

Quality attributes of modified atmosphere packaged bell pepper (*Capsicum annuum* L.) during storage

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Abstract

Bell pepper is one of the most important horticultural commodities of commercial importance owing to the presence of flavonoids, carotenoids and vitamin C. This is one of the main export produce of Israel. Export and local market both demand high quality vegetables, possessing long shelf-life and freshness at the market. The main aim of this study was to evaluate the effect of modified atmosphere packaging using two different packaging materials viz., Xtend® (XF) and polyethylene (PE) films at 1.5°C, 7°C and 17°C storage temperatures. Fruits were evaluated for total soluble solids, gaseous composition, colour, firmness, elasticity, weight loss, chilling injury, decay and sensory parameters to assess the quality and shelf-life. XF and PE minimized weight loss and maintained firmness and freshness. Further, XF reduce the development of decay in the fruits stored at 7°C and chilling injury at 1.5°C. The fruit storage was best at 7°C using XF packaging.

Keywords: capsicum, xtend film, temperature, MAP, storage

Introduction

Bell pepper (*Capsicum annuum* L.) is an American commodity which originated in Mexico, Central America and Northern South America¹ and its commercial cultivation started in Spain in the middle of the 17th century.² Bell pepper is a cultivar group of *Capsicum annuum* species, member of the night shade *Solanaceae* family, which also includes potato, tomato and eggplant. It is popular horticultural commodities in different regions of the world and is the second most important horticultural crop in Israel with 189,149 tonnes produced in 2016.³ Israel has conducted research in protected cultivation and postharvest of this commodity and notable success has been achieved in maintaining quality and extending storage life by adopting different postharvest practices thus allowing export of this commodity to markets in Europe and North America.

Export and local market both demand high quality sorted fruits, which possess long shelf-life and freshness.¹ Pepper importing countries may also require quarantine security protocols against the Mediterranean fruit fly (Medfly) and fruits must be certified as free of Medfly.⁴ The uniformity and appearance of fruits also have a significant effect on product choice by the consumer. Bell pepper quality is determined by attributes like colour, shape, size, taste, texture, firmness, weight, and internal chemical composition. Quality also depends on the preferences and requirements of consumers.⁵ The principal physiological factors

of pepper quality that are negatively impacted during shipment, storage and marketing are water loss and chilling injury.⁶⁻¹⁰ Studies suggest that packing pepper inside plastic bags creates a modified atmosphere within storage, reducing its susceptibility to water loss and chilling injury.¹¹ However, other authors reported that modified atmospheric storage did not affect weight loss or softening.¹²

Sweet pepper can be stored for moderately long periods at temperatures between 7°C and 13°C, depending upon the variety and the stage of maturity.¹³ Main factors of quality degradation of sweet pepper during storage include decay development, susceptibility to chilling injury and shriveling associated to rapid water loss, which limits storage at temperatures above 7°C.¹³ Water loss in commercial bell pepper has been identified as the main physiological factor limiting pepper fruit quality and prolonged storage.⁸ Furthermore, reduced temperatures do not completely inhibit decay development during prolonged storage and red pepper has been found as the most perishable.^{13,14}

Modified atmosphere packaging (MAP) is a technology used to extend the shelf-life of fruits and vegetables of high commercial value. Packaging of pepper in perforated plastic films and storing them at optimum temperature could be one of the viable alternatives to extend shelf-life. Manolopoulou et al¹⁵ have demonstrated that by

using polyvinyl chloride (PVC), low density polyethylene (LDPE) and medium density polyethylene (MDPE) packaging of different O₂/CO₂ permeability, it is possible to generate a model associating mass loss, firmness of bell peppers and the packaging films. Packaging bell peppers with polyethylene bags at low temperature (7.5°C) reduced the water loss by 40-50% and maintained the fruit quality.¹³ The use of packaging films has been shown to increase the shelf-life of perishable produce establishing a beneficial in-package atmosphere containing low O₂ and high CO₂ and reduced water loss.¹⁶ Xtend® films (StePac LA Ltd, Israel) have been developed to modify atmosphere and humidity for prolonged packaging. Rodov et al¹⁷ have suggested that this packaging material prolonged shelf-life of fresh produce such as melon, broccoli and green onions, among other products. Therefore, the main aim of this study was to evaluate the effect of modified atmosphere packaging of bell pepper at different storage temperatures in order to determine the ideal packaging material to maintain their physical and chemical properties without compromising the quality.

