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EFFECTS OF HARVEST TIME AND GROWTH CONDITIONS ON STORAGE AND POST-STORAGE QUALITY OF FRESH PEPPERS (*CAPSICUM ANNUUM* L.)

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Abstract

Studies were carried out to see the effect of modified atmosphere packaging (MAP) on extending postharvest longevity of mid-season, late-season and greenhouse grown pepper fruits stored at 8 and 20ºC. Also, effects of MAP on post-storage quality of peppers stored at 20ºC were determined. Significant varietal differences in water loss and turgidity were observed in ambient atmosphere at each storage temperature. 'Keystone' (bell pepper) fruits had the lowest weight and turgidity loss followed by 'NuMex R Naky' (long green) and 'Santa Fe Grande' (yellow wax). Storage life for late-season field harvested peppers placed in ambient atmosphere was 10 to 14 days at 8ºC, whereas it was less than 7 days at 20ºC. Late-season field harvested peppers lost their quality at 8ºC primarily due to disease (fungal decay) and at 20ºC due to wilting and disease. Greenhouse grown peppers lost their quality after approximately 10 days at 8ºC and 5 days at 20ºC due to high water loss. MAP reduced postharvest water loss, maintained turgidity of fruits and delayed red colour development and disease. Compared to non-packaged fruits MAP extended postharvest life for another 7 days at 8ºC and 10 days at 20ºC as compared to non- packaged fruits held at these temperatures. Postharvest water loss and turgidity were similar for fruits stored in packages with and without 26-guage holes at 8 and 20ºC. Packaging was successful in extending the postharvest storage life of both mid-season field picked and greenhouse grown peppers. Packaging did not affect post-storage quality of fresh peppers as after removal of packaging fruits started dehydrating like the ones kept in open trays.

Introduction

With the increasing demand of fresh fruits and vegetables, postharvest technology for extending shelf life of these perishable commodities has gained significant importance in recent years. Amongst different techniques modified atmospheric packaging (MAP) has been reported as cost effective and successful technique for extending postharvest longevity of several fresh horticultural crops (Amin *et al*., 2001; Banaras *et al*., 2002; Nawa *et al*., 2001; Raja, 2001; Thompson, 1996; Zagham, 2003). The packaged produce had also better market acceptability (Gibe, 1999). MAP significantly extended longevity of mid-season field harvested pepper fruits (Lownds & Bosland, 1988). From a shipping point of view it would be important to know whether MAP can extend longevity of late-season field harvested or greenhouse grown pepper fruits. For these types of studies, it is important to know whether greenhouse grown peppers behave similar to field harvested. Information on post-storage longevity of MAP stored fruits is also limited (Collins & Peckins-Veazie, 1993). Therefore, this study was undertaken to evaluate and compare longevity of greenhouse grown and late-season field harvested peppers stored at 8 and 20ºC with and without polyethylene packaging and to determine effects of MAP on post-storage quality of peppers stored at 20ºC.

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Materials and Methods

Plant material: Fresh, green mature, firm, full sized and with good brightness pepper fruits of three distinct pepper cultivars viz., 'Keystone', 'NuMex R Naky' and 'Santa Fe Grande' were harvested from plants grown under standard cultural practices at the Leyendecker Plant Science Research Center, Las Cruces, NM (USA). During the fall of the same year, these cultivars were also grown in a greenhouse under standard growing conditions for peppers. Standard sized fruits, free of visible defects were hand-picked from field during mid- and late-season and greenhouse grown plants, placed into plastic bags and immediately transported to the laboratory.

