Temperature of Broccoli Florets at Time of Packaging Influences Package Atmosphere and Quality

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Abstract. Warm (20C) or cold (3C) broccoli florets (*Brassica oleracea* L., Italica Group) were sealed in bags of two types of nonperforated flexible polyvinylchloride film, TPM 87 or RMF 61, and kept at 5C for 7 days. Temperature of the warm florets cooled to 5C in $\approx$ 8 hours. Warm broccoli had 40% to 50% more CO₂ and 25% to 30% less O₂ than cold broccoli in packages of both film types 6 hours after sealing. After 48 hours, however, concentrations of CO₂ in bags of cold and warm broccoli had reached a steady state of $\approx$ 14.5% in TPM 87 bags and 6% in RMF 61 bags. Concentrations of O₂ were more variable. After 48 hours, O₂ concentrations were $\approx$ 2% to 4% in TPM 87 bags and 5% to 10% in RMF 61 bags. Initially, warm florets were rated lower for color, turgidity, and general appearance than initially cold ones after 7 days at 5C. Objectionable off-odors were formed from florets held in TPM 87 packages that had O₂ concentrations of $<$ 1.5%.

Atmosphere modification, by lowering O₂ and/or increasing CO₂ concentrations, has been shown to maintain quality and extend the storage life of many fresh commodities (Hardenburg, 1971; Hardenburg et al., 1986; Kader et al., 1989). Packaging techniques can be used to achieve these beneficial atmospheres. One technique, referred to as modified-atmosphere (MA) packaging, depends on the respiration rate of the commodity and the gas permeation properties of the packaging film to determine the package atmosphere composition (Kader et al., 1989; Labuza and Breene, 1989; Varriano-Marston, 1989). Both of these factors are influenced by temperature, concentrations of O₂ and CO₂ in the atmosphere, and humidity (Forney et al., 1989; Kader et al., 1989). If these environmental factors remain constant, the MA inside the package will come to steady state soon after sealing (Ballantine et al., 1988; Forney et al., 1989; Kader et al., 1989; Tomkins and Cumming, 1988). A properly designed package can maintain a desired atmosphere throughout the storage and marketing of a fresh commodity.

Rapid cooling of fresh produce following harvest is important for maintaining quality by slowing the rates of respiration and senescence (Brennan and Shewfelt, 1989; Ryan and Lipton, 1979). Icing is used on many fresh vegetables for rapid cooling and pre-

vention of water loss (Ryan and Lipton, 1979). However, with the development of precut vegetables for food service and institutional markets, iceless packages are more convenient and avoid the problem of water accumulation from melting ice in coolers (Patterson, 1989). With the departure from traditional icing, cooling of these fresh vegetables following harvest may be inadequate. However, quality deterioration at higher-than-recommended temperatures may be slowed through the use of MA.

Broccoli has been traditionally cooled with package ice. In recent years there has been an increasing market for broccoli florets packaged without ice (Patterson, 1989). Broccoli responds favorably to MA of 1% O₂ and/or 10% CO₂ (Lebermann et al., 1968; Lipton and Harris, 1974), which have been achieved through packaging in polymer films (Elkashif et al., 1983; Rij and Ross, 1987; Wang and Hruschka, 1977). These MA maintain the quality of broccoli held at 5 or 7.5C for longer periods than would be possible in air. However, temperature of broc-

coli at the time of packaging affects respiration rates, and, therefore, the rate of atmosphere modification in the package. Understanding how temperature alters the package MA is important to design a package that will develop and maintain a desirable environment to extend the storage life of fresh produce and replace the need for ice. In this study, the effect temperature of broccoli florets at the time of packaging had on the modification of the package atmosphere and the quality of florets was determined.