Materials and methods

Sample preparation

Bell pepper (*Capsicum annum* L. cv Kannon) were harvested at optimum maturity determined by the firmness and the onset of colour change from the Arava Desert of Israel in January 2014. The fruit were washed, graded and stored at optimum storage temperature until further study. Eight, randomly selected fruits were used for each treatment (Table 1) and experiment was replicated 3 times and standard deviation of the mean value in each parameter was calculated. Fruits were assessed for total soluble solids, colour, firmness, elasticity and weight before storage under different packaging conditions. Following initial measurements, fruit samples were stored at 1.5°C, 7°C and 17°C under different atmosphere conditions depending on the plastic material used viz., Control with no bag, Xtend® film (XF) and Polyethylene (PE) film. Three Samples each containing eight fruits were evaluated at the beginning of the experiment (Day 0) and after two weeks of storage (Day 14) for different physico-chemical and sensory parameters. Samples kept at 1.5°C and 7°C for 11 days were subjected to a further three-day storage period at 17°C. Samples kept at 17°C were stored for 14 days without temperature change.

Table 1 Experimental design of Bell pepper stored under different conditions*

Packing material	Storage temperature		
	1.5°C	7°C	17°C
Control	T ₁	T ₂	T ₃
Xtend® film (XF)	T ₄	T ₅	T ₆
Polyethylene film (PE)	T ₇	T ₈	T ₉

*Relative Humidity (RH): 94%

Texture analysis

Fruit firmness and elasticity was measured using a pressure tester, as described by Ben-Yehoshua et al.¹⁸ Each fruit was placed horizontally between two flat plates, a 2kg weight was placed on top of the upper plate, and the deformation of the fruit in millimeters was expressed. The full deformation was measured after 3 sec of initial force application onto fruits and recorded as firmness. Pressure was then removed, and the residual deformation was measured and regarded as the capacity of a body to recover its original shape (Elasticity).

Total soluble solids

Bell peppers were diced and juice was taken out by squeezing the material. Total soluble solids were measured by placing a drop of pepper juice (approximately 0.1 mL) on the lens of the refractometer (Palette, PR-32α, Atago, Japan). Results were expressed in percentage of soluble solids.

Colour analysis

Colour analysis was conducted by capturing the reflectance using a Chroma meter (Minolta, CR-300, Osaka, Japan) at two different areas of each bell pepper marked for the said purpose. The Hue angle was recorded and represented the tangent of a and b values from the Lab colour scale (i).

$$H^{\circ} = \tan\left(\frac{b}{a}\right) \quad (i)$$

Weight loss

Bell peppers were weighed at the beginning of the experiment and at the end of the experiment. The weight loss (WL) percentage was calculated according to equation (ii) where the final weight (FW) was related to the initial weight (IW) of each sample.

$$WL(\%) = \frac{(IW - FW)}{IW} \times 100 \quad (ii)$$

Gaseous composition

Concentrations of oxygen (O₂) and carbon dioxide (CO₂) were recorded by using a portable gas analyzer (Oxybaby®6.0, Witt-Gasetechnik, Witten, Germany) and expressed as a percentage during the experiment. Two samples were taken from each treatment and data were expressed in percentage of each gas.

Chilling injury and decay

Visual evaluation of fruits was conducted at the end of the experiment (Day 14) to assess decay and chilling injury. The incidence of mould infestation was recorded and results were expressed as percentage of decayed fruit compared to the entire population. Chilling injury appeared as pitting on the fruit surface. Symptoms were evaluated visually after storage. An index was used to express results for mild (1), moderate (2) and severe (3) chilling injury. A null value (0) was assigned to samples which did not contain injury.

Sensory evaluation

At the end of storage (Day 14), samples were drawn from each treatment to assess sweetness, texture, juiciness, and off-flavor by a panel of judges. Three samples were analyzed as per the treatment and data were expressed in a 5-point scale for each attribute evaluated.