Postharvest storage: Pepper fruits harvested from the field (mid- and late-season) or from the greenhouse were stored at 8 and 20ºC using refrigerators in open trays and in low density polyethylene packages (17.5cm x 20cm x 45µm). Keeping in view the size of fruit, two fruits each of 'Keystone' and 'NuMex R Naky' and five fruits of 'Santa Fe Grande' were used per replication. Postharvest storage studies were conducted separately for mid- and late-season and greenhouse grown pepper fruits. Treatments were arranged in a split plot design, assigning main plots to cultivars and subplots to package treatments. Each treatment was replicated three times. For mid-season field harvested pepper fruits, each package had eight 26-gauge needle holes, adequate to maintain 20% oxygen atmosphere (Lownds & Bosland, 1988). Packages used for late-season field harvested and greenhouse grown fruits had no holes based upon our preliminary findings that there was no effect of low density polyethylene packaging (17.5cm x 20cm x 45µm) with or without having eight 26-guage needle holes in terms of prolonging shelf life of mid- season field harvested peppers stored at 8, 14 or 20ºC. Fruits were evaluated daily for weight loss, wilting (turgidity) and colour development.

Weight loss, wilting and colour development: Weight loss was determined by weighing storage packages and/or individual fruit and calculating total and daily percent weight loss. Wilting was determined by measuring surface yield to applied finger pressure and assigning this a quantitative score (Risse & Miller, 1986) ranging from 0 (hard, fully turgid) to 9 (completely soft). Colour rating was scored on a scale of 0 (100% green) to 9 (100% red). Data were subjected to analysis of variance using Statistical Analysis System (Anon., 1982) and treatment means were separated with LSD procedures.

Post-storage evaluation: Following two weeks of MAP storage, greenhouse grown fruits were removed from each package and placed in open trays at 20ºC. Daily measurements of weight loss, wilting (turgidity) and colour development were recorded.

Results and Discussion

Post-harvest storage weight loss: Significant cultivar differences in rates of water loss were observed for non-packaged fruits at both 8 and 20ºC (Tables 1, 2 and 3). Water loss for field harvested pepper fruits (mid-season) after two weeks storage ranged from 4.47% for 'Keystone' to 11.28% for 'Santa Fe Grande' at 8ºC and 44.75% for 'Keystone' to 73.90% for 'NuMex R Naky' at 20ºC (Table 1). Similar cultivar differences for late-season field harvested and greenhouse grown peppers were observed (Tables 2 and 3). The rate of water loss increased with increasing storage temperature. The cultivar differences in rates of water loss were due to different fruit surfaces area to volume ratio and quantity and distribution of epicuticular waxes in different cultivars as reported by Banaras *et al*., (1994). The small sized 'Santa Fe Grande' fruits with large fruit surface area to volume ratio lost weight at considerably higher rate as compared to other two types of peppers. The bell shaped 'Keystone' fruits with small fruit surface area to volume ratio lost weight at the lowest rate (Wills *et al*., 1981). Moreover, cultivars that lost weight at lower rate had more epicuticular wax contents as compared to the others (Banaras *et al*., 1994).

Table 1. Average weight loss, wilt and colour ratings of packaged (with holes) and non-packaged field harvested (mid-season) pepper fruits after two weeks storage at 8 and 20ºC.

Cultivars	Storage temp. (ºC)	Packaged	Weight loss (%)	Wilt rating[z]	Colour rating[y]
Keystone	8	Yes	0.12	0.0	1.6
		No	4.47	1.1	1.3
NuMex R Naky	8	Yes	0.20	0.0	2.0
		No	7.17	1.0	3.7
Santa Fe Grande	8	Yes	0.18	0.0	1.8
		No	11.28	2.0	2.8
LSD at P<0.01			0.80	0.6	1.5
Significance[x]					
Cultivar			0.0001	0.0105	0.0071
Package			0.0001	0.0001	0.0133
Cultivar x Package			0.0001	0.0105	0.0365
Keystone	20	Yes	0.62	0.0	3.9
		No	44.75	7.7	7.7
NuMex R Naky	20	Yes	1.18	0.0	6.5
		No	73.90	9.0	9.0
Santa Fe Grande	20	Yes	1.25	0.0	4.0
		No	69.79	9.0	9.0
LSD at P<0.01			4.17	0.3	3.3
Significance					
Cultivar			0.0001	0.0001	0.0549
Package			0.0001	0.0001	0.0004
Cultivar x Package			0.0001	0.0105	0.2590

