Modified-humidity Packaging Reduces Decay of Harvested Red Bell Pepper Fruit

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Abstract. Lowering the in-package relative humidity (RH) by adding hygroscopic material (e.g., NaCl) reduced decay of bell pepper (*Capsicum annuum* L.) fruit sealed in low-density polyethylene and stored 2 or 3 weeks at 8C. Without hygroscopic material, the in-package RH was close to saturation, and water droplets condensed on the fruit and inner film surfaces. Depending on the amount of NaCl, condensation was prevented or significantly reduced. Humidity level varied from $\approx 88\%$ with 15 g NaCl to $\approx 97\%$ with 5 g NaCl for a package containing 0.5 to 0.6 kg of fruit. Adding hygroscopic material increased the water vapor pressure deficit (VPD) in the packages and, accordingly, the weight loss of the fruit. However, peppers packaged with NaCl still had lower weight loss and better quality than the nonsealed fruit. The water regime formed in four-fruit packages in the presence of 10 g NaCl (92% to 95% RH, VPD 65 to 77Pa) enabled optimal balance between reduced fruit desiccation and inhibited pathogen development, thus extending the postharvest life of bell pepper.

Alleviation of water stress is the main factor extending postharvest life of bell pepper sealed in plastic film (Ben-Yehoshua et al., 1983; Lurie et al., 1986). However, excessive relative humidity (RH) and consequent water condensation may increase the risk of fruit decay (Polderdijk et al., 1993). Janssens (1993) recommended a 90% to 95% RH at 8C for an optimal balance between decay and dehydration for container transportation of bell pepper in controlled atmosphere. Shirazi and Cameron (1992) developed the concept of modified-humidity packaging based on applying hygroscopic materials possessing type III sorption isotherm behavior, such as sorbitol, xylitol, and NaCl. The life of tomato (*Lycopersicon esculentum* Mill.) fruit was extended from 5 days in the control (packaged without hygroscopic materials) to ≈ 16 days in the presence of a NaCl-containing pouch; this occurred mainly by retarding surface mold development (Shirazi and Cameron, 1992).

Our objective was to test the effect of modified-humidity packaging on the keeping qualities of red bell pepper fruit.

Materials and Methods

'Maor' red bell peppers were obtained directly from the field or from the packinghouse within 24 h of harvest. Fruit were washed, selected, weighed, and packed [four fruit per polypropylene tray (Kibbutz Maapil, Israel)]. The trays were sealed in low-density polyeth-

ylene (LDPE) of 20, 40, and 80 μ m thickness (Plastnir, Kibbutz Nir Eliahou, Israel). Sodium chloride (Yoel Naim, Rehovot, Israel) was used as the hygroscopic material and was added to the experimental packages within the pouches of spunbonded polyethylene (Tyvek; Du Pont, Geneva, Switzerland). Tyvek is permeable to water vapor but practically impermeable to liquid water. The NaCl was dried at 75C for 24 h before use. One, two, or three pouches (each containing 5 g NaCl) were added to the four-fruit packages (average weight 0.5 to 0.6 kg of fruit). Nonsealed fruit, packaged in cardboard boxes, and fruit sealed without hygroscopic material were used as controls. The packaged peppers were stored at 8C and 85% RH for 2 or 3 weeks, with an additional 4 to 6 days at 17C and 85% RH to simulate marketing conditions. After storage, fruit quality was evaluated. Firmness was determined by compression test and was expressed as residual fruit deformation (millimeter) after instant application of 19.8 N pressure to the equatorial region of the fruit (Ben-Yehoshua et al., 1983).

For evaluating the in-package conditions, the combined temperature and humidity probe (model I-350; Rotronic, Zurich, Switzerland) equipped with a hygrometer solid polymer humidity sensor and a platinum temperature sensor was inserted into the sealed package through a tight rubber sleeve on the tray bottom, and sealed hermetically. Temperature and humidity values were collected every 5 h with a data logger (Picologger; YM Electronics, Ramat Gan, Israel). The vapor pressure deficit (VPD) for the given conditions was determined using Williams and Brochu's nomogram (Ryall and Lipton, 1972). Headspace

Fig. 1. Effect of NaCl on the relative humidity in bell pepper packages.

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was sampled with a syringe that went through a silicone septum mounted on a small piece of polyvinyl-chloride insulating tape stuck on the package (Shirazi and Cameron, 1992). The O_2 and CO_2 concentrations in gas samples were determined using a gas chromatograph with a thermal conductivity detector (model P7500; Packard, Downers Grove, Ill.) equipped with a CTRI column (Alltech, Deerfield, Ill.) that used He_2 as the carrier gas.

All experiments were performed at least three times with ≥ 20 fruit (five packages) per replication. Data were analyzed by analysis of variance, and means were separated by Duncan's multiple range test. The experiments described in this paper were conducted during the 1992–93 season. Similar results were obtained during the 1991–92 and 1993–94 seasons.

