Controlling Humidity Improves Efficacy of Modified Atmosphere Packaging of Fruits and Vegetables

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Keywords: storage, broccoli, green onion, radish, carrot, bean, strawberry, nectarine

Abstract

In a joint venture between Agricultural Research Organization, Volcani Center and StePac L.A Ltd. (Tefen, Israel), a series of plastic films have been developed (commercial name Xtend®) with higher permeability to water vapor than most commercially available MAP products. Using hydrophilic Xtend® films manufactured from various proprietary blends of polyamides with other polymeric and non-polymeric compounds allowed achieving in-pack relative humidity that prevented accumulation of condensed water on the produce. A beneficial modified atmosphere was achieved in the package by microperforation of the film. Film composition and the extent of microperforation were tailored in accordance with the respiratory activity and weight of the packaged produce, anticipated temperature fluctuations during storage and shipment, and expected physiological and pathological responses of the produce to CO_2/O_2 concentrations and humidity levels inside the package. The effectiveness of Xtend® films in maintaining quality of MA-packed fresh produce was greater than that of other commercially available films such as polyethylene, polypropylene, and polyvinyl chloride. The microperforated Xtend® packaging resulted in the formation of desirable modified atmospheres that retarded ripening and senescence of the produce. Additional beneficial effects of Xtend® films included reduction of decay and chilling injury, prevention of leaf elongation leaf sprouting, tissue discoloration, peel blemishes, off-odors, and inhibition of bacterial growth on the produce surface. Description of the above mentioned effects are presented for a number of different commodities.

INTRODUCTION

Although the principles of modified-atmosphere packaging (MAP) of fresh produce are well known, the method is still limited because of the difficulties in controlling in-package atmosphere and humidity during commercial shipments. Very often, anaerobic respiration is likely to occur if the packaged produce is exposed to higher temperatures. This is typical for produce with medium-high respiration rate packed in bulk packaging (Hardenburg, 1971; Zagory and Kader, 1988). The most common and simple way for increasing OTR (oxygen transmission rate) of plastic films, used for a wide range of fresh produce is the addition of microperforations. This technology can enhance gas permeation, thereby preventing anaerobic respiration. The relative humidity (RH) in most sealed packaging is close to saturation. Therefore, even very small fluctuations in temperature during storage and/or shipment may result in water condensation on the surface of both film and produce. The most deleterious effect of in-pack condensation is enhancement of growth of many plant pathogens, resulting in produce decay. In addition, a combination of high humidity and low O_2 is favorable for the development of human pathogens (Hintlian and Hotchkiss, 1986; Brackett, 1994).

In previous studies several microperforated films of the Xtend® series characterized by relatively high water vapor permeability were tested (Aharoni et al., 1997). Use of these films resulted in modified-atmosphere (MA) associated benefits and reduced water condensation in the packaging of several commodities. Aharoni and Richardson (1997) tested two types of microperforated Xtend® packaging designed for prolonged storage of sweet corn which reduced in-pack relative humidity to 95-98%. It was found that the type of film having the higher permeability to water vapors was more suitable for bulk packaging, whereas the less permeable one was better for consumer packaging. Rodov et al. (2000) tested PVC-wrapped consumer trays of trimmed corn cobs placed within microperforated Xtend® liners that were opened before transfering to shelf life. The addition of the Xtend® liners resulted in a suitable in-pack MA that inhibited mold growth. Desired MA combined with reduced humidity in Xtend® packaging for mango resulted in reduced chilling injury (CI) and reduced level of sap in the packaging (Pesis et al., 2000). Xtend® packaging effectively reduced the development of CI as well as other types of rind disorders of oranges, tangerines, and grapefruits (Porat et al., 2004). In another CI-sensitive fruit, Charentais-type melon, the desired in-pack atmosphere and humidity produced in Xtend® packaging resulted in extended postharvest life by delaying ripening, softening, change of rind color, soluble solids depletion, and inhibiting development of postharvest pathogens (Rodov et al., 2002). Packaging of summer squash in Xtend® packaging improved the general appearance of the fruits and inhibited yellowing, softening, and decay (Rodov et al., 1988). The efficacy of Xtend® films for various vegetables has recently been reviewed (Aharoni et al., 2007).