[z]Wilt rating = based on 0-9 scale where 0 = firm and 9 = soft
[y]Colour rating = based on 0-9 scale where 0 = 100% green and 9 = red
[x]Factorial effects = Pr>F

Greenhouse grown peppers stored at 8ºC lost 2- to 3-fold more weight over 14 days (Table 3) relative to field grown fruits (Tables 1 and 2). Similarly, at 20ºC greenhouse grown 'Keystone' lost more weight than field grown, however, the reverse was true for 'NuMex R Naky' and 'Santa Fe Grande'. Late-season field harvested fruits did not store for two weeks because of disease development at 20ºC. Postharvest weight loss was considerably higher for greenhouse grown peppers reducing the postharvest longevity of greenhouse peppers as compared to field-harvested peppers. This could be due to rapid growth and development of pepper fruits with relatively less quantity of epicuticular waxes.

Table 2. Average weight loss, wilt and colour ratings of packaged (without holes) and non-packaged field harvested (late-season) pepper fruits after two weeks storage at 8 and 20ºC.

Cultivars	Storage temp. ºC)	Packaged	Weight loss (%)	Wilt rating[z]	Colour rating[y]
Keystone	8	Yes	0.13	0.0	3.3
		No	4.98	1.3	2.4
NuMex R Naky	8	Yes	0.19	0.0	2.0
		No	9.57	3.3	3.7
LSD at P<0.01			1.48	1.9	5.4
Significance[x]					
Cultivar			0.0005	0.0231	0.9545
Package			0.0001	0.0013	0.6655
Cultivar x Package			0.0006	0.0231	0.1938
Keystone	20	Yes	1.09	0.0	5.7
		No	-[w]	-	-
NuMex R Naky	20	Yes	2.08	0.0	5.5
		No	-	-	-
LSD at P<0.01			1.21	0.0	4.3

[z]Wilt rating = based on 0-9 scale where 0 = firm and 9 = soft

[y]Colour rating = based on 0-9 scale where 0 = 100% green and 9 = 100% red

[x]Factorial effects = Pr>F

[w]- = data were not recorded due to non-marketability of pepper fruits.

MAP significantly reduced water loss from all cultivars at each temperature (Tables 1, 2 and 3). No cultivar differences in weight (water) loss were observed for fruits stored in MAP. Maximum water loss after two weeks storage at 8ºC ranged from 0.12% to 0.28% while at 20ºC water loss ranged from 0.62% to 2.04%. No significant differences were observed for mid- and late-season field harvested and greenhouse grown pepper fruits stored at 8ºC in MAP. However, at 20ºC water loss was higher for late-season harvested and greenhouse fruits. Maximum water loss for mid-season field harvested was 1.25% while for greenhouse grown fruits maximum was 2.04%.. MAP made a significant contribution in extending the postharvest longevity of pepper fruits having a high rate of postharvest water loss (Lownds & Bosland, 1988). Water saturated atmosphere within the packages controlled water loss due to transpiration delayed senescence in the absence of water stress and thereby extended postharvest longevity of pepper fruits (Banaras *et al*., 2002; Gibe, 1999; Nawa *et al*., 2001). An interaction between cultivar and packaging was noticed. The interaction resulted from significant varietal differences in postharvest water loss (Banaras *et al*., 1994) occurring for unpackaged fruits. These differences were overcome in MAP, where there was very little water loss.

Wilting: Generally turgidity of pepper fruits was inversely related to weight loss. Significant cultivar differences in wilt rating were observed for field harvested (mid- and late-season) and greenhouse grown pepper fruits stored for 14 days at 8ºC in open trays (Table 1, 2 and 3). The wilt rating for 'Keystone' after two weeks storage at 8ºC was significantly lower than 'NuMex R Naky' and 'Santa Fe Grande'. At 20ºC, only field (mid-season) 'Keystone' had wilt rating less than 9 (soft). As one might expect wilt rating was considerably higher at 20ºC as compared to 8ºC because of high rate of water loss at 20ºC (Banaras & Khan, 2004).

Table 3. Average weight loss, wilt and colour ratings of packaged (without holes) and non-packaged greenhouse grown pepper fruits after two weeks storage at 8 and 20ºC.

