Controlling Relative Humidity in Modified Atmosphere Packages of Tomato Fruit

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Abstract. The feasibility of controlling relative humidity in modified atmosphere packages using compounds possessing Type III sorption isotherm behavior was studied. Ten grams each of dry sorbitol, xylitol, NaCl, KCl, or CaCl, sealed with one mature-green tomato (*Lycopersicon esculentum* L.) fruit at 20C in simulated packages for 48 days resulted in stable relative humidities of ≈75%, 80%, 75%, 85%, and 35%, respectively. Relative humidity was a function of the ratio of chemical to fruit mass. Relative humidities within control packages were in the range of 96% to 100% throughout the experiments. A simple system that uses spunbonded polyethylene pouches for the application of this humidity control method to packages is described. The storage life of packaged red-ripe tomato fruit at 20C was extended from 5 days using no pouch to 15 to 17 days with a pouch containing NaCl, mainly by retardation of surface mold development.

Modified atmosphere packaging (MAP) has been used as a supplement or even a substitute for refrigeration to prolong the storage life of fresh produce during transport and retail handling (Kader et al., 1989). Recently, improved models and techniques have been developed for prediction and control of O_2 levels in MAP systems for tomatoes (Cameron, 1990; Cameron et al., 1989). However, even when packages constructed from low-density polyethylene (LDPE) were designed to give optimal O_2 and CO_2 concentrations, the shelf life was not equal to that obtained under controlled-atmosphere conditions. For instance, red-ripe tomatoes held in a flow-through system at 2% O_2 remained in salable condition for 40 days at 20C compared to 15 days in a package optimized to the same O_2 concentration (Boylan-Pett, 1986). The limiting factor in the package was the appearance of molds that were associated with high in-package relative humidity (RI-I), but were not observed in the flow system. Several other researchers have noted condensation and/or mold and bacterial development in MAP systems (Grierson, 1969; Hardenburg, 1951; Scott et al., 1964).

Most of the major pathogens affecting the postharvest life of tomato fruit need an environment with a water activity of more than 0.80 for their growth (Troller and Christian, 1978). Reduction of humidity to levels below the critical water activity of microorganisms should be an effective way to limit their growth. The generally recommended levels of 85% to 95% RH (Hardenburg et al., 1986) for storage of fresh produce represent a compromise to prevent excessive weight loss while providing some control of microbial spoilage.

Perforation of bags has been used to reduce in-package RH (Hardenburg, 1954; Kaufman et al., 1956) although perforations large enough to affect in-package RH preclude the possibility of modified-atmosphere conditions within the package. In-package RH can be reduced by using films with a high water vapor transmission rate but cannot be controlled to specific levels using this approach alone, since in-package RH is also a function of RH in the surrounding environment, which can change markedly during handling and storage (Saguy and Mannheim, 1975). Desiccants such as $CaCl_2$ have been used to lower in-package RH (Bedrosian and Schiffman, 1983; Eaves, 1960; Scott et al., 1964).

The moisture content of any material approaches an equilibrium level after exposure to a given RH by gaining or losing water. Establishment of equilibrium, however, may take days or even weeks, depending on the system (Labuza, 1984). Compounds, such as sorbitol, xylitol, and NaCl, that exhibit Type III sorption isotherm behavior as defined by Brunauer (1945), absorb relatively little moisture until RH increases to some critical level (Kaufmann, 1960; Labuza, 1984; Xyrofin, 1985). As the RH is increased above this point, these compounds absorb increasingly more water. At higher RH levels, such compounds can absorb several times their own dry weights in water. This behavior is the basis for RH control by saturated salt solutions that has long been used in experiments (Winston and Bates, 1960 Young, 1967).

The ability to create a stable predetermined RH in sealed packages with the po-

tential for reducing decay problems and without causing shriveling would be valuable for improving the success of MAP systems. Currently, no reliable method for controlled reduction has been reported. The primary purpose of this study was to determine the feasibility of using predried crystals of compounds possessing Type III sorption isotherm behavior for control of RH within fresh-produce packages. In addition, we show how the concept can be simply and efficiently adapted for a MAP system to reduce mold and extend shelf life of tomato fruit.

