Nested modified-atmosphere packages maintain quality of trimmed sweet corn during cold storage and the shelf life period

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Abstract

Retail packages of sweet corn (film-wrapped trays containing a pair of trimmed cobs) were stored at 2°C within additional plastic liners. The modified atmosphere (MA), generated in these nested packages by corn respiration, complied with the recommended range of 5–10 kPa CO2 and inhibited mold growth. Opening the liner after transfer to non-refrigerated conditions compensated for the respiration rise caused by elevated temperature, maintained the desirable MA range and prevented fermentation and off-flavor development. The produce kept for 2 weeks at 2°C within nested packages, and for 4 additional days at 20°C, and combined relatively low microbial spoilage with acceptable organoleptic quality, provided the liners were open at 20°C. The method was successfully tested during a trial shipment of sweet corn from Israel to Europe. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Sweet corn; Zea mays L.; Packaging; Modified atmosphere; Storage temperature; Fermentation; Oxygen; Carbon dioxide

1. Introduction

Fresh sweet corn (Zea mays L.) is a perishable food product prone to fast postharvest deterioration caused by kernel desiccation, loss of sweetness, husk discoloration and development of pathogens. Keeping cobs in a modified atmosphere (MA) enriched with CO2 (5–10 kPa) may reduce the mold growth and inhibit sugar and chlorophyll loss. On the other hand, concentrations of CO2 above 10 kPa and/or O2 below 2 kPa spoil the product due to off-flavor and odor development (Saltveit, 1997).

Sweet corn is exported from Israel to Europe within retail cardboard trays overwrapped with stretch polyvinylchloride (PVC) film. The PVC wrap reduces moisture loss from kernels. The MA sphere (MA) enriched with CO2 (5–10 kPa) may reduce the mold growth and inhibit sugar and chlorophyll loss. On the other hand, concentrations of CO2 above 10 kPa and/or O2 below 2 kPa spoil the product due to off-flavor and odor development (Saltveit, 1997).

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action between produce respiration and barrier properties of packaging material. However, the relatively high permeability of PVC film for CO₂ does not allow a fungistatic CO₂ concentration to accumulate, sufficient for disease control during shipment. Substituting the PVC wrap with less permeable polyolefin stretch films improved the keeping quality of sweet corn due to elevated CO₂ accumulation (Aharoni et al., 1996). On the other hand, the use of relatively high-barrier films for retail packaging may increase the risk of O₂ depletion and off-flavor development after transferring packages from cold storage to non-refrigerated stores (shelf-life), since elevated temperature enhances produce respiration to a greater extent than it increases the permeability of regular packaging films (Exama et al., 1993).

An alternative to using high-barrier films may be to enclose retail packages inside an additional polymeric liner, which is removable at the end of the cooling chain. Opening or removal of the outer liner during the shelf-life period would counterbalance the enhancement of produce respiration at higher temperature and prevent or ameliorate O₂ depletion. The required characteristics of such nested packages may be estimated from the following rationale.

The internal (retail) package should be permeable enough to maintain the MA composition during shelf-life within the beneficial range (CO₂ between 5 and 10 kPa and O₂ higher than 2 kPa). According to previous results (Aharoni et al., 1996), the regular PVC-wrapped sweet corn packages may meet these demands at 20°C. The temperature quotient \( Q_{10} \) describes the effect of temperature change of 10°C on rates of biological and chemical processes. Similar to many other fruits and vegetables, the \( Q_{10} \) value for sweet corn respiration varies between 2 and 3, accounting for a reported 5–8-fold enhancement of respiration with a temperature increase of 20°C (Day, 1993; Shiina et al., 1997). Oxygen and CO₂ diffusion through a PVC package would increase in this case only by about three times, according to the \( Q_{10} \) values of PVC films (Exama et al., 1993). Therefore, when a sweet corn package is transferred from 1–2°C to 20–22°C, the temperature-dependent increase in PVC permeability would compensate for one third to a half of the product’s respiration upsurge, while the rest should be balanced by the removal of the outer liner. As a rough estimation, in order to achieve inside the nested package at 1–2°C the same MA composition as inside the PVC-wrapped retail pack at 20–22°C, the outer liner should provide half to two-thirds of the total barrier properties of the whole nested package.