Cultivars	Storage temp. (ºC)	Packaged	Weight loss (%)	Wilt rating[z]	Colour rating[y]
Keystone	8	Yes	0.09	0.0	3.2
		No	14.12	7.5	3.9
NuMex R Naky	8	Yes	0.28	0.0	1.2
		No	18.50	8.2	3.5
Santa Fe Grande	8	Yes	0.24	0.0	1.2
		No	24.53	8.5	3.8
LSD at P<0.01			3.23	0.9	2.4
Significance[x]					
Cultivar			0.0004	0.0787	0.0675
Package			0.0001	0.0001	0.0022
Cultivar x Package			0.0001	0.0787	0.1384
Keystone	20	Yes	0.79	0.0	3.7
		No	52.72	9.0	9.0
NuMex R Naky	20	Yes	1.33	0.0	2.5
		No	60.06	9.0	9.0
Santa Fe Grande	20	Yes	2.04	0.0	2.2
		No	64.53	9.0	7.3
LSD at P<0.01			7.73	0.3	2.7
Significance					
Cultivar			0.0045	0.0	0.0593
Package			0.0001	0.0	0.0001
Cultivar x Package			0.0081	0.0	0.4328

[z]Wilt rating = based on 0-9 scale where 0 = firm and 9 = soft
[y]Colour rating = based on 0-9 scale where 0 = 100% green and 9 = 100% red
[x]Factorial effects = Pr>F

Following two weeks storage at 8ºC greenhouse grown fruits of each cultivar had a higher wilt rating than field harvested fruits (Tables 1, 2 and 3). Greenhouse fruit had become almost completely soft (wilt rating up to 8.5), while field harvested peppers remained firm (wilt rating 0.0) most likely due to less quantity of epicuticular waxes (Banaras *et al*., 1994). MAP stored fruits of each cultivar at both 8 and 20ºC remained fully turgid for 14 days (Tables 1, 2 and 3). There were no differences in wilt rating for field and greenhouse grown fruits as the water saturated environment within the package kept the fruit fully turgid without transpiration loss (Satyan *et al*., 1992; Thompson, 1996; Zagham, 2003). There was an interaction between cultivar and packaging (Tables 1 and 2) except for greenhouse peppers (Table 3) indicating that cultivar and packaging effects were not independent. MAP overcome the differences in postharvest rate of water loss in different cultivars (Banaras *et al*, 1994).

Colour: No differences in colour rating for field and greenhouse grown peppers were observed at 8 and 20ºC. Without packaging at 8ºC field harvested (mid-season) 'Keystone' had significantly lower colour rating than 'NuMex R Naky' and 'Santa Fe Grande'. Similarly for late-season and greenhouse fruits, 'Keystone' generally had the lowest colour rating at each storage temperature. Colour development was generally correlated with postharvest rate of water loss. Cultivars loosing weight at higher rate developed red colour earlier. High rate of water loss caused water stress and led fruit ripen earlier.

Storage temperature had a considerable effect on colour development. Non-packaged fruits had considerably higher colour rating at 20ºC than at 8ºC because of high transpiration and other metabolic activities that led towards fruit ripening (Forney *et al*., 1989; Nawa *et al*., 2001). Colour rating for the mid-season field harvested fruit was considerably lower than for the late-season field harvested and greenhouse-grown peppers stored at 8ºC with less water loss. After two weeks at 20ºC colour rating for field harvested and greenhouse grown pepper fruits was similar as all fruits ripened with greater loss of water faster at relatively high storage temperature. Water stress in fruits might have caused ethylene production and relatively earlier fruit ripening (Ben-Yehoshua, 1987).

Colour development for pepper fruits harvested from the field (mid- and late-season) or grown in a greenhouse and stored at 8ºC was similar for packaged treatments having least postharvest water loss and slow metabolic activities. However, at 20ºC field harvested (mid- and late-season) fruits had higher colour rating as such fruits might be close to physiological maturity when compared to greenhouse grown tender pepper fruits.