The present work reports on the unique beneficial effects of Xtend® packaging for vegetables: broccoli, leek, topped radishes, carrots, snap beans, and on fruits: strawberries and nectarines.

MATERIALS AND METHODS

Export grade vegetables were obtained from commercial packing houses or directly from growers, and packed on the day of harvest. Package weight and storage temperature and duration are provided together with the results. Samples of the headspace atmosphere within the packaging were taken periodically during cold storage and shelf life for testing O_2, CO_2 and ethylene. The plastic liners used for MAP were Xtend® (XF). Two types of XF films (20 µm thick) were used: XF10 and XF12, having the following permeance to water vapor: 18×10^{-10} and 6×10^{-10} mol s^{-1} m^{-2} Pa^{-1}, respectively. Oxygen permeance of XF10 was 48×10^{-14} and of XF12: 24×10^{-14} mol s^{-1} m^{-2} Pa^{-1}. Due to the very low gas transmission rate of the XF films to both O_2 and CO_2, the actual gas transmission characteristics of the packages were determined by microperforations. According to Day (1993) the O_2 transmission rate of microperforated film is $>70.5\times10^{-12}$ mol s^{-1} m^{-2} Pa^{-1} at 23°C. The total perforated area relative to film surface, was in the range of 0.00012-0.0012% and 0.19% for microperforated and macroperforated films, respectively. In most of the experiments, low density polyethylene (LDPE) packaging was used as a control to XF packaging. Water vapor and O_2 permeance of non-perforated LDPE film were about 11.8×10^{-11} and 35×10^{-12} mol s^{-1} m^{-2} Pa^{-1}, respectively. The permeability data were provided by the manufacturers and converted into SI units according to Banks et al. (1995). At the end of shelf life, visual quality was evaluated as follows: general appearance was graded on a scale of 1-5 where 5 denotes excellent quality and 1 denotes poor quality. Grades below 2.5 represent an unmarketable condition. For yellowing, decay and condensation, a scale of 1 (none) -5 (severe) was used.

RESULTS AND DISCUSSION

The effect of controlling the humidity in MAP on pathological and physiological disorders was investigated on several commodities that might be affected by in-pack condensation. In all the experiments the efficacy of the high water vapor-permeable film, XF, was compared to that of the low water permeable, PE.

Retardation of Yellowing, Decay, Bacterial Load, and Off-Odors

1. Broccoli. In a commercial microporous packaging (mineral-impregnated LDPE) the gas transmission rate was inadequate and after 19 days at 1ºC followed by one day at 20ºC, concentrations of O_2, CO_2, and ethanol in the sealed packaging were 2.7 and 19.5 KPa, and 190 ppm, respectively (Table 1). At this stage, the broccoli heads remained green without decay but developed offensive odors that persisted even after removal of the heads to ventilated conditions. In microperforated PE packaging after cold storage followed by one day at 20°C, O_2 decreased to 4.6 KPa and CO_2 increased to 14.0 KPa and the broccoli developed slight off-odors that dissipated with subsequent ventilation. In microperforated XF12 packages after the same storage conditions, O_2 decreased to 2.2 KPa and CO_2 increased to 18 KPa. No ethanol or off-odors were detected. The broccoli remained fresh and green, weight loss was only 2.0% and levels of yellowing and decay were significantly lower than for broccoli packed in the PE packaging. Only the XF12-packed broccoli remained in a salable state after 3 additional days at 20°C in ventilated packaging (data not shown). These results suggest that in the hydrophilic XF12 packaging characterized by a slight water loss, broccoli can tolerate lower levels of O_2 and higher levels of CO_2 without shifting to anaerobic respiration and developing undesirable odors.