Results and Discussion

Effect of NaCl on in-package RH. RH in the sealed pepper packages without hygroscopic material reached 99% to 100%, and the packages at 8°C contained condensed water droplets. Adding the NaCl pouches substantially reduced the in-package humidity (Fig. 1). The humidity was stabilized at 96% to 98%, 92% to 95%, or 87% to 90% with 5, 10, or 15 g NaCl, respectively (Fig. 2). Depending on the amount of NaCl added, water condensation inside the package was prevented or significantly reduced. In accordance with the relationship between temperature and RH (Ryall and Lipton, 1972), the RH in NaCl-containing packages decreased by 1.5% to 2% after transfer to 17°C, but it remained saturated in the control packages.

The RH-reducing effect of NaCl in our experiments was less than that described with tomato by Shirazi and Cameron (1992). This discrepancy could be explained by different temperature conditions, type of package, and fruit peculiarities. However, stronger RH depression might have deleterious effect on desiccation-sensitive bell pepper. Thus, when RH in pepper packages was reduced to 85% by adding $CaCl_2$, there were no positive effects of sealing (Ben Yehoshua et al., 1983).

VPD and fruit weight loss. VPD is a more accurate characteristic for describing atmosphere water saturation than RH because VPD is not temperature dependent (Ben-Yehoshua, 1987; Lipton, 1993). Although the difference in RH between NaCl-containing packages and the storage atmosphere (85% RH) was not more than 10% to 13%, it was accompanied by a significant difference in VPD (Fig. 2). For example, in the packages containing 10 g NaCl at 8°C, VPD varied from 65 to 77 Pa, but in the surrounding atmosphere of the cold-storage room, it exceeded 150 Pa. VPD in pepper packages without hygroscopic material was as low as 11 Pa.

The transpiration intensity in stored commodities is directly related to VPD in the atmosphere (Ben-Yehoshua, 1987). Accordingly, although adding NaCl increased the weight loss of packaged bell pepper, fruit stored under these conditions had at most half

Fig. 2. Effect of NaCl dosage on in-package relative humidity (RH), water vapor pressure deficit (VPD), and the weight loss of packaged bell peppers. The steady-state RH levels were measured and VPD was calculated after 2 weeks of storage at 8°C; the weight loss was determined after 3 weeks at 8°C plus three additional days at 17°C. Mean separations by Duncan's multiple range test at $P \leq 0.05$.

Fig. 3. Effect of NaCl dosage and film thickness on bell pepper firmness (expressed as deformation in compression test) after 3 weeks at 8°C and three additional days at 17°C. Means separations by Duncan's multiple range test at $P \leq 0.01$.

the weight loss of nonsealed fruit (Fig. 2). At termination of the 17C holding period, fruit from NaCl-containing packages were not shriveled and were firmer than nonsealed peppers (Fig. 3). The thickness of plastic film had no effect on the firmness of sealed bell peppers (Fig. 3). Apparently, the difference between the two films in barrier properties for water vapor permeation was insignificant in respect to fruit weight loss.

Effect of NaCl on fruit decay. Adding NaCl markedly reduced the decay of packaged bell pepper compared to nonsealed fruit and fruit sealed without hygroscopic material (Fig. 4). *Botrytis cinerea* Pers. ex Fr. and *Alternaria alternata* (Fr.) Keissler were the main postharvest pathogens encountered in our experiments.

Without adding NaCl, the effect of sealing on fruit decay was not statistically significant, although a trend toward reduced incidence of disease was evident after 2 weeks of storage and the additional holding period at 17C. However, during 3 weeks of storage, tray-packaged fruit had a higher incidence of decay. The NaCl practically prevented this decay increase, thus extending the life of packaged bell pepper by ≈ 1 week. After 3 weeks of storage at 8C and an additional 3 days at 17C, the least decay was with 10 g NaCl per four-fruit package (Fig. 5).

The decay incidence in the four-fruit tray packages without NaCl was higher than that for individually sealed fruit (Ben-Yehoshua et al., 1983). This difference may be related to the absence of condensed water droplets and the lower RH (97%) in the individually sealed packages (Ben-Yehoshua et al., 1983).

Effects of CO₂ and O₂ concentrations. The composition of in-package atmosphere depended on film thickness. Packages sealed with 20- μ LDPE contained $\approx 18\%$ to 19% O₂ and 1.5% to 2% CO₂ at steady state; 40 μ , 10% to 13% O₂ and 4% to 5% CO₂; and 80 μ , 5% to 6% O₂ and 8% to 10% CO₂. There tended to be less decay in packages sealed with the thicker film (80 μ) (Fig. 4), but this effect was not statistically significant. Moreover, in other experiments (data not reported) such conditions brought about a marked increase in decay that probably was related to the deleterious effect of excessive CO₂ concentration on bell pepper (Mercado-Carmona et al., 1991; Wang, 1977). The different sensitivity of main postharvest pathogens of bell pepper that we encountered—*Alternaria* and *Botrytis*—to the modulated atmosphere composition (Meir et al., 1993) may provide one possible explanation of the inconsistent effect of film thickness.