Eight, randomly selected fruits were used for each experiment and three experiments were carried out each time. The mean of three replicated experiment for each quality parameter was calculated and data were expressed as Mean ± Standard Deviation.

Results and discussion

The data generated during the assessment period were analyzed and the information is presented in the Tables (2 and 3) and Figures (1–6) below:

Table 2 Elasticity, gaseous composition and total soluble solids of Bell pepper stored for 14 days at various temperatures and packaging materials

Packing Material	Temp ¹ (°C)	Elasticity		Gaseous atmosphere (%)		Total Soluble Solids (%)
		(mm)	(%)	O ₂	CO ₂	
Control ²	1.50	3.25± 1.3	41.9± 6.9	21.0± 0.0	0.30 ± 0.0	5.70 ± 1.8
	7.00	3.38± 0.7	38.2± 7.0	21.0± 0.0	0.30 ± 0.0	7.73 ± 1.0
	17.0	4.38± 1.0	32.7± 6.4	21.0± 0.0	0.30 ± 0.0	7.60 ± 0.3
Xtend® film	1.50	2.69± 0.9	46.1± 11	18.4± 0.1	3.85 ± 0.2	7.53 ± 0.3
	7.00	3.00± 0.9	45.6± 7.6	19.1± 0.1	2.70 ± 0.6	7.37 ± 0.2
	17.0	3.69± 1.0	35.4± 5.5	19.0± 0.1	2.70 ± 0.1	8.53 ± 2.0
Polyethylene film	1.50	2.56± 0.7	48.6± 6.6	19.2± 0.0	2.15 ± 0.2	6.67 ± 0.4
	7.00	2.25± 0.6	43.0± 4.2	19.1± 0.0	2.20 ± 0.0	7.17 ± 0.4
	17.0	2.94± 1.1	47.4± 4.9	19.3± 0.1	1.90 ± 0.1	6.70 ± 0.0
Initial conditions ³		3.13± 0.5	51.9± 4.2	21.0± 0.0	0.30± 0.0	7.09± 0.6

¹Temperature of storage; ²Samples stored without bagging; ³Measurements were conducted on the entire lot before subjecting samples to different storage conditions

Table 3 Colour measurements, chilling injury and decay of Bell pepper stored under various temperatures and atmospheres for 2 weeks

Packing Material	Temp ¹ (°C)	Hue Angle (H°)		Chilling Injury ³	Decay ³ (%)
		Day 0	Day 14		
Control ²	1.50	19.1 ± 3.5	15.4 ± 3.5	1.25 ± 0.7	0%
	7.00	22.0 ± 2.6	13.8 ± 2.0	N/A ⁴	25%
	17.0	18.8 ± 2.9	13.5 ± 1.5	N/A	38%
Xtend® film	1.50	16.7 ± 2.3	14.3 ± 2.1	1.00 ± 0.0	0%
	7.00	18.0 ± 3.0	12.4 ± 2.4	N/A	0%
	17.0	20.0 ± 3.5	15.1 ± 3.1	N/A	38%
Polyethylene film	1.50	18.8 ± 5.6	15.5 ± 4.5	1.13 ± 0.6	38%
	7.00	19.4 ± 4.5	14.3 ± 2.9	N/A	63%
	17.0	18.1 ± 2.9	13.6 ± 2.4	N/A	38%

¹Temperature of storage; ²Samples stored without bagging; ³Results are reported at the end of the experiment (Day 14); ⁴Not applicable

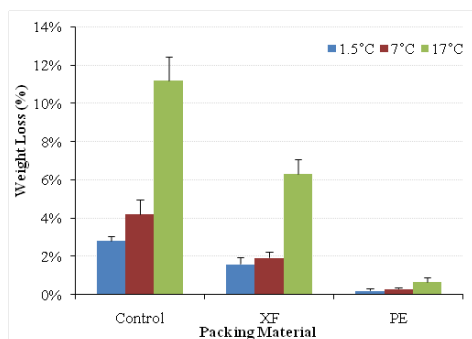


Figure 1 Effect of packing material and storage temperature on weight loss [Control: No packing material; XF: Xtend® film; PE: Polyethylene film].



Figure 2 Shriveled Bell pepper of control treatment after 14 days of storage at different temperatures.