The effect of MAP that developed in microperforated PE and XF12 on the total microbial count (TC) in broccoli heads was tested. Waxed cartons containing broccoli in crushed-ice served as the control. After 3 weeks at 1ºC followed by two days shelf life at 20ºC (in perforated consumer packages) the increase of TC in broccoli previously stored in crushed-ice, PE, and XF was ×7500, ×300, and ×120, respectively (Table 2). The results indicate the efficacy of MAP and the reduced humidity in XF in controlling bacterial load in fresh produce.

Retardation of Yellowing, Decay, and Leaf Elongation

1. Green Onion and Leek. Bunched green onions were packed in macroperforated PE, microperforated PE, and microperforated XF12. Packing in macroperforated PE resulted in severe decay, yellowing and leaf elongation. Even though the perforation rate was the same in both microperforated PE and XF12 (which has lower gas permeability), the latter packaging suppressed leaf elongation and decay more efficiently (Table 3). It would appear that the ability of XF packaging to preserve quality of the bunched onions better than the other packaging was due to the higher level of CO_2 (20.1 KPa) and the lower level of O_2 (2.5 KPa) that were obtained at the end of storage (one day at 17ºC after cold storage). Even after such extreme conditions of MA, no off odors were detected. It would appear that the reduced humidity in the XF packaging as reflected by a moderate weight loss (0.7%) and the almost complete lack of condensation (index of 1.3 compared with 3.5 in PE) may also contribute to the reduction in leaf elongation and decay. Both fungal and bacterial decay, leaf elongation and regrowth are known to be enhanced by excess humidity. Similar results have also been achieved with leek in MAP (data not shown). XF12 packaging was more efficient than PE in the retardation of yellowing, decay, and leaf regrowth (“telescoping”).

Retardation of Leaf Sprouting, Decay, and Discoloration in Root Vegetables

1. Topped Radishes. Packing 13.5 kg roots (‘Sakata’) in microperforated XF12-lined cartons, retarded leaf sprouting and reduced decay more efficiently than packing in a microperforated PE liner (data not shown). Decay was mostly bacterial black spot caused by *Xanthomonas vesicotoria*. The reduction of leaf sprouting and decay in the XF12 is attributed to the effective MA that was created in the packaging as well as the elimination of condensed water. Levels of CO_2 and O_2 were in the range of 4-8 and 8-16 KPa, respectively. Therefore, the beneficial effect of MAP in preserving the quality of the radishes was attributed to the elevated CO_2 rather than to the reduced O_2. In-pack elevated CO_2 in cold storage caused purplish discoloration of the roots that was found to be reversible following removal from the packaging and ventilation (Aharoni et al., 1998). They concluded that the purplish discoloration of red radishes in ventilated atmosphere is an irreversible process, being part of senescence, whereas CO_2-induced purplish color is a reversible reaction. Therefore, when elevated CO_2 inhibits senescence, it also reduces purplish discoloration during the final stages of the postharvest supply chain.

2. Topped Carrots. Modified atmosphere packaging of 15 kg carrots in either micro-perforated liners of PE or XF12 resulted in decreased decay and leaf sprouting (Table 4).

Again there was total elimination of water condensation in the XF-packed carrots, and this was correlated with a reduction in the rate of decay and sprouting.

Retardation of Chilling Injury and Decay

1. Snap Beans. Mechanically harvested snap beans were packed in microperforated packaging of PE and XF10 (MAP) and macroperforated PE (control). Naked beans also served as a control. Beans are very susceptible to chilling injury that is manifested as rusty brown spots on the pods. The MAP that developed in both PE and XF10 markedly reduced the percentage of decay and rusty spots that were noticed, but XF10 was more effective (Table 5). Fallik et al. (2002) showed that the use of XF films that prevent excess humidity in the packaging increased the tolerance of the beans to high CO_2, thereby allowing the use of effective MAP during both storage and marketing. In their experiments the concentrations of CO_2 and O_2 were 6-8 KPa, respectively, during 7 days storage at 5°C and 12 and 7 KPa, respectively, during additional 2 days at 20°C.

