Modified-atmosphere Packaging Improves Keeping Quality of Charentais-type Melons

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Abstract. Modified-atmosphere (MA) packaging using bag-in-box Xtend® liners extended the postharvest life of nonnetted Charentais-type muskmelons (*Cucumis melo* L., Cantalupensis Group, cv. Luna) by delaying over-ripening: excessive softening, change of rind color, decreased soluble solids, and the development of postharvest pathogens. The most delayed fruit ripening was achieved by an atmosphere of 13–14 kPa CO₂ and 7–10 kPa O₂, even though ethylene concentrations were as much as 120 µL·L⁻¹. Charentais fruit stored in this atmosphere at 6 to 7 °C maintained marketable quality for 12 days plus additional 3 days at 20 °C. In contrast, lifespan under commercial conditions in air did not exceed 3–5 days at 10 to 11 °C plus 3 days at 20 °C. The recommended MA was achieved by using the liners with low microperforation level (total perforation area 25 × 10⁻⁵ percent of the film surface), 8–9 fruit of total weight ≈5 kg per liner. MA packaging of Charentais melons makes possible their transportation from Israel to Europe by sea instead of air.

Nonnetted Charentais-type melons belong to Cantalupensis group (Robinson and Decker-Walters, 1996) and are the most perishable variety of *Cucumis melo* L. Typical Charentais fruit have a pronounced climacteric behavior. Within days after harvesting at commercial maturity (pre-ripe), they become over-ripe, which is expressed as excessive softening, a yellow-orange peel color, flavor deterioration, a decline in sugar content, and increased susceptibility to pathogens. Some Charentais cultivars (e.g., Clipper) demonstrate a less pronounced climacteric behavior and relatively long shelf life (Lacan and Baccou, 1996). However, these cultivars have less market demand because of their lack of the notable Charentais aroma. In a previous work, the cultivar Luna had adequate flavor and aroma, combined with relatively good storage potential vs. other high-quality Charentais cultivars (Rodov et al., 1998).

Costly air transportation is currently used to deliver high-quality Charentais fruit from Israel to Europe. Temperatures as high as 10 to 12 °C are usual for storage and transportation

because Charentais melons are chilling sensitive. Slowed ripening therefore is needed to retard postharvest losses and to enable sea transportation. Ripening has been inhibited in transgenic Charentais fruit by blocking ethylene biosynthesis using the ACC oxidase antisense gene (Ayub et al., 1996), and these fruit are chilling-tolerant (Ben Amor et al., 1998). However, to reach acceptable fruit quality these melons need to be gassed with exogenous ethylene.

Although modified-atmosphere (MA) packaging is a well-known method to delay fruit ripening, no data about MA packaging non-netted Charentais fruit have been published. MA packaging in low-density polyethylene reduces weight loss and preserves quality of netted muskmelons (Cantalupensis group, cv. Durango) stored at 5 °C (Yahia and Rivera, 1992). However, decay incidence sharply increases in polyethylene-packaged melons when held at 20 °C due to water condensation. Microperforated polymeric Xtend® films allow for relatively high water vapor permeability (Aharoni et al., 1997). Use of this material produced MA benefits and reduced water condensation in packages of sweet corn (Aharoni and Richardson, 1997; Rodov et al., 1999) and mango (Pesis et al., 2000).

Our purpose in the present work is to investigate the use of Xtend MA packaging in combination with relatively low storage temperature to delay ripening of highly perishable Charentais melons.

Materials and Methods

Nonnetted Charentais muskmelons of cv. Luna, grown near the Dead Sea, Israel, were

obtained directly from the packinghouse on the day of harvest. In the packinghouse, the melons were sorted, individually packaged in soft sleeves of foamed plastic net as a protection from mechanical damage, and placed in standard export cartons. Each carton contained 8 or 9 melons (≈5 kg). The packinghouse treatment did not include forced precooling, fungicide application or germicidal wash. Upon arrival at the laboratory, the melons were repackaged in the same cartons with the addition of 0.75 × 0.75 m, 20 µm microperforated Xtend plastic liners (StePac L.A., Tefen, Israel) (“bag-in-box” package type), which were tightly closed using rubber bands. The control fruit packages contained no plastic liners.