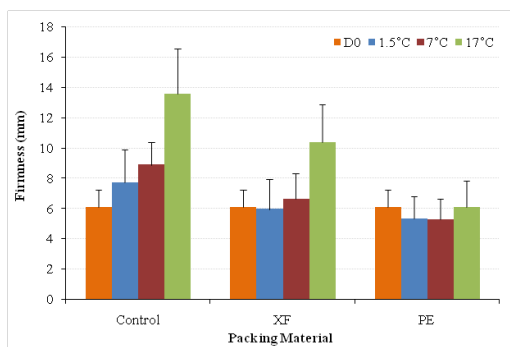


Figure 3 Effect of packing material and storage temperatures on firmness [D0: Measurements at day 0; Control: No packaging material; XF: Xtend® film; PE: Polyethylene film].

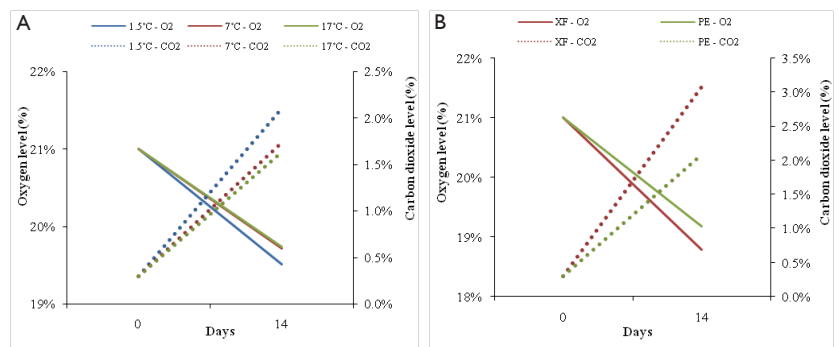


Figure 4 Gaseous conditions during storage of peppers according to temperature (A) and packing material (B).



Figure 5 Incidence of decay and chilling injury in Bell pepper after 2 weeks.

Weight loss

The physiological loss in weight is represented in Figure 1. Control samples of Bell peppers stored at 17°C had the maximum loss in weight (11%) followed by the samples of peppers packed in Xtend® film stored at the same temperature (6%). There was minor loss in weight for the samples packed in polyethylene irrespective of the storage condition. In general, all the control samples (No packing film) stored at all the 3 temperatures had considerable weight loss during the storage and shelf-life period of 14 days. More percentage of weight loss was recorded in highly shriveled Bell pepper of the control treatment after 14 days of storage at 17°C (Figure 2).

Fruits and vegetables are living commodities which continue to respire and transpire even after their detachment from the parent plants. When these commodities are attached to the parent plant, the loss in water and the substrate is replenished but once they are detached, they have to maintain themselves on their reserves. Respiration is one of the important physiological processes important to maintain the living nature of the commodity after harvest and during storage. Therefore, the main goal during storage is to restrict the respiration and transpiration processes to delay the ripening and senescence thereby maintaining the quality, shelf-life and marketability of the produce. Modified atmosphere packaging is a postharvest technology that regulates storage conditions to maintain the quality of fresh produce.¹⁵

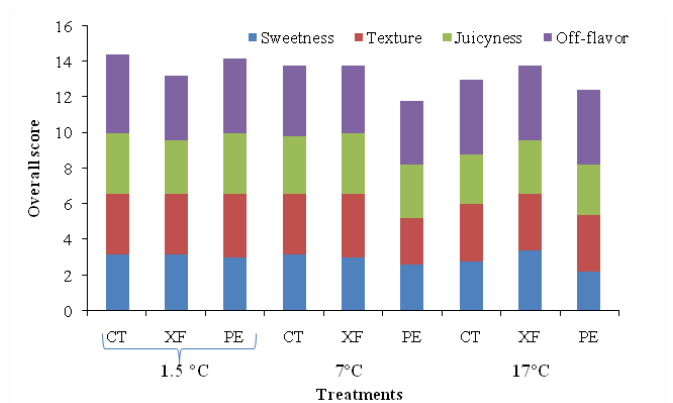


Figure 6 Sensory analysis of bell peppers after 14 days of storage [CT: Control with no packing material; XF: Xtend® film; PE: Polyethylene film].