For simulated package experiments, 'Duke' tomato fruit were harvested mature-green from the Plant Science greenhouses, Michigan State Univ., or red-ripe fruit were purchased from a local market. For the MAP experiment, 'Summer Flavor 6000' fruit were received at the breaker stage and ripened at 20C to red-ripe. In all cases, fruit of uniform size and free of visible defects were held in unsealed polyethylene bags at 20C for a minimum of 24 h to reach temperature equilibrium before the start of the experiments. Each fruit was weighed before an experiment was started. In the first experiment, fruit weighed 70 to 90 g; in the second experiment, fruit weight ranged from 130 to 160 g.

Each experimental chamber had a solid base, a top, and a cylindrical body of 6.4-mm-thick polyacrylic plastic (8.3 cm height, 10.2 cm id.). A hole of 10.2 cm id. was cut in the top for film insertion, and two holes of 6.4 mm id. were cut in the cylinder wall for probe access and headspace gas sampling. A piece of 0.051-mm-thick (2-roil) LDPE film (LDF-301, Dow Chemical, Midland, Mich.) was held in place at the top of the chamber by two rubber gaskets. The film's permeability at 20C was 102 and 486 $cm^3 \cdot mm/m^2$ per day per atm for O_2 and CO_2, respectively. Water vapor transmission rate of the film was 0.81 $g \cdot m^{-2} \cdot day^{-1}$ (a perme-
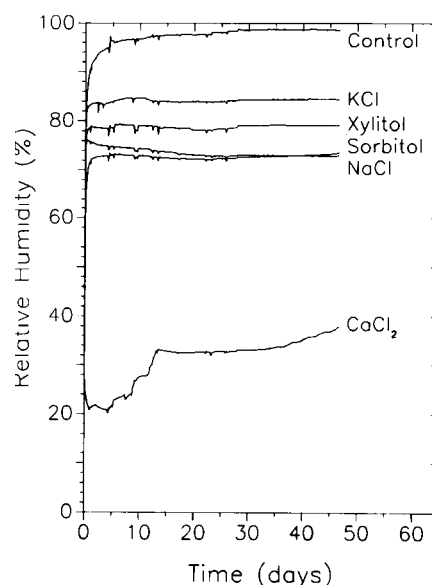

Fig. 1. In-package relative humidity for 48 days at 20C using one mature-green 'Duke' tomato fruit with 10 g sorbitol, xylitol, NaCl, KCl, or $CaCl_2$, or no sorbent (control).
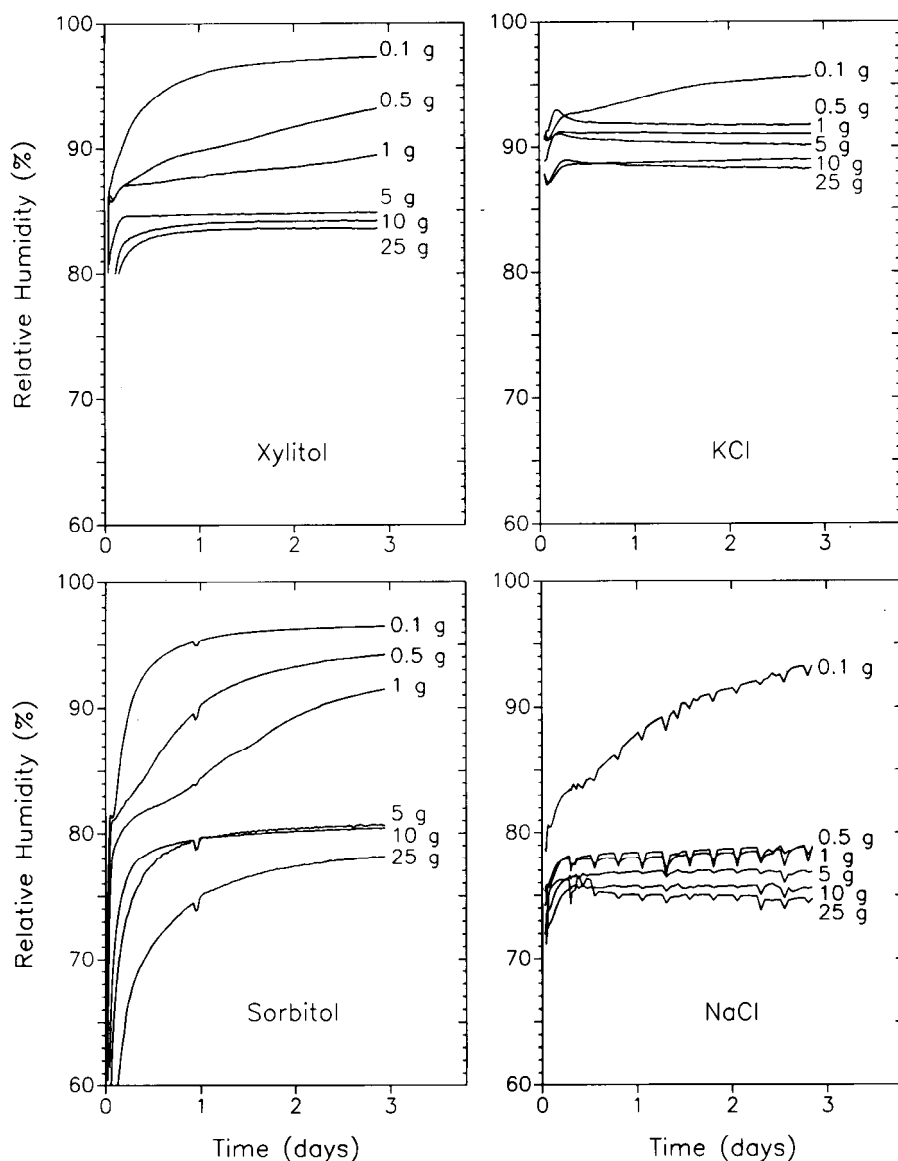
Fig. 2. In-package relative humidity for 3 days at 20C using one red 'Duke' tomato fruit with 0.1, 0.5, 10.0, or 25.0 g xylitol, sorbitol, KCl, or NaCl.

