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Evaluation of vacuum containers for consumer storage of fruits and vegetables

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Abstract

Plastic containers, capable of being evacuated to 50 kPa, were investigated for maintaining quality of fruits and vegetables. Celery, lettuce, broccoli, grapes, green beans, melon, and strawberry were kept at 4°C, broccoli, okra and tomato were kept at 8°C in vacuum containers and in conventional, sealed, plastic food containers. For each produce item, similar concentrations of carbon dioxide accumulated in each container type. After sealing containers for 3 days oxygen fell below 5 kPa for strawberry, okra and broccoli in conventional containers and for all types of produce in vacuum containers. The color of produce in vacuum containers was usually darker (lower L value) and less saturated (lower chroma) than in conventional containers. A higher proportion of strawberry fruits were infected by fungi in vacuum containers than in conventional. Water soaked lesions appeared on green beans kept in vacuum containers. Okra in vacuum showed less darkening of seeds than in conventional containers. Overall the vacuum containers showed little advantage over conventional containers for the types of produce tested.

Keywords: Carbon dioxide; Color; Consumer; Fruit; Oxygen; Vacuum; Vegetable

1. Introduction

Postharvest research has focused on improvement in the industrial handling and conservation of crops. This has led to development of technology that can be implemented by producers to maximize marketable yield and quality. In recent years increased attention has been given to improvements in handling through distribution and market channels, but little research exists on minimizing losses between retail and final consumption. Estimates of postharvest losses of perishable crops vary greatly; the scale of in-home loss is virtually unknown, but suspected to be high (Coursey, 1983). Modern houses do not include a larder or pantry for cool-storage of foods; the domestic refrigerator has become the default storage location for perishables, although sporadic advice cautions against holding chilling-sensitive materials there.

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Sub-atmospheric pressures are known to prolong the life of a wide range of plant crops, although the technology of hypobaric storage has not been widely applied (Burg and Burg, 1966). The present research was prompted by the appearance on the European market of containers for holding small amounts of food under a partial vacuum. The primary objective was to determine whether such containers were superior to existing, sealable food containers for common produce types.

2. Materials and methods

Fruits and vegetables were purchased from local stores and used immediately for experiments. Strawberries (*Fragaria Xananassa* Duchesne), okra (*Abelmoschus esculentus* L.), green beans (*Phaseolus vulgaris* L.) and cherry tomatoes (*Lycopersicon esculentum* Mill.) were kept whole. Celery (*Apium graveolens* var. *dulce* (Mill.) Pers.) petioles and Romaine lettuce (*Lactuca sativa* L.) leaves were cut transversely into 3 cm pieces. Bunches of ‘Thompson Seedless’ grapes (*Vitis vinifera* L.) were broken into smaller units that would fit the containers. Individual branches were cut from broccoli (*Brassica oleracea* L.) heads and cantaloupe melon (*Cucumis melo* L.) flesh was cut into 3 cm cubes. Each kind of produce was put in two vacuum containers (Vacu Products B.V., Delft, Holland) and two conventional containers (1 pint or 1 quart Servin’ Saver, Rubbermaid Inc., Wooster, OH). The vacuum containers were partially evacuated with a VacuVin pump (Vacu Products B.V., Delft, Holland); this required 18 strokes of the pump for a container with a nominal volume of 500 ml and 24 strokes for a 750 ml container. The containers were kept in a chromatography refrigerator (Model GDM-49, Revco Scientific, Asheville, NC) at 4°C for all products except tomato and okra which were held at 8°C. Broccoli and strawberries were also kept in loosely sealed plastic containers (bags or plastic retail packs) and an additional experiment was run with broccoli at 8°C.

At 3, 6 and 9 days the atmosphere inside containers was analyzed for carbon dioxide and oxygen. Syringe samples (1 ml) were taken through the lid of the conventional container which was resealed with PVC tape. Before sampling from the vacuum containers a tube carrying nitrogen at 100 Pa was connected to the seal, which was then squeezed to allow nitrogen to flow into the container in order to release the vacuum. A syringe with a 10-cm hypodermic needle was inserted through the seal to sample atmosphere from the container itself. Samples were injected into a gas chromatograph with porous polymer column for carbon dioxide and molecular sieve for oxygen, and a thermal conductivity detector (Knee 1995). Oxygen values were corrected by subtraction of 0.9 kPa, corresponding to the partial pressure of argon in the atmosphere. The absence of oxygen when GC analysis indicated ca. 1.0 kPa was confirmed by analysis with a paramagnetic oxygen analyzer (Model OA 250, Servomex Controls, Crowborough, UK).

