroma reduction which was 5.13% followed by 7.38% in MAP sample by the end of their respective storage period (42–49 days). The initial hue angle (h^*) was 119.51 and presented non-significant variations in AMAP and MAP samples throughout the storage. However, a significant difference in h^* value was noticed in CS and CR treatments by the end of day 21 and day 35, respectively. Both the AMAP and MAP samples had low L^* or high h^* angle values at the end of the storage, indicated retention of the initial green color which may be due to limited dehydration and/or limited chlorophyll degradation which is responsible for the green color. In both the cases, the small L^* reduction (<3%), C^* and h^* retention, throughout the MA storage indicated retention of the initial green color of the whole capsicum fruit. Retention of the green color due to limited chlorophyll degradation in fruits and vegetables can also initiated from the elevated CO_2 and/or depleted O_2 in-package concentrations and establishment of steady-state micro-environment inside the package. Similar observation was also reported by Weichmann (1986) for control atmospheric storage of fresh fruits and vegetables and Zhou, Abe, and Iwata (1992) for pepper fruit.

Table 7 – Color value (L^*, h^* and C^*) of capsicums during storage.

Treatment	Day 0	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42	Day 49
L^*								
CS	34.3	26.54	23.47	–	–	–	–	–
CR	34.3	33.98	32.42	30.87	27.47	27.24	–	–
AMAP	34.3	34.2	33.92	33.45	32.32	33.93	33.47	33.45
MAP	34.3	33.5	32.04	33.24	32.61	33.29	32.45	–
h^* hue								
CS	119.51	98.32	88.74	85.23	–	–	–	–
CR	119.51	116.31	110.87	103.14	102.55	102.3	–	–
AMAP	119.51	119.26	118.58	117.81	118.45	117.74	118.22	118.32
MAP	119.51	119.63	119.22	118.62	118.42	117.36	118.89	–
C^* chroma								
CS	19.61	15.70	14.82	12.86	–	–	–	–
CR	19.61	19.83	19.59	18.78	16.76	15.84	–	–
AMAP	19.61	19.52	18.52	19.35	19.58	18.93	18.81	18.74
MAP	19.61	19.00	20.17	19.95	18.28	18.12	18.34	–

3.7. Fruit decay and marketability

The major sign of decay in capsicum fruit in all packaging treatments are one or in combinations of the following: surface pitting, peel disorder, color deterioration and microbial degradation. The decay was largely exhibited in CS and CR fruits and significantly differs with MAP and AMAP. Package treatment CS had maximum decay of 71% by the end of storage life (day 14) followed by decay of 68% in CR treatment by the end of storage life (day 28). AMAP and MAP treatment had minimum decay value of 2.7% and 10% by day 49 and day 42, respectively. The fruit decay in active packaging was significantly reduced by the use of moisture absorbents sachets during storage period. Using absorbent in headspace had a 65–68% reduction in the decay compared to CR and CS treatment during storage $8 \pm 1\,^{\circ}C$ temperature (Fig. 8). The favorable effect of using absorbent in fruit package headspace along with refrigerated MA storage in reducing the decay percentage of capsicum fruit was clearly revealed in our study. The inhibition of decay by the use of absorbent sachets using silica crystals in fruit during MA storage could be related to reduction of water vapor inside the package, inhibition of growth of micro-organism and exacerbate the disease incidence in fruit (Gonzaléz-Aguilar et al., 2004). Polderdijk et al. (1993) reported the incidence of decay in pepper during post-storage that increased with increasing levels of RH during storage. Silica gel has been reported to delay aging of seeds by absorbing toxic gases including ethylene during storage of seed (Gomez-Campo, 2007). Delayed and reduced respiration rate, senescence and establishment of conducive in-pack gas composition in AMAP and MAP sample might have increased its resistance to infection and deterioration resulting in lower decay compared to control samples (Smith, Stommel, Fung, Wang, & Whitaker, 2006). Such other studies have shown similar results in which the fruit rotting was significantly reduced by reducing RH inside packages by use of moisture absorbents (Gonzalez-Aguilar, Cruz, Baez, & Wang, 1999; Pesis et al., 2000).

AMAP and MAP retained significantly more percentage marketable fruits throughout the storage period compared to CS and CR samples. The highest percentage marketability was observed in active packages with moisture absorbent followed by MAP treated fruits and control samples kept in refrigerated condition. The effect of moisture absorbent on % marketability

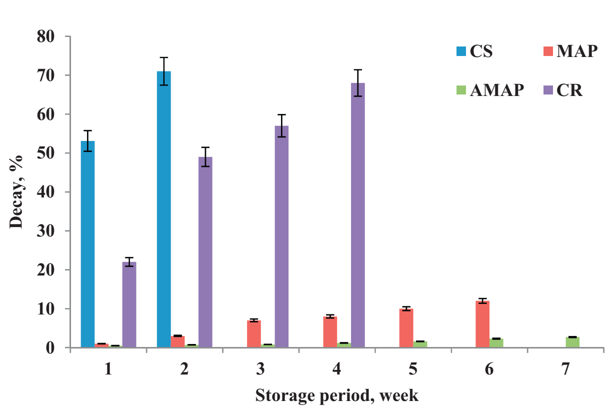

Fig. 8 – Fruit decay (%) during storage by different methods.