Nesting retail packages within external liners may minimise temperature fluctuations and thus diminish water condensation in the package and reduce the risk of microbial spoilage. On the other hand, addition of another plastic layer would increase the overall barrier properties of the nested packaging towards water vapor, as compared to the retail package alone. Therefore, in addition to thermal isolation provided by a two-layer structure, sufficient water vapor permeability of both plastic layers is required in order to prevent condensation inside nested packages.

In the present work we tested nested packages of sweet corn, using three kinds of plastic films for retail packages, and microperforated Xtend® liners (StePac L.A. Ltd, Tefen, Israel) as outer plastic layers. The films of the Xtend series are characterised by a relatively high water vapor permeability (Aharoni et al., 1997). The successful application of Xtend films for sweet corn storage has been reported earlier by Aharoni and Richardson (1997), but combined use with PVC or other retail packages was not considered. The present communication describes the performance of nested packages during cold storage and shelf life of sweet corn, as well as during trial shipment of the produce from Israel to Europe.

### 2. Materials and methods

#### 2.1. Packaging and storage

Harvested ‘Jubilee’ corn cobs were trimmed at both ends at a commercial packinghouse. Flag leaves were pulled from the cobs to leave a 3-cm wide ‘window’ in which the kernels were exposed. On a packinghouse line the trimmed cobs were visually sorted by length, and pairs of cobs of
similar size were placed in appropriate retail cardboard trays. Trays containing cobs of the ‘large’ size group (length 170–190 mm, cob weight about 240–250 g) were selected for packaging experiments.

The trays were packaged in one of the three following films: regular 15-μm-thick PVC wrap; perforated 20-μm-thick Cryovac® polyolefin SM60M (W.R. Grace Ltd., London, UK); or microperforated 20-μm-thick Xtend® (StePac L.A. Ltd, Tefen, Israel) film. The three films had the following values of permeance to water vapor: 7.9 × 10⁻¹⁰, 4.4 × 10⁻¹⁰, 19.0 × 10⁻¹⁰ mol m⁻² s⁻¹ Pa⁻¹, respectively. The Xtend film was manufactured from the proprietary blend of polymeric materials having permeance to O₂ ≥ 23.5 × 10⁻¹⁴ mol m⁻² s⁻¹ Pa⁻¹. However, actual gas transmission characteristics of the packages were imposed by the presence of perforation. The degree of perforation, expressed as percentage of total perforation area related to film surface, was 0.16% for the Cryovac SM60M polyolefin and 0.001% for the Xtend film. According to Day (1993), the O₂ transmission rate of microperforated films is > 70.5 × 10⁻¹² mol m⁻² s⁻¹ Pa⁻¹. Since selectivity of perforations for different gases is negligible, a similar rate may be expected also for transmission of CO₂ through microperforated films. For comparison, the PVC film had an O₂ transmission rate of 89.3 × 10⁻¹², 23.5 × 10⁻¹², and a CO₂ transmission rate of 658.1 × 10⁻¹² mol m⁻² s⁻¹ Pa⁻¹. The Cryovac SM60M film exhibited practically no barrier properties towards O₂ and CO₂ diffusion due to its high perforation level. The permeability data were provided by film manufacturers as determined by the ASTM D1434 method at 23°C and 0% RH for O₂ and by the ASTM E96 method at 38°C and 85–90% RH for water vapor. The data were converted into SI units according to Banks et al. (1995).

The retail trays were packed in open export cartons, ten trays (ca. 5 kg of sweet corn) per carton. For the nested package treatment, liners of microperforated Xtend film (liner dimensions 0.75 × 0.75 m) were inserted into the cartons prior to placing the retail trays, and subsequently tightly closed using a rubber ring. The characteristics of Xtend film used for the liners corresponded to those presented above for retail Xtend packages. No liners were used in control packages.

The produce was stored at 2°C and about 90% relative humidity (RH) for 2 weeks, followed by 4 days of simulated retail marketing (shelf-life period) at 20°C. After transfer to 20°C, the rubber rings were removed and the liners opened and rolled down on the carton. In a separate experiment, the nested packages containing PVC-wrapped retail trays, were divided into three groups, three cartons in each group. In the first group the liners were opened during shelf life as described above, in the second one they were left closed and in the third one the liners were folded after removal of the rubber rings.