Retardation of Decay in Fruits

1. Strawberries. Strawberries were obtained directly from farms after commercial harvest, sorting and packaging. Eight retail punnets (250 g fruit per punnet) were sealed within XF10 liners in standard commercial cartons. Control consisted of the punnets in the carton without the liner. The cartons were stored under conditions imitating strawberry shipment and marketing (see temperatures in Table 6). The modified atmosphere generated inside XF liners comprised 7-10 KPa CO_2 and 10-14 KPa O_2.

The effects of XF10 packaging were tested during at least three consecutive seasons with a number of strawberry cultivars (‘Oso Grande’, ‘Sharon’, ‘Yael’, ‘Dorit’, ‘Malach’, ‘Tamar’) and in almost all cases positive results were obtained. Controlling *Botrytis* decay was the most prominent effect of XF packaging that significantly improved the keeping quality of strawberries. Therefore, with cultivars relatively less susceptible to *Botrytis* (e.g., ‘Yael’) the improvement of keeping quality was not statistically significant. The outcome of a typical storage trial is presented in Table 6. The MA-packaged fruit in most trials was still marketable by the end of shelf life, while the strawberries in standard commercial packages (without MA) had typically deteriorated by that time.

In addition to static experiments, the efficacy of the XF10 packaging was tested in a trial shipment of strawberries (‘Tamar’ and ‘Malach’.) from Israel to the UK by sea freight. The XF packaging maintained the fruit quality above the marketability threshold for 11 days of transportation and storage at 2ºC followed by an additional 1-2 days of shelf life at 17ºC. In addition to controlling *Botrytis*, the MA packaging reduced the incidence of *Rhizopus* by 2-3 fold, as compared to standard commercial packaging in these trials (ventilated plastic punnets). It was demonstrated that the XF packaging facilitated sea freight of strawberries for export from Israel to UK.

2. Nectarines. A late ripening cultivar of nectarines, ‘Flamekist’ was harvested in late August and stored, in XF12, or in PE film or non-bagged. In previous studies it was noticed that 10 KPa CO_2 helped to prevent the storage disorder of wooliness in peaches and nectarines (Zhou et al., 2000). After storage at 0ºC for 4 weeks, the CO_2 in the XF12 bags reached 8.5 KPa and in the PE bags, 4.3 KPa. These concentrations remained steady for up to 6 weeks, the limit of storage. After removal from storage after 4 weeks at 0ºC and storage in opened bags at 20ºC for 5 days, over 50% of the non-bagged fruit was woolly compared to 0% wooliness of fruit in both XF12 and PE film. Over 10% decay was noticed in fruit that had been held in PE in comparison to 1% decay of fruit in the XF12 packages. After 6 weeks of storage at 0ºC, followed by 5 days at 20ºC, 70% of the XF12 fruit still had no woolliness, while over 50% woolliness was noticed in the PE packaged fruit.

CONCLUSIONS

The use of microperforated hydrophilic Xtend® packaging was found to effectively modify both atmospheric composition and humidity inside packaging containing various fruits and vegetables. The combination of reduced in-pack humidity with safe level of O_2 allows the accumulation of high non-injurious levels of CO_2 within the fungistatic range (>10 KPa), thereby resulting in a reduction in decay and microbial contamination. Additionally, the elevated concentrations of CO_2 in Xtend® packages were found to effectively retard ripening and senescence processes as well as physiological disorders. The hydrophilic Xtend® packaging is a suitable method for commodities that respond positively to moderate-high CO_2 concentrations and especially for those that are sensitive to excessive humidity and water condensation in the packaging. Most of the technologies based on the Xtend® packaging described herein are successfully implemented on a commercial level in Israel, USA and other countries, particularly for long-distance shipments.

ACKNOWLEDGEMENTS

Contribution from the Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel, No. 501, 2007 series. The research was supported by StePac L.A. Ltd., Agrexco Agricultural Export Co, Ltd. and the Vegetables Board of Israel.

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Tables

Table 1. Effect of various bulk packages of broccoli on weight loss, yellowing, decay, general appearance and development of off-odor. Source: Aharoni et al. (2007).