According to the producer’s specification, the polymeric material of Xtend liners had a water vapor permeance of (25.0 × 10⁻¹⁰ mol·m⁻²·s⁻¹ Pa and oxygen permeance of (23.5 × 10⁻¹⁴ mol·m⁻²·s⁻¹ Pa at 23 °C. The actual gas transmission characteristics of the packages were imposed by microperforation. According to Day (1993), the O₂ transmission rate of microperforated films is >70.5 × 10⁻¹² mol·m⁻²·s⁻¹ Pa at 23 °C. A basically similar rate may be expected for the transmission of CO₂, since the ratio of CO₂ to O₂ mass transfer coefficients through microperforated films is between 0.72 and 1.0 (Oliveira et al., 1998). Xtend films with three different microperforation levels—low, medium, and high—were tested in these experiments. The degrees of perforation, expressed as percentage of total perforation area related to film surface, were ≈25 × 10⁻⁵, 75 × 10⁻⁵, and 125 × 10⁻⁵, respectively. The relative humidity level inside the Xtend packages was maintained within the optimal range of 90% to 95% (Pesis et al., 2000).

Fruit were stored for 12 d at 10 to 11 °C or at 6 to 7 °C [relative humidity (RH) in both cases 80% to 90%] plus the additional 3 d at 20 °C and 60% to 70% RH simulating sea transportation from Israel to Europe and subsequent retail marketing. Immediately after transfer to 20 °C, the rubber bands were removed from the carton liners. The liners were kept folded without tight closure for 2 d (simulating nonrefrigerated storage in a retail outlet) and then were completely open for one additional day (simulating exposure on a retail shelf). The effect of simulated sea transportation on the quality of cv. Luna melons was compared with that of simulated air transportation (3 d at 11 °C plus the additional 3 d at 20 °C).

Gas-tight syringes were used to sample headspace atmosphere through septa made of silicone sealant (100% Silicone RTV) mounted on a polyvinyl-chloride insulating tape attached to the film surface of the packages. Oxygen, carbon dioxide and ethylene were analyzed by gas chromatography and compared to external standards. Oxygen and carbon dioxide concentrations were determined by gas chromatograph (GC) (model 7500; Packard, Downers Grove, Ill.) with a thermal conductivity detector and a CTR-I packed column, using helium as the carrier gas. Oxygen concentrations were corrected for the

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presence in the atmosphere of 0.94 kPa argon, inseparable from the O₂ by GC. Ethylene concentration was determined with a Varian 3300 gas chromatograph equipped with a flame ionization detector and a C-5000 packed column using nitrogen as the carrier gas; column, injector and detector temperatures were 80, 50, and 56 °C, respectively.

Fruit quality included decay incidence (expressed as percentage of infected fruit), extent of physiological disorders (watery flesh breakdown, chilling injury), visual color index, fruit firmness, soluble solids concentration (SSC, %), flavor, and general appearance. The decay-causing fungi were isolated from symptomatic plant material, grown on potato-dextrose agar (PDA) and identified using the keys described by Barnett (1955).

The peel color was assessed visually by grading the fruit according to the following scale: 1 = grayish-green; 2 = color break; 3 = yellowish-beige; 4 = yellow-orange. For assessment of watery flesh breakdown fruit were halved through the equator region and severity was visually determined by the extent of water-soaked area around the seed cavity, from 0 (no breakdown) to 4 (>50% of the cut surface water-soaked). The incidence of chilling injury was assessed by the appearance of either pitting, discoloration, or both, on the fruit surface. The general appearance was evaluated by an experienced panel of research team members, taking into account the complex of visual characteristics affecting the market acceptability of the given melon variety, such as typical peel color, blemishes, appearance and severity of rots, shriveling, peduncle separation, etc. The general appearance index ranged from 1 (poor) to 5 (excellent), while fruit rated 2.5 and above were considered marketable (Aharoni et al., 1993).

The quality indices for general appearance, peel color and watery breakdown severity were calculated for each replication as follows:

$$\text{Quality indices} = \frac{\sum_{i=1}^N (i \cdot n_i)}{\sum_{i=1}^N n_i},$$

where N is the maximum score and n_i is the number of fruit of each score i .