2.2. Atmosphere analysis

Samples of headspace atmosphere were withdrawn from packages during cold storage and shelf-life by gas-tight syringes through silicone septa attached to the film surface. Our data on atmosphere composition inside nested packages relate to samples withdrawn from internal spaces of retail packages enclosed within plastic liners.

Concentrations of O₂, CO₂, ethylene, ethanol and acetaldehyde were analysed by gas chromatography (GC) using external standards for quantification. Oxygen and CO₂ concentrations were determined using a Packard 7500 gas chromatograph (Packard, Downers Grove, IL) with thermal conductivity detector and CTR-I packed column using helium as the carrier gas. Oxygen concentration data were corrected for the 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 ionisation 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. Concentrations of ethanol and acetaldehyde vapors were determined with a Varian 3300 gas chromatograph equipped with a flame ionisation detector and a C-5000 packed column using nitrogen as the carrier gas; column, injector and detector temperatures were 80, 110 and 180°C, respectively.
2.3. Quality evaluation

At the end of the shelf-life, visual quality was evaluated for individual cobs using the following parameters: fungal growth, kernel desiccation and general appearance. Additionally, the cobs were subjected to informal sensory evaluation in order to check the presence of off-flavors.

The abundance of fungal growth was evaluated using a scale from 0 to 4, separately for cut cob ends, flag leaves and kernels. For cut ends and flag leaves, the following infection rating was used: 0, no visible infection; 1, sparse fungal growth (several small points of mycelial growth on the evaluated surface); 2, up to 10% of the evaluated surface covered with mycelium; 3, 10–30% of the evaluated surface covered with mycelium; 4, more than 30% of the evaluated surface covered with mycelium. For kernels, the infection rating was as follows: 0, no infection; 1, sparse fungal growth on one to two kernels in the cob; 2, advanced fungal growth on one to two kernels; 3, up to five kernels in the cob visibly infected; 4, more than five kernels visibly infected.

The sum of the infection scores for cut ends, flag leaves and kernels of a specific cob (maximal possible value 12) served for total infection rating of that cob.

Degree of desiccation was evaluated by abundance and severity of kernel denting using a scale from 0 to 4. The visual desiccation rating was as follows: 0, no kernel denting; 1, slight denting on up to 20% of the ‘window’ surface; 2, slight denting on more than 20% of the ‘window’ surface; 3, severe denting on up to 20% of the ‘window’ surface; 4, severe denting on more than 20% of the ‘window’ surface.

General appearance was graded on a scale of 1–5, taking into account desiccation and green color retention of flag leaves, kernel denting and decay severity. The score 5 corresponded to excellent quality and 1 to poor quality (dry and brown flag leaves associated with fungal growth). A cob that was rated higher than 2.5 was considered marketable.

The scores of individual cobs from the same replication were summarised by calculating weighted mean indices of the replication. The weighted means were calculated separately for fungal growth, desiccation severity and general appearance indices. For example, if \( n_1, n_2, n_3, n_4 \) and \( n_5 \) were numbers of cobs that got general appearance scores of 1, 2, 3, 4 and 5, respectively, the general appearance index for the replication was calculated as follows:

\[
I = (n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5)/N,
\]

where \( I \) – general appearance index and \( N \) – total number of cobs in the replication.

The experiments were conducted at least in triplicate and the means were separated by Duncan’s multiple range test. The experiments were repeated during 1996–1998 harvest seasons.

2.4. Trial shipment

Harvested ‘Dynasty’ corn cobs were trimmed, sorted and packaged in PVC-wrapped retail trays at a commercial packinghouse as described above. The shipment included packages of cobs of three size groups — medium (length 140–160 mm), large (170–190 mm) and extra-large (200–230 mm). Average cob weights for these groups were about 200, 240 and 300 g, respectively. One export carton contained 12, ten or eight retail packages of medium, large or extra-large size, respectively. There were 40 export cartons of every size group, 20 with Xtend liners and 20 without the liners, arranged on commercial pallets. Pallets were subjected to forced-air cooling and shipped at 4–5°C to the port of Marseille (France). The sea transportation took 5 days followed by 2 additional days of land transportation in refrigerated truck to Rotterdam (the Netherlands). On arrival in Rotterdam, the liners were opened. Visual and organoleptic quality of the produce was checked on the day of arrival and after 4 additional days of shelf life at 21°C.