Broccoli florets, $\approx$ 15 to 30 mm in diameter and 40 mm long, were obtained at a packinghouse in Salinas, Calif., on the day of harvest, packed in ice, and transported to the Horticultural Crops Research Laboratory in Fresno, Calif. Ice was removed, and florets were divided into two groups and kept overnight at 20C (warm) or 3C (cold) with 85% to 90% relative humidity. The following morning, broccoli florets were placed into 250 $\times$ 480 mm polyvinylchloride (PVC) film bags of two formulations, designated as TPM 87 or RMF 61 (Borden Chemical, North Andover, Mass.). Gas transmission rates of three samples of each of these films were determined in our laboratory using gas permeation cells and the "isostatic" procedure described by Hernandez et al. (1986). Values reported are the means $\pm$ SD. TPM 87, a heat-shrinkable film, was 20.3 μ m thick and had O₂ and CO₂ transmission rates at 5C of 390 ± 37 and 380 ± 74 ml·m⁻²·h⁻¹ (one atmosphere), respectively. RMF 61, a stretch film, had the same thickness but was more permeable, having O₂ and CO₂ transmission rates at 5C of 560 ± 110 and 2410 ± 60 ml·m⁻²·h⁻¹ (one atmosphere), respectively. Four bags of each film type were filled with 1500 ± 3 g of florets from each holding temperature. In addition, florets from each holding temperature were placed in vented bags (eight 3-mm holes per bag) of each film type to serve as controls for quality evaluation. Bags were filled at the respective holding temperature, sealed with an L-bar sealer, and immediately transferred to a 5C cold room. We used 5C because it is a common temperature encountered during transportation and marketing.

Temperatures of broccoli and room air were monitored every 5 min from the time broccoli was placed at 5C by using thermocouples inserted into the stem centers of a single

Table 1. Changes in atmosphere composition in packages of broccoli florets over time as affected by package film type and temperature at the time of packaging.

Film type	Temp (°C)	Time after sealing (h)					
		6		48		168	
		O ₂	CO ₂	O ₂	CO ₂	O ₂	CO ₂
TPM 87	20	11.1	5.9	2.3	14.6	3.0	15.2
	3	15.7	3.9	3.8	14.1	4.6	14.4
RMF 61	20	12.0	4.8	5.0	6.0	6.7	5.0
	3	16.0	3.4	10.1	6.2	10.7	5.0
Significance							
Film		NS	**	*	***	**	***
Temp		***	***	*	NS	NS	NS
F $\times$ T		NS	NS	NS	NS	NS	NS

NS, **, ***, ***Nonsignificant or significant at $P = 0.05, 0.01, \text{ or } 0.001$, respectively, according to F test.

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Table 2. Effect of film type and temperature at the time of packaging on the quality of broccoli florets after 7 days at 5C. Values represent the average ratings of the means of three replications.

Film type	Temp (°C)	Rating ^a				General appearance
		Odor	Decay	Color	Turgidity	
TPM 87	20	7.8	8.6	7.8	7.3	7.3
	3	7.6	8.8	9.0	8.7	8.8
RMF 61	20	8.8	8.3	7.5	7.4	7.0
	3	8.8	8.8	8.8	9.0	8.4
Significance						
Film		**	NS	NS	NS	NS
Temp		NS	NS	***	***	***
F × T		NS	NS	NS	NS	NS

^aRating scale: odor, 9 = normal, 1 = nauseating; decay, 9 = none, 1 = severe; color, 9 = dark green, 1 = yellow; turgidity, 9 = turgid, 1 = dry; general appearance, 9 = excellent, 1 = very poor.

NS, **, ***Nonsignificant or significant at $P = 0.01$ or 0.001 , respectively, according to F test.

Fig. 1. Mean temperatures of broccoli florets packaged at 20C (warm) or 3C (cold) after indicated time at 5C.

Fig. 2. Concentrations of O_2 and CO_2 over time in bags of two formulations of polyvinylchloride polymer films (TPM 87 and RMF 61) filled with broccoli florets that had been kept at 20C (warm) and 3C (cold) before being sealed and kept at 5C starting at time 0. Each point is the mean of 12 packages $\pm$ SE.

floret in each treatment. Holes to allow thermocouple wires into bags were sealed with silicon rubber caulking.

The atmosphere inside each package was sampled using a 1-ml gas-sampling syringe inserted through a septum made of silicon rubber caulking. Samples were taken 2, 4, 6, 12, 24, 30, 48, 72, 120, 144, and 168 h after packages were placed at 5C. The 1-ml gas samples were analyzed for O_2 and CO_2 concentration using a Shimadzu GC-8A gas chromatography (Shimadzu Scientific Instruments, Columbia, Md.) equipped with a thermoconductivity detector and a 1.9-m

CTR1 column (Alltech Assoc., Deerfield, Ill.).

Quality of broccoli florets was evaluated 7 days after packaging. Broccoli was removed from bags and evaluated for color, turgor, decay, and general appearance using a rating scale of 9 to 1 as described by Rij and Ross (1987). Odor was evaluated using a similar subjective scale based on the criteria of Wang and Hruschka (1977).

The experiment was a 2×2 factorial in a randomized complete-block design. The experiment was replicated three times and treatment means of each replication were treated as a block.