Containers were opened at 3, 6 and 9 days and the surface color of all produce, except melon was measured using illuminant ‘c’ with a Chroma Meter (Model CR 100, Minolta, Ramsey, NJ). To minimize random variation, readings were taken on the same surfaces of the same fruit or vegetable pieces on each occasion. L*a*b* values were converted to hue angle and chroma (Little, 1975). The firmness of some materials was measured with a load cell mounted on a drive (Ametek Accuforce II and Ametek 100, Mansfield and Green, Largo, FL). For strawberry and melon peak force was recorded as a 5 mm, flat tipped probe was driven 5 mm into the fruit flesh at 2.2 mm s^{-1}. For tomatoes the force required to compress the fruit by 3.5 mm was recorded.

Data were analyzed using the ANOVA procedure of SAS Release 6.12 (SAS Institute, Cary, NC). Because readings were taken on the same experimental units, effects of time were analyzed as repeated measures.

3. Results

In preliminary experiments the volumes of containers were estimated by measuring the water required to fill them. Although their nominal volumes differed, the observed volumes of conventional and vacuum containers were nearly equal (Table 1). When the VacuVin pump was used on a flask with a vacuum gauge a minimum pressure of 50 kPa was attained. With the vacuum containers, resistance to pumping increased until it was judged that no more air was being withdrawn. This occurred at 18 strokes for the 500 ml container and 24 strokes for the 750 ml container. When the valves were opened under water slightly less than 50% of the volume was drawn in (Table 1); this volume remained constant when the containers were held for 3 days after pumping. When the pressure was released with nitrogen, the partial pressure of oxygen in the containers was a little more than half that in the atmosphere (Table 1).

Produce occupied between 10 and 30% of container volume (Tables 2 and 3). There was little change with time in gas composition measured at 3-day intervals during the experiment. Partial pressures of CO_2 were similar for each kind of produce in both types of container; broccoli, beans, okra and strawberries exceeded 10 kPa CO_2 (Tables 2 and 3). In the conventional containers, only okra, strawberry and broccoli in one experiment fell below 5 kPa oxygen. In vacuum all types of produce fell below 5 kPa; okra, strawberry and broccoli were below 1 kPa (Tables 2 and 3). Partial pressures of CO_2 and oxygen in the loosely sealed containers of broccoli and strawberries were close to those in air (data not shown).

Initially, the hue angles were ~50° for two red items, tomato and strawberry and ~120° for the remaining, green items. For all types of produce, except lettuce and beans, the L value decreased more in vacuum than in the conventional containers (Fig. 1A, Table 3). Broccoli at 8°C, grapes and

Table 1
Volumes of containers as reported by manufacturer and measured by filling with water, water drawn in by suction and partial pressure of oxygen estimated by chromatography after evacuation of containers

Container	Nominal volume (ml)	Actual volume (ml)	After pumping	
			Water intake (% vol)	Oxygen (kPa)
Conventional	665	750	–	–
Vacuum	500	770	47.5	11.8
Conventional	984	1140	–	–
Vacuum	750	1010	46.5	11.7

Table 2
Proportion of volume occupied by produce and partial pressures of carbon dioxide and oxygen (corrected for argon) in containers (average of values at 3, 6, 9 days)

Contents	Wt./vol. ratio	Conventional		Vacuum	
		pCO_2 (kPa)	pO_2 (kPa)	pCO_2 (kPa)	pO_2 (kPa)
Celery	0.16	6.57	11.2	5.08	2.73
Lettuce	0.08	3.27	15.6	2.82	4.33
Broccoli 8°C	0.15	14.2	5.30	14.1	0.13
Broccoli 4°C	0.15	15.7	0.60	14.2	0.42
Beans	0.14	11.0	8.33	13.6	1.31
Grape	0.25	4.52	16.4	7.50	3.27
Melon	0.28	5.63	13.9	7.18	2.08
Okra	0.14	18.5	2.79	21.4	1.06
Strawberry	0.26	16.3	1.97	15.6	0.73
Tomato	0.28	11.7	7.47	7.72	2.62