Slight or no positive effect of modified atmospheres on the keeping quality of bell pepper (Saltveit, 1989) supports our opinion that water regime, rather than O₂ and CO₂ concentrations, is a major factor determining storage life of bell pepper. However, optimal humidity combined with controlled atmosphere brought additional advantages (Polderdijk et al., 1993).

The effect of relative humidity on decay development in stored agricultural produce

Fig. 4. Effect of sealing bell peppers in films of two thicknesses, adding NaCl, and storage duration on fruit decay. The decay percentage was determined after 2 or 3 weeks of storage at 8C and three additional days at 17C. Means separations by Duncan's multiple range test at $P \leq 0.01$.

Fig. 5. Effect of NaCl dosage on the decay of seal-packaged bell pepper after 3 weeks at 8C and three additional days at 17C. Each point is an average of four replications $\pm$ SE.

includes two opposite trends. On one hand, the water-saturated atmosphere often increases disease incidence, as it did for peppers in our and Polderdijk et al.'s (1993) experiments. This effect is usually attributed to the presence of condensed water on the fruit surface forming the favorable conditions for pathogen development (Eckert, 1978; Grierson and Wardowski, 1978). In contrast, excessive water loss and wilting also increased vegetable susceptibility to *Botrytis* and other postharvest pathogens (Eckert, 1978).

Stabilizing the in-package RH within 92% to 95% may provide an optimal balance between reduced fruit desiccation and water condensation prevention, thus inhibiting disease development and extending the storage life of red bell pepper.

Literature Cited

- Ben-Yehoshua, S. 1987. Transpiration, water stress and gas exchange, p. 113–170. In: J. Weichmann (ed.). Postharvest physiology of vegetables. Marcel Dekker, Basel, N.Y.
- Ben-Yehoshua, S., B. Shapiro, Z. Even Chen, and S. Lurie. 1983. Mode of action of plastic film in extending life of lemon and bell pepper fruits by alleviation of water stress. *Plant Physiol.* 73(1):87–93.
- Eckert, J.W. 1978. Pathological diseases of fresh fruits and vegetables, p. 161–209. In: H.O. Hutlin and M. Milner (eds.). Postharvest biology and biotechnology. Food & Nutrition Press, Westport, Conn.
- Grierson, W. and W.F. Wardowski. 1978. Relative humidity effects on the postharvest life of fruits and vegetables. *HortScience* 13:570–574.
- Janssens, M.F.M. 1993. Sea transportation of bell peppers by a controlled atmosphere container, p. 18. 6th Intl. Controlled Atmosphere Res. Conf. 15–17 June 1993. Cornell Univ., Ithaca, N.Y. (Abstr.)
- Lipton, W.J. 1993. Relative humidity may not be enough. *ASHS Nwsl.* 9(5):12.
- Lurie, S., B. Shapiro, and S. Ben-Yehoshua. 1986. Effects of water stress and degree of ripeness on rate of senescence of harvested bell pepper fruit. *J. Amer. Soc. Hort. Sci.* 111:880–885.
- Meir, S., I. Rozenberger, and Z. Aharon. 1993. Effect of controlled atmosphere on rot development during storage of red bell pepper (cv. Maor) (in Hebrew, resume English). *Hassadeh* 73:876–881.
- Mercado-Carmona, J.A., M. Cantwell, and M. Reid. 1991. Quality of bell peppers stored in air and controlled atmosphere at chilling and non-chilling temperatures. Dept. of Vegetable Crops, Univ. of California, Davis.
- Polderdijk, J.J., H.A.M. Boerrigter, E.C. Wilkinson, J.G. Mejer, and M.F.M. Janssens. 1993. The effects of controlled atmosphere storage at varying levels of relative humidity on weight loss, softening and decay of red bell peppers. *Sci. Hort.* 55(3–4):315–321.
- Ryall, A.L. and W.J. Lipton. 1972. Handling, transportation and storage of fruits and vegetables. vol. 1. Vegetables and melons. AVI, Westport, Conn.
- Saltveit, M.E., Jr. 1989. A summary of requirements and recommendations for the controlled and modified atmosphere storage of harvested vegetables, p. 329–351. *Proc. Fifth Intl. Controlled Atmosphere Res. Conf.* vol. 2. 14–16 June 1989. Wenatchee, Wash.
- Shirazi, A. and A.C. Cameron. 1992. Controlling relative humidity in modified atmosphere packages of tomato fruit. *HortScience* 27:336–339.
- Wang, C.Y. 1977. Effect of CO₂ treatment on storage and shelf life of sweet peppers. *J. Amer. Soc. Hort. Sci.* 102:802–812.