Fruit firmness was determined on the equator region of the fruit from two opposite locations without removing the exocarp using a Chatillion penetrometer (John Chatillion and Sons, New York) with a 6-mm conical head (Aharoni et al., 1993). The SSC in expressed fruit juice was measured with a refractometer (model PR-32; Atago Co., Tokyo). Juice was squeezed from pieces excised from the fruit's equator region from the skin to the seed cavity. Fruit flavor was evaluated by the authors according to a hedonic scale from 1 (inedible) to 5 (excellent).

The storage trials were conducted at least in triplicate, each replicate included 16–18 fruit, and was analyzed by analysis of variance (ANOVA) using Duncan's multiple range test. At least eight healthy fruit were taken for destructive tests, each fruit serving as replicate. The experiments were performed twice during the 1997 and 1998 spring harvests. The results

of the two seasons were not combined since the details of experimental design (storage temperatures, the particular types of Xtend film) were not exactly the same. The data presented here were obtained during the 1997 harvest, but are representative of trends observed in 1998, as well.

Results

Postharvest quality of Charentais-type melon fruit (cv. Luna) stored without MA in regular commercial packages showed a decline as early as in 6 d (3 d at 11 °C followed by 3 d at 20 °C). The peel color changed from predominantly

grayish-green to yellowish-beige, along with fruit softening (Table 1). However, by the end of this six-day period the fruit were still marketable. Fruit stored for 12 d at 11 °C plus 3 d at 20 °C (the duration necessary for sea transportation from Israel to Europe) exhibited a significant decline in SSC and were completely unmarketable due to severe fungal decay and over-ripe (yellow-orange) peel color (Table 1). The major fungal genera attacking over-ripe Charentais melons in commercial packages were *Alternaria*, *Fusarium*, *Geotrichum*, *Aspergillus*, and *Penicillium*.

The atmosphere composition inside the MA packages depended on microperforation

Table 1. Quality of Charentais-type melons (cv. Luna) at harvest and after storage in standard commercial packages (open cartons).

Quality factors	Storage duration (days at 11 °C + days at 20 °C)		
	0	3 + 3	12 + 3
Color (index 1–4)	2.6 b ^z	3.3 a	3.6 a
SSC (%)	15.4 a	14.8 a	11.9 b
Firmness (N)	72.0 a	46.7 b	40.2 b
Breakdown (index 0–4)	0.2	0.3	0.7
Flavor (index 1–5)	4.1	3.7	3.2
Decay incidence (%)	0.0 b	4.9 b	35.7 a
Gen. appearance (index 1–5)	3.9 a	3.2 ab	2.0 b

^zMeans separation across columns; means followed by the same letter are not significantly different by Duncan's multiple range test at $P = 0.05$.

Fig. 1. Effect of storage temperature and Xtend liners with different microperforation levels on average oxygen, carbon dioxide and ethylene concentrations inside packages of Charentais (cv. Luna) fruit ($n = 3$). The liners were tightly closed with rubber bands during 12 d of storage at 7 or 11 °C and kept folded without rubber band closure for 2 d at 20 °C. Bars show confidence intervals for $P = 0.05$.

level and storage temperature (Fig. 1). Carbon dioxide partial pressure in the liners of low microperforation level reached a maximum of 15 kPa at 7 °C and 18 kPa at 11 °C, and stabilized at a steady-state level of 13–14 kPa. The time course of O₂ was almost a mirror reflection of that of CO₂. High ethylene concentrations accumulated in the MA packages, peaking after 2 d of storage. Peak ethylene concentrations were higher at 7 °C than at 11 °C and decreased significantly with increased levels of microperforation. Very little headspace CO₂ and ethylene accumulated in control packages (open cartons) due to their unrestricted ventilation (obviously, these values did not reflect the internal concentrations of gases in the tissues of control fruit). Practically no accumulation of condensed water was observed inside any Xtend liners.

Spoilage of Charentais melons was inhibited by packaging in Xtend liners (Fig. 2), depending upon level of microperforation. Liners of low microperforation provided the best decay control, especially in combination with a 7 °C storage temperature. This combination also delayed the development of all over-ripening symptoms (Fig. 3). Liners of high microperforation had almost no inhibitory effect on fruit deterioration.

The two-factor ANOVA analysis revealed effects of storage temperature and MA packaging in low-microperforation liners on fruit decay, firmness, color, and general appearance index ($P \leq 0.05$). SSC percentage was significantly affected by MA packaging but not by the temperature. Interactions were only significant for fruit firmness.

