ELSEVIER

Postharvest Biology and Technology 4 (1994) 319–329

Postharvest Biology and Technology

Application of casein-lipid edible film emulsions to reduce white blush on minimally processed carrots

Roberto J. Avena-Bustillos [a,*], Luis A. Cisneros-Zevallos [a], John M. Krochta [a], Mikal E. Saltveit, Jr. [b]

[a] *Department of Biological and Agricultural Engineering and Department of Food Science and Technology, University of California, Davis, CA 95616, USA*

[b] *Mann Laboratory, Department of Vegetable Crops, University of California, Davis, CA 95616, USA*

Accepted 21 December 1993

Abstract

White blush on the surface of peeled carrots is a major cosmetic disadvantage in marketing this lightly processed, ready-to-eat product. The loss of quality is exacerbated by surface dehydration. To maintain good appearance, edible coatings consisting of emulsions incorporating caseinates with beeswax, stearic acid or acetylated monoglyceride were tested. All except the latter increased water vapor resistance. Sodium caseinate–stearic acid was particularly effective in ameliorating the disorder.

Keywords: Baby carrots; Edible coatings; Whitish index; Water vapor resistance

1. Introduction

The market-life of minimally processed or "ready-to-eat" fruits and vegetables is limited by a series of problems related to cell disruption such as leakage of nutrients, enzymatic reactions, mold growth and lactic acid fermentation, loss of texture, development of off-flavors and off-odors, and appearance defects (Carlin et al., 1990). Peeled carrots are raw, sweet carrots that have been selected, washed, cut into 5 cm long pieces, peeled, hydro-cooled to 1.5°C with chlorinated water, and packaged in low-density polyethylene bags as a ready-to-eat product. Formation of a whitish appearance or "white blush" on the surface is a major factor reducing consumer acceptance of minimally processed carrots. Development of this blush has been attributed to dehydration following abrasion peeling, and was reported to be reduced by using razor-sharp blades (Tatsumi et al., 1991). Bolin and Huxsoll

* Corresponding author.

0925-5214/94/$07.00 © 1994 Elsevier Science B.V. All rights reserved.
SSDI 0925-5214(94)00002-A

(1991) concluded that the white blush was caused by lignin formation due to an enzymatic reaction, and claimed that dipping peeled carrots for 30 s in an acidic (pH 2) solution at 70°C retarded this disorder.

Application of an edible coating, formulated with FDA-approved ingredients with desirable physical, sensory and microbiological properties, to minimally processed carrots could reduce the development of white blush. Edible films and coatings derived from biological materials have been studied for many years, and interest appears to have intensified recently. Kester and Fennema (1986), Guilbert (1986) and Krochta (1992) have written reviews on edible films and coatings discussing reasons for using edible films, formation procedures, types and characteristics of various films, and mechanical and permeability properties.

Edible coatings are thin layers of material applied to the surface of the fruit or vegetable as an addition to or replacement for the natural protective waxy coating. Traditionally, edible coatings have been used to reduce water loss, but recent development of formulated edible coatings with a wider range of permeability characteristics has extended the potential for fresh produce application. Research by Krochta et al. (1990) indicated that edible coatings made from milk protein and vegetable oil derivatives substantially reduced moisture loss and oxidative browning in apple slices. Films formulated with these two food components also had different permeability values depending on the protein/lipid ratio (Avena-Bustillos and Krochta, 1993). Utilization of a calcium caseinate, Alanate-310™ (New Zealand Milk Products, Inc., Santa Rosa, CA), makes possible the stabilization at room temperature of an emulsion of an acetylated monoglyceride, Myvacet-5-07™ (Eastman Chemicals). This preparation is cumbersome to apply alone as a coating for produce because it melts at 48°C (Avena-Bustillos et al., 1993).

The objectives of this study were to investigate the nature of the mechanism for white blush formation on minimally processed carrot sections and to assess the effectiveness of casein-lipid coatings on: (1) reduction of white blush development; (2) reduction of moisture loss and gas transfer; and (3) modification of internal gas composition and head space gases in packaged peeled carrots.

2. Materials and methods

Peeled carrots were taken from the de-watering belt of the processing line after hydro-cooling from a processing plant in Bakersfield, Calif. Samples were stored under crushed ice in insulated chests and transported to the University of California, Davis.

Effect of dehydration and relative humidity on white blush

Change of color (white blush formation) during storage of peeled carrots was evaluated using a Minolta chroma-meter CR200 (Minolta Camera Co., Japan) by determining L, a and b from the CIE color scale after calibration with a standard orange tile. Twenty samples were used for each treatment at each time, averaging three color measurements on the surface of each carrot. The color parameters were used to estimate a whitish index (W_i) according to Judd (1963):

$$W_i = 100 - \sqrt{(100 - L)^2 + a^2 + b^2}$$

The effect of dehydration on whitish blush was studied by blowing air at 20°C and 55% RH with an electric fan at 180 m/min over individual uncoated peeled carrots and measuring the whitish index and weight loss. Also, the effect of relative humidity (RH) on whitish blush and weight loss was studied by storing uncoated peeled carrots inside hermetic chambers equilibrated at constant RH with saturated salt solutions at 10°C (ASTM, 1985).