The packing films and storage temperatures used in this experiment i.e. Xtend® film and polyethylene film have clearly shown that it is possible to curtail the loss in weight at a storage temperatures of 1.5°C and 7°C. However, peppers packed in Xtend® film stored at 17°C showed significant loss which could be attributed to increase in respiration and transpiration rate at this temperature. The permeability of films to moisture and gases is directly responsible to the loss in weight. Polyethylene films acted as a complete barrier to moisture whereas Xtend® film showed permeability to moisture at all storage temperatures with maximum levels at 17°C.

Firmness and elasticity

Fruit firmness and elasticity was assessed on samples after a 14-day storage period. At the beginning of the study, samples were already soft according to the scale used¹³, which suggested that fruits over 3 mm of firmness were considered soft (Figure 3). This could be attributed to the shelf-life of peppers used for this experiment as they were stored for a significant period of time prior to this experiment. Storage temperature and packing material had a significant effect on the firmness of samples. Firmness in fruit was decreased as storage temperature increased. Samples with no packing material (control) showed the lowest firmness which coincided with water loss of samples. Firmness was maintained in samples stored in Xtend® films except when storage temperature was 17°C where firmness

was reduced by 71 percent. Polyethylene film showed best results in maintaining firmness despite of storage temperature.

Elasticity is the difference between the initial firmness and the capability of the fruit to recover its initial form. Results suggested that initial samples had a higher elasticity (52%) while samples stored for 14 days at various temperatures and packing materials reduced its capacity to recover its original shape (Table 2). Results showed that samples stored with packing materials (XF and PE) maintained more elasticity with losses of 6% of the original values. Only samples stored with XF at 17°C showed a reduction of more than 15% which was similar to values in samples with no packing material (Control). Temperature also showed an impact on loss of elasticity especially in control samples. As storage temperature increased, elasticity was diminished losing almost 20% of the original elasticity (Control samples at 17°C).

Firmness and elasticity properties of fruits and vegetables are related to the structures present in cell walls such as pectin, cellulose and hemi-cellulose. These carbohydrates are susceptible to enzyme attack and other biological processes during ripening.¹⁹⁻²¹ Enzymes responsible for fruit softening include cellulase, pectin methyl esterase, polygalacturonase, β -galactosidase, among others.^{19,22} The breakdown of these polymers leads to the formation of smaller particles hence, the reduction of firmness and integrity of the samples, and water loss among other changes in fruits and vegetables are not desirable during storage.^{19,23,24}

Total soluble solids

Table 2 shows that fruit stored at 7°C displayed an increase in total soluble solids (TSS). The fruit packed in Polyethylene (PE) film showed a decrease when stored at 1.5°C and 17°C. This increase in TSS during MAP storage of bell pepper is consistent with the findings of Aguilaret al²⁵ and Sakaldas and Kaynas.²⁶ An increase in TSS content particularly the sugars may indicate ripening and the use of packaging is to delay this process.²⁵ An increase in TSS may also be a result of breakdown of other complex sugars such pectin, which is broken down by either (or both) the fruit's own enzymes, as well as by microbial enzymes. Overall, the treatments which exhibited a decrease in TSS were considered to be less optimal because this might indicate a reduction in sugars, which are an important quality parameter i.e. sweetness for Bell pepper as will be discussed later. However, the change in TSS during storage period did not exhibit any specific trends and it is important to consider this parameter in combination with the other quality parameters to determine quality loss.

Gaseous atmosphere

The results of gaseous composition for different packing materials and storage temperatures are presented in Table 2. O₂ and CO₂ concentration for different treatments varied in between 18.4 – 21.0% and 0.3 – 3.85%, respectively. Maximum CO₂ (3.85 ± 0.2%) concentration was observed in the samples packed in Xtend® films and stored at 1.5°C for 14 days while the minimum (1.90 ± 0.1%) in the polyethylene packing stored at 17°C (Figure 4).

Normal atmospheric composition of three major gases is 78.0% N₂, 20.8% O₂ and 0.3% CO₂. During modified atmospheric storage, the gaseous composition varies according to the type of packing material and storage temperature. Depending upon the packaging barrier for different gases, the concentration of O₂ decreases and CO₂ goes up.