Table 3
Probabilities of main effects of time, produce type and container type on atmosphere composition and changes in color variables and standard errors applicable to Table 2 and Fig. 1, according to repeated measures analysis of variance

Dependent variable	Effect of			
	Time	Produce	Container	S.E. ($n = 6$)
Carbon dioxide	0.030	0.0001	0.797	13.4
Oxygen	0.035	0.0001	0.0001	12.7
L value	0.0009	0.0001	0.0001	0.254
Hue angle	0.0001	0.171	0.053	0.510
Chroma	0.0001	0.0037	0.010	0.325

tomatoes showed decreases in hue angle (from green towards yellow or orange to red) in conventional containers (Fig. 1B, Table 3). In vacuum containers changes in hue angle were less than, or in the opposite direction from conventional containers for all produce except celery and lettuce (Fig. 1B, Table 3). Chroma generally increased more or showed a smaller decrease for produce in conventional containers than in vacuum (Fig. 1C, Table 3). Color changes for produce in loosely sealed containers were different from those in sealed containers. Broccoli in the loosely sealed bags showed little change in color by comparison with the sealed containers. However, strawberries in retail containers showed a larger decrease in L value and chroma than in the sealed containers (Fig. 1).

Little or no change in firmness was recorded for strawberries or melon pieces in any container. The firmness of tomatoes decreased from 12.1 to 7.6 N but was not affected by the type of container. In vacuum containers 36% of green beans developed water-soaked lesions by the end of the experiments, but in conventional containers none developed. At the end of the experiment (9 days) fungal infection was found on 35% of strawberry fruits in vacuum containers, 11% in conventional containers and 22% in retail packs. Grapes also developed fungal infections but these were not affected by container type. Seeds in okra fruits turned brown during storage; this affected 65% of fruit in conventional containers, but 10% in vacuum.

4. Discussion

Fifteen years ago it was difficult to find gas-tight plastic containers for research on apple ripening (Knee et al., 1987). Modern plastic food containers are well-sealed and living plant material rapidly alters the gas composition in the container. Although there is widespread interest in modified atmosphere packaging for wholesale and retail marketing of perishables, the potential for occurrence of modified atmospheres in consumer storage of fruits and vegetables does not seem to have been widely recognized (Cameron et al., 1995; Rooney, 1995). The atmospheres that developed in sealed containers were generally consistent with data on the respiration rates of individual fruits and vegetables (Hardenburg et al., 1986). Large increases in CO_2 and decreases in oxygen were expected for broccoli, green beans and okra because of their high respiration (ca. 30–50 mg CO_2 kg^{-1} h^{-1} at 4–5°C) Smaller changes were expected for celery, grape, melon because of their low rates (5–10 mg kg^{-1} h^{-1}). Lettuce (4–5°C), strawberry (4–5°C) and tomato (10°C) have intermediate rates (15–25 mg kg^{-1} h^{-1}). The difference in composition between lettuce and strawberry or tomato can be accounted for by variation in the ratio of tissue mass to container volume. Gas concentrations would have been continuously changing during the 3-day sealing periods in these experiments, and would have continued to change if containers had remained closed. It was thought likely, and certainly desirable that a consumer would look at fruit or vegetables after 3 days in a container, and it is unlikely or undesirable that they would be kept beyond 9 days.