ability coefficient of 20,000 $cm^3 \cdot mm/m^2$ per day per atm) as measured at 20C and 50% RH.

All chemicals were dried at 75C for 48 h before use; NaCl and KCl were analytical grade (Mallinckrodt Chemical Works, Paris, Ky.), $CaCl_2$ was desiccant grade (Mallinckrodt Chemical Works), D-sorbitol was anhydrous (Sigma Chemical Co., St. Louis), and xylitol was crystalline with a mean crystal size of 0.57 mm (Xyrofin, Basel, Switzerland). Chemicals were spread evenly in a 100×15-mm petri dish base around a 60×15-mm dish at the center (covering an area of ≈ 50 cm^2). A combined temperature and humidity probe (Model 850; General Eastern, Watertown, Mass.) was inserted through a septum and positioned above the fruit before the container was sealed. The probe was precalibrated by the manufacturer and had a sensitivity of 0. 1% RH, repeatability of 0.5%, and accuracies of ±2% within 15% to 99% RH at 25C and ± 0.5C within 5 to 50C according to specifications. The performance of the probe was checked against known humidities before each experiment.

Temperature and humidity values were collected at regular intervals with a datalogger (Model no. 516B-32; Omnidata International, Logan, Utah) (Shirazi, 1989). All experiments were conducted at 20C and repeated with similar results unless otherwise noted.

Headspace was sampled using 1-ml plastic syringes at least two times after equilibrium was established. Oxygen and CO_2 concentrations were determined with an O_2 analyzer (Model S-3A/II; Ametek, Pittsburgh) and an infrared gas analyzer (Type 225 MK3; ADC, Haddesdon, England) connected in series to a strip chart recorder (Model 1200; Linear Instruments Corp., Reno, Nev.). Nitrogen was used as the carrier gas at 200 ml·min⁻¹

The possibility of using a water source other than fresh produce was investigated to minimize variation. Rates of weight (water) loss from red tomatoes and from containers of deionized water were monitored for 2 days in a controlled environment room set at 20C and 35% RH, using an analytical balance

(AE 163; Mettler, Hightstown, N.J.). The average rates of weight (mostly water) loss from red tomatoes within the 110- to 140-g range and evaporation from 50-ml beakers containing 30 ml deionized water were 0.0418 $g \cdot h^{-1}$ (SD = 0.0066, n = 3) and 0.0416 $g \cdot h^{-1}$ (SD = 0.0013, n = 3), respectively.