3. Results

3.1. Atmosphere composition

The nested packages comprising regular PVC-wrapped retail trays with a removable external
Xtend liner, maintained the CO$_2$ partial pressure within the recommended range of 5–10 kPa both during the cold storage and the shelf life, provided the liner was opened after transfer to 20°C. Without the external liner, the steady-state CO$_2$ level inside cold-stored PVC-wrapped trays did not exceed 3 kPa. If the liners were left closed or just folded during the shelf life, the in-package O$_2$ levels inside the retail packages decreased to 4 or 8 kPa, and CO$_2$ concentrations increased to 27 or 17 kPa, respectively (Fig. 1). These changes in atmosphere composition were accompanied by an increase in ethanol accumulation (Fig. 1), indicating active fermentation.

When Xtend film was used for retail packaging instead of PVC wrap, the CO$_2$ level was kept within the limit of 10 kPa during the cold storage (Fig. 2). However, after transfer to 20°C the atmosphere composition in these Xtend retail packages demonstrated clear signs of fermentation, similar to those observed within external Xtend liners closed during the shelf life period. On the contrary, substitution of PVC wrap by perforated SM60M polyolefin did not create a modified atmosphere if not combined with an external liner. Combining these highly perforated retail packages with the Xtend liner allowed accumulation of
about 5 kPa CO₂ during cold storage, but CO₂ declined sharply after opening the liner during the shelf life period.

3.2. Produce quality

Major fungal species that attacked trimmed sweet corn cobs during storage and shelf life, were Alternaria alternata (Fr.) Keissler, Fusarium moniliforme Sheldon, and Mucor hiemalis Wehmer, in agreement with previous report of Barkai-Golan (1981). In addition to fungal pathogens, bacterial and yeast species were also present on spoiled cobs.

The most severe microbial spoilage was on cobs sealed in perforated Cryovac SM60M film, either within nested packages or alone (Fig. 3). Condensed water accumulated in retail trays packaged in this perforated polyolefin. The lowest fungal growth was observed within retail packs made of the Xtend film. This film treatment also resulted in the highest CO₂ level in the in-package atmosphere shown in Fig. 2. However, after transfer to higher temperatures during the shelf life period the corn in these retail packages developed a distinct off-odor, reflected in high concentrations of ethanol and acetaldehyde vapors in the headspace (Fig. 3). Similar levels of fermentation volatiles, but more severe decay, were detected in regular PVC-wrapped trays. It should be noted that accumulation of ethanol in retail PVC-wrapped trays varied by experiments and, for example, in the experiment associated with Fig. 1, was less than half that shown in Fig. 3.

Storage in PVC + Xtend nested packages allowed a combination of reduced microbial spoilage with low accumulation of fermentation products. The levels of ethanol and acetaldehyde were significantly lower in nested packages as compared to the same kinds of retail packages (PVC or SM60M) used alone (Fig. 3), provided the liners were open during the shelf life period.

3.3. Trial shipment

Packaging in Xtend liners markedly improved the appearance of cobs by inhibiting the fungal growth and reducing the kernel desiccation (Table 1). The most substantial improvement was achieved with the cobs of extra-large size. When these cobs were shipped within standard PVC packages alone, their quality declined below the marketability threshold by the end of shelf life period, mainly due to extensive fungal growth. On the other hand, these extra-large cobs, similar to other size groups, maintained acceptable visual quality (Table 1) and taste (data not shown) when the PVC trays were shipped inside Xtend liners, with subsequent opening of the liners after transfer to shelf life.