Deterioration of fruits and vegetables is often delayed when they are kept below 10 kPa oxygen or above 5 kPa carbon dioxide (Kader, 1992). Abnormal metabolism and flavors can develop when oxygen is below 2 kPa or carbon dioxide is above 10 kPa. Most plant species produce ethanol

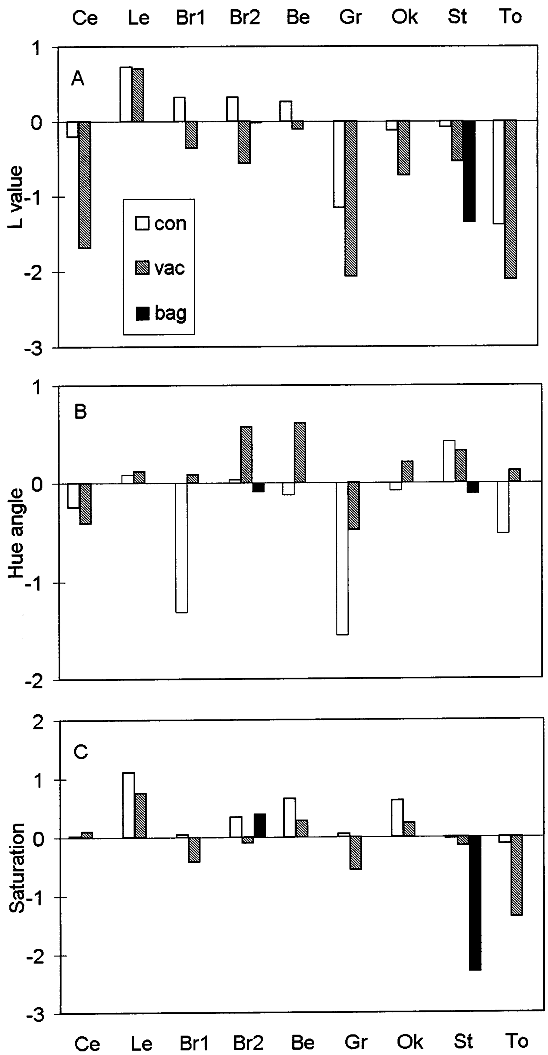

Fig. 1. Average changes in color for each 3-day interval over a period of 9 days of celery (Ce), lettuce (Le), broccoli at 8°C (Br1), broccoli at 4°C (Br2), green beans (Be), grapes (Gr), okra (Ok), strawberries (St) and cherry tomatoes (To) in conventional containers, vacuum containers and retail bags or packs.

and related metabolites under these conditions, but the organic sulfur compounds produced by *Brassica* vegetables, such as broccoli are particularly offensive (Di-Pentima et al., 1995). The partial pressures of oxygen and carbon dioxide that developed in containers were compared with the recommendations for storage of different commodities found in Hardenburg et al. (1986). The partial pressures in the vacuum containers were within 1 kPa of recommended levels for celery and lettuce in vacuum containers; for all of the other items the conditions were more extreme than recommended in both types of container.

Storage below atmospheric pressure can also affect physiological processes by accelerating diffusion of gases in bulky plant organs (Burg and Burg, 1966), but to be effective in reducing internal ethylene concentrations, hypobaric containers require continuous ventilation. Under static conditions the effects of low pressure are similar to the equivalent partial pressure of oxygen (Stenvers and Bruinsma, 1975). In conventional containers oxygen fell over 3 days below 10 kPa in six out of ten trials and below 2 kPa in one trial. The partial pressure of oxygen in vacuum containers was immediately lowered to 12 kPa, fell below 10 kPa in every trial and below 2 kPa in five. Use of vacuum containers increased the risk of anaerobic metabolism. Physiologically active concentrations of CO_2 (Kader, 1992) accumulated in virtually all containers and there was little difference between conventional and vacuum. The likelihood of CO_2 injury was not affected by container type.

The lightness (L value) and chroma of most products in vacuum became lower than in conventional containers. Although the fruits and vegetables were not obviously spoiled, this is evidence that the effects of vacuum were adverse rather than beneficial. Similarly the effects of vacuum on decay and other visual deterioration were mostly neutral or adverse. The implications of modified atmophere packaging for microbial safety of foods have been considered (Hotchkiss and Banco, 1992). Anoxic conditions are required for growth of *Clostridium botulinum*, but the organism does not seem to grow on packaged vegetables until they are visibly spoiled (Larson et al., 1997). Although the risk of botulism is probably minimal, other organisms, such as *Listeria* could grow on certain vegetables in sealed containers as they do in modified atmosphere packages (Hotchkiss and Banco, 1992).

In conclusion, these results do not encourage the use of vacuum containers for home storage of fruits and vegetables, but there more studies on consumer storage of perishable produce are needed.

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