A shelf life experiment was conducted at 20C using two red-ripe tomato fruits (≈ 450 g) per sealed LDPE film package (4.4×10-3 cm thick, 600 cm^2 surface area, permeability for O_2 and CO_2 of 125 and 567 cm^3 (STP) mm/m^2 per day per atm, respectively). One-half of the packages contained a pouch constructed of spunbonded polyethylene (9 $\times$ 2 $\times$ 15 cm; Tyvek type 1059B, Dupont, Wilmington, Del.) in which was sealed 20 g of dry crystalline NaCl. The pouch was heat-sealed through the middle such that each half contained ≈ 10 g of the compound. Eight perforations were made in half the sealed LDPE packages using a 26-gauge needle (≈ 0.5-mm-diameter, two holes per corner) to compare the effects of nearly ambient vs. low O2. Gas samples were withdrawn by means of 1-ml plastic syringes through a dap of silicone (no. 280; General Electric Co., Waterford, N.Y.) cured on a small piece of PVC electrical tape placed on each package (Boylan-Pett, 1986). Oxygen and CO_2 concentrations in the packages were measured 3, 6, and 12 days after the initiation of the experiment. Visual evaluations were performed daily, and the shelf life of each fruit was defined as the time until the first signs of fungal growth or of a disorder appeared. A two-way factorial arrangement of treatments (humidity and O_2 control) in a randomized complete block design was used for the experiment with 18 observations per treatment. Shelf life data were subjected to analysis of variance (ANOVA). Average concentrations of O_2 and CO_2 were calculated from the gas analysis data.

RH in control packages reached 98% and remained at that level for the duration of the experiment (Fig. 1). Ten grams of xylitol, KCl, NaCl, or sorbitol held RH at 78% to 79%, 84% to 85%, 73% to 76%, and 72% to 74% for 48 days, respectively, in packages with a single tomato fruit (70-90 g). The RH values over NaCl and KCl were very similar to ERH values over their saturated solutions, which are 75% and 85%, respectively (Weast, 1984). The in-package RH over xylitol, however, was $\approx 6\%$ lower than the published RH over a saturated solution (Xyrofin, 1985). The in-package RH over 10 g $CaCl_2$ with one 150-g tomato fruit was between 30% to 35%.

The amount of each compound used affected the respective in-package RH. In the case of sorbitol, very little reduction of in-package RH took place when 0.1 g/fruit (130 to 160 g) was used (Fig. 2). Sorbitol at 1 g reduced in-package RH to 80% initially but apparently became saturated with time since RH slowly increased over 3 days to $\approx 90\%$. Five and 10 g both produced similar in-package RH of $\approx 80\%$. Sorbitol at 25 g produced a slightly lower in-package RH value initially but equilibrated at about a 2% lower
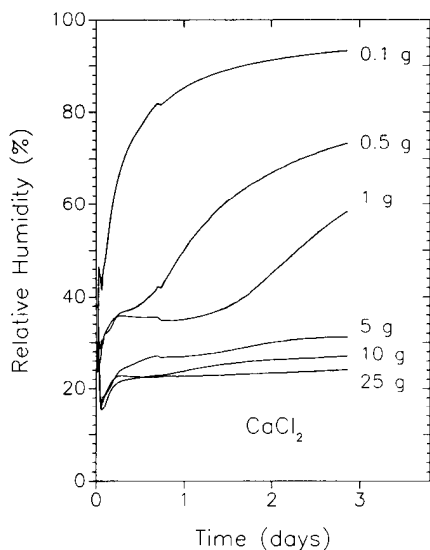
Fig. 3. In-package relative humidity for 3 days at 20C using one red 'Duke' tomato fruit with 0.1, 0.5, 10.0, or 25.0 g CaCl₂.
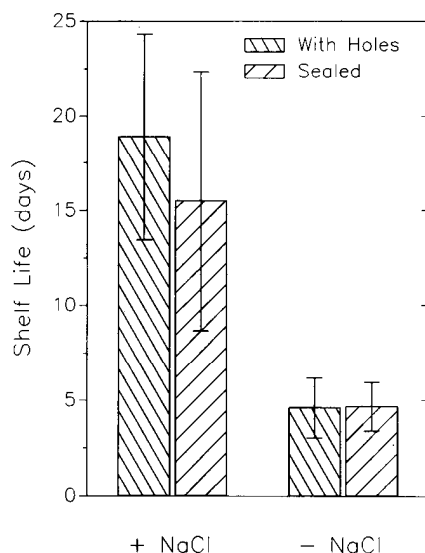

Fig. 4. Effects of controlled humidity on storage life of red-ripe 'Summer Flavor 6000' tomato fruit in modified atmosphere packages. Each bar represents mean shelf life for 18 fruit ± SD. Dry NaCl (10 g/225 g fruit) packed in spunbonded polyethylene was used to control in-package relative humidity at ≈80%. Average O_2 and CO_2 were ≈3% and 6% in sealed packages and 17% and 4% in packages with holes.