No deleterious effects of MA packaging were detected on typical Charentais flavor and aroma (data not shown). Moreover, MA-packaged fruit received higher flavor scores than the controls in agreement with higher SSC (Fig. 3). Chilling injury symptoms (pitting or discoloration) were not observed on fruit stored at 7 °C, either with or without MA packages. However, non-MA packaged fruit stored at 7 °C had higher severity of internal watery breakdown: index 1.3 vs. 0–0.3 in the other treatments (difference significant at $P = 0.05$). None of the fruit, including the control, exhibited shriveling symptoms.

Discussion

The results of this study confirm the pronounced climacteric behavior of Charentais melons and their highly perishable character. Accumulation of ethylene in the Xtend packages of Charentais melons (up to 120 $\mu\text{L}\cdot\text{L}^{-1}$) was much higher than in similar packages of Galia-type melons, belonging to the same *Cantalupensis* group (Rodov, Copel, and Aharoni, unpublished). This is in agreement with the observations that climacteric Charentais cantaloupe displayed higher internal ethylene concentration (Ayub et al., 1996) and ethylene production rate (Zheng and Wolff, 2000) than other melon varieties. Zheng and Wolff (2000) showed that ethylene production and postharvest decay rating of various melon cultivars were positively correlated. Indeed, in

Fig. 2. Effect of storage temperature and Xtend liners with different microperforation levels on decay incidence in Charentais (cv. Luna) fruit ($n=3$). The liners were tightly closed with rubber bands during 12 d of storage at 7 or 11 °C, kept folded without rubber band closure for two following days at 20 °C, and kept open for one additional day at 20 °C. Bars with the same letter were not significantly different by the Duncan's multiple range test at $P = 0.05$.

our study the over-ripe Charentais melons were readily attacked by a wide range of fungi, including genera such as *Aspergillus* and *Penicillium*, which only rarely cause decay in other melon varieties in Israel (Barkai-Golan, 1981).

The process of ripening in Charentais melons involves both ethylene-dependent phenomena (softening, peel color change) and ethyl-

ene-independent pathways, such as flesh pigmentation and sugar accumulation (Ayub et al., 1996). Modified-atmosphere packaging inhibited ethylene-dependent ripening processes in Charentais melons in the presence of high ethylene concentration. Elevated CO₂ level could be responsible for the inhibition of the ethylene effect (Burg and Burg, 1967). Similar delay of

Fig. 3. Effect of storage temperature and Xtend liners with low microperforation level on visual color index (A), soluble solids concentration (B), fruit firmness (C) and general appearance index (D) of Charentais (cv. Luna) fruit ($n=8$). The liners were tightly closed with rubber bands during 12 d of storage at 7 or 11 °C, kept folded without rubber band closure for two following days at 20 °C, and kept open for one additional day at 20 °C. Bars with the same letter were not significantly different by the Duncan's multiple range test at $P = 0.05$.

ripening was achieved in Charentais fruit by application of the inhibitor of ethylene action, 1-methylcyclopropene (Kubo et al., 2001). In nonclimacteric melon variety Tendral *Cucumis melo* L., Inodorous group) the MA did not affect neither peel color, nor decay incidence (Martinez-Javega et al., 1983).

The beneficial MA composition for Charentais melons, 13–14 kPa CO₂ and 7–10 kPa O₂, was consistent with general CA/MA recommendations for cantaloupes, i.e., CO₂ not higher than 15–20 kPa and O₂ not lower than 3–5 kPa (Saltveit, 1997). It was also close to the controlled atmosphere of 10 kPa CO₂ plus 10 kPa O₂ used for Galia melons by Aharoni et al. (1993).

Using low-density polyethylene for MA packaging of 'Durango' muskmelons required humidity control with NaCl-containing bags to prevent water condensation that favored growth of postharvest pathogens (Yahia and Rivera, 1992). In contrast to polyethylene packages, practically no condensation was observed in the Xtend liners due to relatively high water vapor permeability of the packaging material.

In conclusion, storage in microperforated Xtend liners at 6 to 7 °C may be recommended for extending postharvest life of Charentais-type cantaloupes, allowing their transportation from Israel to Europe by sea.

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