Packaging	O_2 (kPa)	CO_2 (kPa)	Weight loss (%)	Yellowing index (1-5)	Decay index (1-5)	Off-odor	Appearance index (1-5)
Microperforated PE	4.6	14.0	1.1 b	2.6 a	2.1 a	Slight	2.4 a
Microperforated XF12	2.2	18.0	2.0 a	1.9 b	1.4 b	None	3.1 b
Microporous PE	2.7	19.5	1.1 b	2.0 b	1.2 b	Severe	-

Broccoli heads packed in 10 kg plastic-lined cartons were checked after 19 days at 1°C followed by one day at 20°C. Means followed by same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.

Indices: 1= the lowest level; 5= the highest level. Appearance indices ≥2.5 are marketable.

Table 2. Total microbial counts (TC)[1] of broccoli packed by different methods.

Packaging	Cold storage + shelf life		
	10 days	3 weeks	Increase in TC
Crushed ice in wax cartons	2.6×10^8	1.8×10^9	× 7,500
PE liner	5.0×10^7	7.2×10^7	× 300
XF12 liner	8.8×10^6	2.9×10^7	× 120

[1] Ziro time = 2.4×10^5 CFU/1 g.

TC of broccoli heads packed in 10 kg cartons was sampled after 7 and 18 days at 1°C followed by 3 additional days at 8°C.

Table 3. Effect of various bulk packages of trimmed green onion on film condensation, CO_2 and O_2 steady state and quality parameters of the stored onions.

Packaging	Condensation index (1-5)	Weight loss (%)	Elongation (cm)	Yellowing index (1-5)	Severe decay (%)	Appearance index (1-3)	Steady state (kPa)	
							O_2	CO_2
Macroperforated PE	2.2 b	1.4 a	7.1 a	2.7 a	86.7 a	2.0 c	-	-
Microperforated PE	3.5 a	0.2 c	4.4 b	1.9 b	16.7 b	2.4 b	3.3	11.2
Microperforated XF12	1.3 c	0.7 b	1.8 c	1.8 b	10.0 c	2.8 a	2.5	20.1

Bunched onions (2 kg) were packed vertically in plastic-lined cartons. Onions were stored for one day at 1°C followed by 4 days at 6°C and an additional day at 17°C.Means followed by same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test; Indices: 1= the lowest level; 5 = the highest level. Appearance indices ≥2.5 are deemed marketable. Source: Aharoni et al. (2007).

Table 4. Effect of various bulk packages of topped carrots on levels of condensation, decay and sprouting.

Packaging	Condensation (1-5)	Decay[1] (%)	Sprouting[2] (%)
Macroperforated PE	2.5 b	32.5 a	50.0 a
Microperforated PE	3.0 a	17.6 b	30.0 b
Microperforated XF10	1.0 c	7.3 c	10.0 c

Topped carrots packed in 15 kg plastic-lined cartons were checked after 36 days at 1°C followed by 7 days at 20°C. Means followed by same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test. Condensation index: 1= the lowest level; 5= the highest level.

[1] Mostly *Erwinia carotovora*.

[2] Sprouting leaves above 5 cm.

Table 5. Effect of various bulk packages of snap beans on levels of weight loss, rusty spots and decay.

Packaging	Weight loss (%)	Severe rusty spots (%)	Decay (%)
Naked	11.3	70.0	10.0
Macroperforated PE	1.5	40.0	12.3
Microperforated PE	0.7	18.0	4.0
Microperforated XF	3.9	7.0	1.0

Beans packed in 2.2 kg plastic-lined cartons were checked after 6 days at 5°C followed by 2 days at 17°C.

Table 6. Effect of modified atmosphere packaging in Xtend® liners on decay incidence in two strawberry cultivars after simulation of airfreight transportation1.

Cultivar	Packaging	Decay (%)		Total
		Botrytis	*Rhizopus*	
Oso Grande	Standard (plastic punnets)	45.0	1.7	45.7
	Punnets within XF10 liner	0.0	13.3	13.3
Sharon	Standard (plastic punnets)	73.0	5.6	78.6
	Punnets within XF10 liner	7.7	4.4	12.1

[1] Strawberries were checked after 1 day at 1ºC + 2 days at 5ºC + 2 days at 17ºC.