4. Discussion

The present results confirm previously published reports of the beneficial effect of elevated...
Table 1
Quality of sweet corn (cv. Dynasty) after 7 days of shipment from Israel to Rotterdam and 4 additional days of shelf life at 21°C1,2

<table>
<thead>
<tr>
<th>Cob size</th>
<th>Liner</th>
<th>Fungal growth index (FG), from 0 (no) to 4 (high)</th>
<th>Total FG</th>
<th>Desiccation index, 0 (no) to 4 (high)</th>
<th>General appearance, 1 (bad) to 5 (excellent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Flag leaf</td>
<td>Cut end</td>
<td>Kernel</td>
<td>Flag leaf</td>
</tr>
<tr>
<td>Medium</td>
<td>0.1 a</td>
<td>0.9 c</td>
<td>0.7 b</td>
<td>1.7 c</td>
<td>1.5 a</td>
</tr>
<tr>
<td>+</td>
<td>0.1 a</td>
<td>1.1 c</td>
<td>0.8 b</td>
<td>2.0 bc</td>
<td>0.7 b</td>
</tr>
<tr>
<td>Large</td>
<td>0.1 a</td>
<td>1.2 c</td>
<td>1 ab</td>
<td>2.3 b</td>
<td>1.3 a</td>
</tr>
<tr>
<td>+</td>
<td>0.1 a</td>
<td>0.8 c</td>
<td>0.5 b</td>
<td>1.4 c</td>
<td>0.5 b</td>
</tr>
<tr>
<td>Extra large</td>
<td>0.3 a</td>
<td>2.0 a</td>
<td>1.5 a</td>
<td>3.8 a</td>
<td>1.2 a</td>
</tr>
<tr>
<td>+</td>
<td>0.2 a</td>
<td>1.6 b</td>
<td>0.6 b</td>
<td>2.4 b</td>
<td>0.8 b</td>
</tr>
</tbody>
</table>

1 The cobs were packaged in PVC-wrapped cardboard trays and shipped either within the Xtend liners (+), or without liners (−). The liners were open during the shelf-life period.
2 Means separated within columns using Duncan’s multiple range test. The values followed by the same letter are not significantly different from each other at P = 0.05.

CO2 concentration in the range of 5–10 kPa on keeping quality of sweet corn (Brash et al., 1992; Aharoni et al., 1996; Saltveit, 1997). Reduced O2 (to 2–4 kPa) has been reported to be of additional help for inhibiting senescence and reduction of sugar conversion in sweet corn at 0–5°C (Brash et al., 1992; Saltveit, 1997). However, at 20°C the onset of fermentation was observed in our study at an O2 level as high as 8 kPa. Avoiding O2 concentrations below 10 kPa may be of help in order to secure quality of sweet corn in MA packages.

Maintaining an optimal atmosphere composition at varying temperatures is one of the major difficulties of MA packaging. As described previously, the temperature increase may result in O2 depletion, fermentation and spoilage of the produce. Development of a special ‘smart’ polymer has been reported, that increases its permeability as temperature rises at a rate comparable to the increase in respiratory activity. However, application of this material is so far restricted to high-cost products (Anonymous, 1996). The design of nested packages for various products may be elaborated on the basis of the rationale given in Section 1, taking into consideration package dimensions and previous experimental knowledge.

The use of microperforated Xtend liners during cold storage of sweet corn did not cause hypoxic fermentation, provided the liner was opened at the onset of the shelf life period. Moreover, the cobs cold-stored within the nested packages, tended to produce less ethanol (Fig. 3) and sometimes less CO2 (Fig. 2) during the shelf life period than those cold-stored in the same kind of retail packages without the liner. One of the possible explanations of this phenomenon may be the higher infection level of cobs stored without external liners, and the contribution of molds and yeast on the cob surface into overall respiration/fermentation rate of the retail package. On the other hand, physiological differences between cobs cold-stored at different conditions may have existed and contributed to observed differences in gas exchange and fermentation.

Packaging in perforated SM60M film caused severe microbial spoilage of sweet corn, probably due to the absence of fungistatic modified atmosphere combined with abundant accumulation of condensed water. These observations are in agreement with the mathematical model of MA packaging (Fishman et al., 1996; Rodov et al., 1998).
predicting that film perforations have much more pronounced effects on $O_2$ concentration, than on relative humidity inside the package. In fact, the highly perforated SM60M film had the lowest barrier properties for gases but the highest barrier properties for water vapor among the three packaging materials tested. In contrast to the poor performance of perforated polyolefin with sweet corn, the same film markedly improved storage life of bell pepper due to providing optimal humidity inside packages (Rodov et al., 1998). This difference probably results from different requirements of the two vegetables to storage conditions and MA composition, as well as from the much higher transpiration rate of sweet corn, which is 20 times more than that of bell pepper (Ben-Yehoshua, 1987).

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