RH on the 3rd day than did 5 or 10 g. Xylitol showed a similar pattern as sorbitol (Fig. 2). In this case, 1 g produced a relatively stable in-package RH over 3 days. The in-package RH values corresponding to 5, 10, and 25 g xylitol were generally similar and ≈84% to 88%. One, 5, 10, and 25 g of KCl produced ≈90% RH (Fig. 2). With 0.1 g, no stable RH was obtained. RH values generated when 0.5 to 25 g of NaCl was used over 3 days were similar (Fig. 2). All of the stated levels held RH stable at ≈75%. No stable RH was obtained when 0.1 g NaCl was used. In experiments with CaCl₂, 5, 10, and 25 g generated similar RH values (20% to 30%) (Fig.

3). When 1 g of CaCl₂ was used, RH stabilized at ≈35% for nearly 1 day and then increased. A similar pattern was observed with 0.5 g of CaCl₂, although the duration of stable RH was only for about one-third of a day.

Bedrosian and Schiffman (1983) claim that CaCl₂ can be used to control in-package RH and that the "amount of desiccant used is not critical" as long as enough of the compound is used so that it remains active during the storage period. Our studies, however, show that in-package RH depends on the amount of CaCl₂ per fruit. For example, when 0.5 g CaCl₂ was used with a 130- to 160-g fruit, in-package RH was in the range of 60% after ≈2 days. Tomatoes packaged with 10 g CaCl₂ lost 16% of their fresh weight over 48 days of storage and shriveled severely. No shriveling was observed in fruits in these experiments as long as weight loss was ≤ 7% (data not shown). It maybe possible to optimize the quantity of CaCl₂ added to the package such that it removes surface moisture during early stages but then becomes saturated.

In general, measured RH values were similar from one experiment to the next, although some variability was noted. Any external factor, such as cultivar or growing condition, that affects the resistance of the fruit skin to water loss may contribute to variation. Accuracy and precision of the humidity sensors may account for some discrepancies observed in the measured in-package RH values, although accuracy of the units was found to conform to the specifications when tested against an electric psychrometer (± 2% RH at 25C, 20% to 85% RH).

The average storage life of red-ripe tomato fruit at 20C was increased from ≈5 to 17 days when NaCl was included in the package (Fig. 4). The NaCl effect was statistically significant; however, there was no significant effect on shelf life of modifying O₂ levels from 16% to 17% (i.e., with perforations) to ≈ 3% in the sealed packages. The corresponding CO₂ levels in the sealed packages ranged from 4% to 6%. The effect of humidity control on shelf life was highly significant ($P = 0.0001$). The experiment was repeated three times with similar results. In general, the limiting factor for shelf life was the appearance of molds on the stem scar. *Fusarium* sp. and *Alternaria* sp. were identified by the Diagnostic Clinic, Plant Biology Lab, Michigan State Univ., on several infected fruits. *Botrytis* sp. and *Penicillium* sp. were noted in fewer cases.

In the trial application experiment, dry crystals of NaCl were enclosed in packets made of a food-grade, spunbonded polyethylene film. The small holes in these films readily permit the movement of water vapor, but completely block that of liquid water. Over extended periods, the salts became saturated with water. The solutions were held separate from the fruit by the spunbonded polyethylene and continued to maintain control of humidity. Spunbonded polyethylene is relatively inexpensive, and pouches con-

taining salts or sugar alcohols could prove to be an affordable, effective system for commercial application. The actual amount of leakage of salt solutions through the film has been minimal under our conditions. The packets can be dried and reused as needed.

The technique of controlling in-package humidity described here is independent of outside RH, as opposed to using films with high water vapor transmission rates (Saguy and Mannheim, 1975). Ultimately, it may be useful to combine the two techniques since it might permit a reduction in the amount of compound that needs to be included in the package. Although this concept is similar to the use of saturated salt solutions, it is important to note that this system never comes to equilibrium, but is at steady state. The ability to control RH thus is based on the rate of water absorption by the compounds relative to the rate of transpiration by the fruit. In these experiments, 5 to 10 g of chemical per fruit of 130 to 160 g was required to maintain a stable RH. Less compound was often unable to absorb water quickly enough to control humidity. The amount of compound per fruit most likely could be reduced if improved methods for dispersion were used to maximize the surface area for absorption.

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