Disease: It was observed that the postharvest storage life of late-season field harvested peppers was shorter than mid-season field harvested peppers primarily due to disease incidence (fungal decay) mainly due to fruit injuries caused by insects (Banaras, 1989).

The postharvest weight loss, turgidity and colour rating for pepper fruits were considerably higher at 20ºC as compared to 8ºC. The postharvest storage life of late-season field harvested pepper fruits was shorter than mid-season field harvested peppers primarily due to disease incidence. Packaging might have reduced respiration rate and other metabolic activities, therefore, delaying ripening of greenhouse grown peppers stored at 8 and 20ºC in the ambient atmosphere (Forney *et al*., 1989, Thompson, 1996).

Post-storage weight loss: Cultivars differed significantly in weight loss after three days post-storage at 20ºC (Table 4). 'Keystone' had the lowest weight loss, followed by 'NuMex R Naky' and 'Santa Fe Grande'. The differences in postharvest rate of water loss in three distinct pepper cultivars were primarily due to differences in physical properties of fruits in relation to postharvest water loss as explained earlier (Banaras *et al*., 1994). Post-storage water loss for pepper fruits already stored for two weeks at either 8 or 20ºC in MAP was similar after three days of post-storage at 20ºC indicating that packaging had no effect on post-storage water loss. As one might expect, MAP had no effect on post-storage quality of pepper fruits. Once fruits were taken out of package, they lost the advantage of water saturated atmosphere, hence lost weight at considerably higher rate at 20ºC (Ben-Yehoshua, 1985).

Table 4. Average weight loss, wilt and colour ratings of greenhouse grown pepper fruits following two weeks MAP storage (8 or 20ºC) and three days post-storage at 20ºC.

Cultivars	Storage temp. (ºC)	Weight loss (%)	Wilt rating[Z]	Colour rating[Y]
Keystone	8	13.4	4.9	4.4
NuMex R Naky	8	17.3	5.6	3.3
Santa Fe Grande	8	21.4	5.8	1.8
Keystone	20	12.5	4.3	4.5
NuMex R Naky	20	18.0	5.7	7.2
Santa Fe Grande	20	23.0	5.7	4.3
LSD at P<0.01		4.4	1.3	2.6

[z]Wilt rating = based on 0-9 scale where 0 = firm and 9 = soft

[y]Colour rating = based on 0-9 scale where 0 = 100% green and 9 = 100% red

Wilting: Following three days post-storage at 20ºC, 'Keystone' fruits were relatively firmer than 'NuMex R Naky' and 'Santa Fe Grande' but the differences were not significant because of high rate of water loss at this storage temperature. Due to considerable loss of turgidity, fruits became soft and therefore were not acceptable for fresh market after three days of post-storage at 20ºC (Collins & Peckins-Veazie, 1993).

Colour: In general, colour development was quite high in all cultivars after three days of 20ºC post-storage as the physiological processes (transpiration, respiration, ethylene production) were relatively faster at 20ºC and enhanced fruit ripening (Banaras & Khan, 2004). There were significant cultivar differences between fruits that had been stored at 8ºC or 20ºC following three days of post-storage. At 8ºC 'Keystone' had significantly higher colour rating than 'Santa Fe Grande'. At 20ºC 'NuMex R Naky' had a significantly higher colour rating than 'Keystone' or 'Santa Fe Grande'. Pepper fruits previously stored at 8 and 20ºC lost weight, turgidity and developed colour at similar rates when stored at 20ºC in ambient atmosphere as postharvest rate of water loss was higher and ripening processes were faster at 20ºC storage temperature (Banaras *et al*., 1994; Ben-Yehoshua, 1987).

Packaging being equally effective at 8 and 20ºC suggests that peppers can be successfully stored at relatively higher temperatures (20ºC). MAP may not be successful for late-season field harvested pepper fruits due to disease (fungal decay/fruit rottening) development in the package. The postharvest longevity of greenhouse grown peppers can be extended and be equal to the mid-season field harvested peppers with MAP. MAP had no effect on post-storage quality of pepper fruits.

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