Warm broccoli (20C) packaged in PVC bags cooled slowly after being placed at 5C (Fig. 1). In ≈ 8 h, the temperature of warm florets was similar to that of florets packaged cold and only ≈ 0.3 C warmer than the ambient temperature. During this time, CO_2 concentrations in the packages were increasing and O_2 concentrations were decreasing more rapidly in the warm than in the cold broccoli in both film types (Fig. 2). After 6 h, O_2 concentrations were 25% to 30% lower in broccoli packaged warm than cold (Table 1). At this time, however, packages of RMF 61 did not differ significantly in O_2 concentration from packages of TPM 87, even though the O_2 transmission rate of RMF 61 is 70% higher than that of TPM 87. The respiration rate of broccoli is more than 10-fold higher at 20C than at 3C (Kader et al., 1989). These higher respiration rates of the warm broccoli for the first 8 h until it cooled to the temperature of the cold florets appears to have had a greater effect on the modification of the package atmosphere than the film permeation properties. Concentrations of CO_2 were 40% to 50% higher in broccoli packaged warm than cold and were significantly different between film types. The CO_2 transmission rate for RMF 61 is over six times that for TPM 87, which resulted in less CO_2 accumulation during the initial 6 h following sealing.

After 48 h, concentrations of CO_2 in bags of initially cold and warm broccoli had come to the same steady state. Concentrations of CO_2 in TPM 87 bags were $\approx 14.5\%$ and in RMF 61 bags $\approx 6\%$ and did not change significantly during the remainder of the ex-

periment (Fig. 2, Table 1). At this time, the differences in atmosphere composition were due to differences in film permeability, since respiration rates would be expected to be similar. Concentrations of O_2 tended to be more variable. In TPM 87, O_2 levels after 48 h were not significantly different between broccoli packed warm or cold and ranged between $\approx 2\%$ and 4% . In RMF 61 bags, however, O_2 levels remained 4% to 5% higher in cold-packed broccoli than in warm throughout the experiment. This difference remained significant up to 72 h after sealing.

In previous studies, atmosphere modification in packages of whole heads of broccoli wrapped in TPM 87 ranged from 8% to 14% O_2 and 7% to 10% CO_2 (Forney et al., 1989; Rij and Ross, 1987), which was 5% to 10% more O_2 and 4% to 5% less CO_2 than in the atmospheres in bags of broccoli florets. The respiration rate of florets may have been higher than that of whole heads because of the removal of stem tissue that probably would have a much lower rate of respiration than flower buds. The higher respiration rate would explain why florets produced a greater modification of package atmosphere than observed in whole heads and indicates that a more permeable film is needed to obtain similar MA in packages of florets than in whole heads.

Quality of broccoli florets was significantly reduced when kept warm overnight before packaging. This reduction in quality was reflected by lower ratings for color, turgidity, and general appearance in broccoli packaged warm rather than cold (Table 2). Film type, including vented bags (data not shown), had no effect on these characteristics. Keeping the florets 17 to 18 h at 20C had caused noticeable acceleration of senescence when florets were evaluated after 7 days of storage at 5C. The higher rate of respiration at 20C may have aided this acceleration of senescence. In addition, the vapor pressure deficit in the storage conditions for the warm broccoli before packaging was three times higher than that for the cold, resulting in increased water loss and the lower turgidity rating (Table 2). Brennan and Shewfelt (1989) reported that delays in cooling as short as 3 h reduced broccoli quality. These observations demonstrate the importance of good pre-cooking and temperature management in order to maintain broccoli quality.

Objectionable off-odors at times were formed by broccoli bagged in TPM 87. These odors were present only in bags that contained less than $\approx 1.5\%$ O_2 . Off-odors have developed in other studies in which broccoli was stored in 10% or higher concentrations of CO_2 in combination with 2.5% or less O_2 (Ballantine et al., 1988; Kasmire et al., 1974; Makhoul et al., 1989). It appears that these odors become stronger as O_2 concentrations decrease or storage times increase. The avoidance of conditions that induce these objectionable odors should be a primary concern in developing a MA package for broccoli.

From these results it appears that the composition of steady-state atmospheres established in film-wrapped packages of broccoli

is not significantly affected by broccoli temperature at the time of packaging. However, the effect of delayed cooling on broccoli quality may be significant, depending on the time elapsed before packaging and cooling. The more rapid atmosphere modification in the packages of warm broccoli may compensate, at least partly, for the detrimental effect of the warm temperature in situations in which the exposure to relatively high temperatures is shorter than 17 h.

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