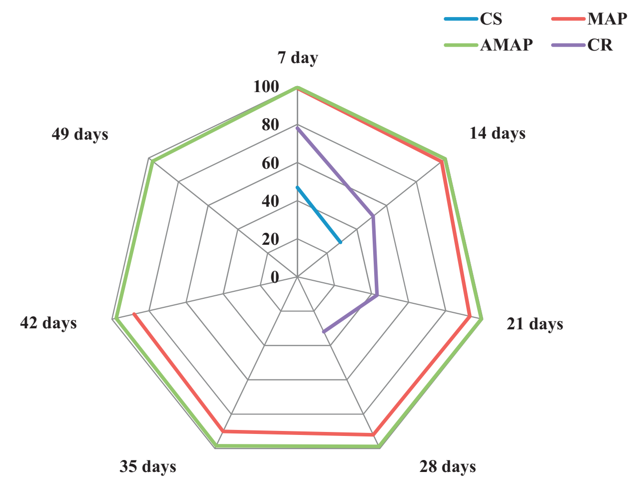

Fig. 9 – Radar diagram for fruit marketability (%) in all packaging treatments (AMAP, MAP, CS, CR) throughout the storage period.

on day 28 was 66.8% more compared to fruits in the CR samples and about 6.8% better than fruits kept in MAP conditions. The MAP treatment samples also improved marketability of fruits by 68% compared to fruits kept in CS samples and 46% compared to fruits kept in CR samples on day 14, respectively (Fig. 9). In all treatments, especially in CS and CR samples, the percentage marketability of fruits decreased with time due to surface pitting, peel disorder, color deterioration and microbial degradation, which could be due to the breakdown of complex micro-nutrients by the passage of storage period. The difference could be due to the effect of lower relative humidity in CS samples as compared to the later treatments (Kader et al., 1989).

There was significant ($p \leq 0.05$) variation in the percentage marketability of the capsicum fruits subjected to different packaging treatments throughout the storage period (Fig. 10). Active packaging showed maximum (97%) fruit suitable for marketability by the end of 49 days of storage period followed by 88% fruits marketable under MAP packages by the end of 42 days of storage period and 32% fruits marketable under control refrigerated (CR) packages by the end of 28 days of storage period. Minimum fruits marketability (29%) under CS packages was reported by the end of 14 days of storage period. Except fruits with moisture absorbent (AMAP) and kept in polyethylene (PP) packages, marketability of fruits in all other treatments was below 90% on day 42 of storage (Fig. 10).

The improvement of percentage marketability in AMAP samples over the other packaging treatment (MAP, CS and CR) could be due to control microenvironment and partially be due to possible difference in air composition around the fruits that might have suppressed respiration and senescence. This result is in agreement with reports of LeDong, Zhou, Sonego, Lers, and Lurie (2001) and Dong, Lurie, and Zhou (2002) that showed modified atmospheric packaging increased shelf life of fruits through decreasing rate of respiration as a result of differential O_2/CO_2 gas composition and through conservation of moisture around the fruit. The combined effect of the

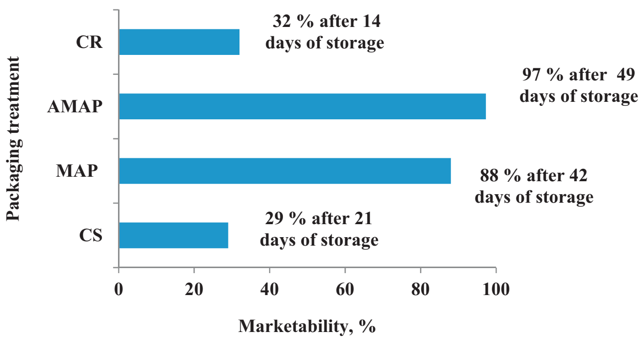

Fig. 10 – Fruit marketability (%) in all packaging treatments (AMAP, MAP, CS, CR) by the end of the storage period.

packaging material and moisture absorbent could be attributed to partly to the moisture conservation by the polyethylene bags around the produce thereby reducing moisture loss and decay of the fruit as well as to reduced concentration of ethylene and consequently slowing down the rate of respiration. The low relative humidity in the CS samples could be the main cause for the rapid deterioration of the fruits due to moisture loss, which resulted in decay of fruits. Moreover, a slight increment in ethylene amount around the fruits could have also contributed to the rapid loss of fruits in the open air (Kotecha & Babasaheb, 1995) through their respiration enhancing effects. As indicated by Kayisu, Hood, and Vansoest (1982) and Wills, Warton, and Ku (2000), fresh produce can release between 0.017 and 0.06 ppm ethylene during marketing and storage, an amount that can cause a 10.0–30.0% loss of the produce.

4. Conclusions

Based on modified atmosphere packaging system in PP films (thickness of 38 μm) for capsicum storage, it can be concluded that the shelf life of bell pepper was 7 weeks in active packages and 6 weeks in MA packages. Both the control samples (CS and CR) having short shelf life (7 and 21 days) fails to keep acceptable quality attributes during storage period. However, samples with moisture absorbent along with MA packaging at refrigerated storage (8 ± 1 °C) had a substantial effect on shelf life enhancement of capsicum fruit with acceptable quality. In nutshell, the use of moisture absorbent as a postharvest tool may be adapted into the supply chain activities of capsicum fruit to enhance storage life and ensure quality during distribution to local/super markets demands and to maximize customer value. The study could further be extended by using other moisture absorber/desiccants, and testing their efficacy in absorbing moisture and other gases in a controlled manner so as to increase the postharvest life of the products.

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