Although, there was no control in the gaseous atmospheres in the packages used (XF and PE), the alteration of the normal gaseous composition due to respiration helped in extending the quality and shelf-life of the produce. Limited respiration is always desirable during the storage of vegetables which give rise in the concentration of CO₂ production inside the package thus preventing mould growth such as *Alternaria alternata* and *Botrytis cinerea*.¹⁶

Besides, optimum storage temperature and humidity inside the package are also responsible for better preservation and decay control. More the respiration rate more will be the production of CO₂ i.e. fast utilization of the substrate, making unfit the commodities for human consumption. In this study, packing material, depending upon the temperature of storage, contributed in the reasonable production of CO₂. No off-flavour was noticed in our samples irrespective of the packaging and storage condition thereby suggesting that the packages had sufficient O₂ to prevent fermentation as a source of energy. In spite of reasonable CO₂ build up inside the polyethylene film, mould growth was noticed, which could be attributed to vapours build-up inside the bags. In the absence of sufficient O₂ in the packing atmosphere during storage, anaerobic respiration leads to the production of acetaldehydes and alcohol leading to off-flavour.²⁷ The ratio of CO₂ and O₂ in various treatments was within the prescribed limits thus causing no harm to peppers in terms of flavour. Production of comparatively more CO₂ in Xtend® films stored at 1.5°C could be attributed to the initial volume of O₂ and CO₂ in the packs while sealing the bags at day 0 and/ or due to subsequent higher respiration rate when the samples of this treatment were put at 17°C to simulate retail market conditions. Differences in gaseous composition build up in Xtend® films and polyethylene films at different temperatures in storage could be attributed to the selective barrier properties of these films to gases and moisture.²⁸ Xtend® films with reasonable production of CO₂ definitely proved better in controlling the quality without having any mould growth, decay and off-flavour.

Colour

The results in Table 3 show that the change in colour at 1.5°C and 17°C was similar across all treatments. At 7°C, the change in colour was larger in the control, which might be an indication, that packaging at this temperature plays a role in delaying further ripening. Other researchers have shown the ability of packaging films such as PE to delay ripening.^{29,30} Our results show that there is no significant difference between the two packaging materials in delaying colour development.

Chilling injury and decay

Chilling injury of the fruit was reported for storage at 1.5°C, at temperatures above 7°C, no chilling injury was observed as expected, in line with the findings of previous work.^{26,31} After the storage period, chilling injury was noted as mild for the control and all treatments. This indicates that the packaging material used had no significant effect in the prevention of chilling injury. Previous researchers have used hot water treatments^{26,32} prior to storage in MAP environment, to reduce chilling injury.

Table 3 shows that XF packaging was more effective in the prevention of decay. In the control, decay was exhibited at 7°C and 17°C, while the fruit stored in PE packaging showed some decay at all storage temperatures. Decay was visible as fungal mycelia on the fruit calyx and surface, as well as rotting (spots) on the fruit surface (Figure 5).

The susceptibility of fruit in PE packaging to decay is probably due to the low permeability of the packaging material resulting in high relative humidity which is conducive for fungal growth.²⁶ This high relative humidity was visible as water droplets were found on the fruit in PE packaging. These results show that overall XF packaging appears to be suitable for decay prevention during storage.

Sensory evaluation

Figure 6 shows that the results of the sensory evaluation were similar across treatments. There was no apparent significant difference between packing materials in the overall score based on sensory analysis. It should be noted that none of the decayed fruit were sampled with regards to sensory parameter. This might be a limitation in the accurate determination of the outcomes of this experiment. However, XF scored highest over PE and control at various temperatures suggesting that this is the best packaging material for the storage of bell pepper.

Conclusion

Use of packing materials *viz.*, Xtend® film and Polyethylene film to modify the atmospheric conditions have shown to maintain the quality of Bell pepper during storage at an optimum temperature of 7°C. Furthermore, Xtend® packaging proved to be ideal for the storage based on prevention of decay, minimizing weight loss, maintaining firmness, elasticity and scored well in the sensory evaluation. No differences were observed in total soluble solids, colour, chilling injury and sensory characteristics.

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