Edible coatings

Edible coating formulations consisted of 2% total solids emulsions incorporating caseinates with beeswax, fatty acids and acetylated monoglycerides (Table 1). Coatings were sprayed on 2.2 kg batches of peeled carrots. Drainage of excess coating was aided by blowing 20°C air over the carrots.

Water vapor resistance

Coated and uncoated (control) peeled carrots were held on individual weighing trays in a storage room at 2.5°C, 70% RH and an air flow of 20 m/min. The carrots were removed from the storage room and weighed every 2 days to the nearest mg during the storage period. The dimensions (length, and minimum and maximum diameter) of each carrot were measured initially to calculate surface area assuming a truncated cylindrical shape. Ten randomly picked carrots were used for each treatment and held in the storage room. The time at each weighing was recorded to the nearest minute to accurately calculate water vapor transmission rate (i.e., the slope of weight loss versus storage time) and water vapor resistance. An estimate of water vapor resistance was calculated using a modified Fick's equation (Ben-Yehoshua et al., 1985):

Table 1
Edible coating formulations for peeled carrots (prepared as 2% total solids emulsions with 1% caseinate:1% lipid).

Treatment code	Components
T1	Calcium caseinate [a]/beeswax [b]
T2	Calcium caseinate/stearic acid [c]
T3	Calcium caseinate/acetylated monoglyceride [d]
T4	Sodium caseinate [e]/beeswax
T5	Sodium caseinate/stearic acid
T6	Sodium caseinate/acetylated monoglyceride
T7	Control, uncoated

[a] Alanate-310 (New Zealand Milk Products, Inc., Santa Rosa, CA).
[b] Australian white beeswax (National Wax Co., Skokie, IL).
[c] Stearic acid 95% (Aldrich Chemical Co., Inc., Milwaukee, WI).
[d] Myvacet 5-07 (Eastman Chemical Products, Inc., Kingsport, TE).
[e] Alanate-110 (New Zealand Milk Products, Inc., Santa Rosa, CA).

$$r = \frac{\left(A_w - \frac{\%RH}{100}\right) P_{wv}}{RT} \frac{A}{J}$$

where r = water vapor resistance, s/cm; A_w = water activity of carrots, 0.991 (Chirife and Ferro-Fontan, 1982); %RH = storage room relative humidity, 70% RH; P_{wv} = saturated water vapor pressure at 2.5°C, 5.486 mm Hg; R = universal gas constant, 3464.629 mm Hg cm^3 g^{-1} K^{-1}; T = storage room temperature, 275.5 K (2.5°C); A = surface area of carrot sections, cm^2; J = slope of curve of water loss vs. storage time for carrots, g/s.

Effect of coating on whitish index

The whitish index was evaluated on coated and uncoated (control) carrots packaged in batches of 165 g in 1.5-mil low-density polyethylene (LDPE) bags, by triplicate, stored at 10°C and 85% RH. Twenty carrots were used for each treatment, by triplicate at each storage time, averaging three color measurements on the surface of each carrot.

Sensory color analysis

Visual ranking of white blush intensity was performed by two judges in 8 replications per treatment at each testing session. They evaluated samples of carrots by ranking six different coating treatments and an uncoated control, with the lowest rank (1) being given to the sample with the least white blush and the highest rank (7) to the sample with the most white blush. Total rank sum was calculated by adding the numbers corresponding to the rank position assigned by the judges at each time of analysis for each treatment (Newell and MacFarlane, 1987).

Respiration rate

A flow-through system was used to measure O_2 consumption and CO_2 production during storage at 2.5°C and 100% RH. Treated carrots, ca. 200 g, were placed by triplicate for each of the six treatments (Table 1) and the control in 1-liter glass jars which were ventilated at 1.5 l/h with humidified air. The flow rate prevented the CO_2 concentration in the outlet stream from exceeding 0.1% and prevented water vapor condensation in the jars and subsequent enhancement of fungus decay. Three 1-ml samples of outlet air were taken from each jar for triplicate measurements of CO_2 and O_2 every 4 to 7 days during two months of storage. Carbon dioxide concentration was measured with an infrared gas analyzer model PIR-2000 (Horiba Instruments, Inc., Irvine, Calif., USA), and the oxygen concentration was measured with a model S-3A Applied Electrochemistry paramagnetic O_2 analyzer (Ametek, Pittsburgh, Penn.) (Saltveit, 1989).

Head space gases and internal gases

After coating and draining, some samples were packaged in 1.5-mil low-density polyethylene (LDPE) bags for shelf-life stability observation at 2.5°C for 45 days. Head space gas samples were taken out by inserting a needle through the plastic

bags and taking a 1-ml gas sample with a syringe for CO_2 and O_2 analysis. Then, bags were opened and samples taken for extraction and analysis of internal gas composition using a procedure recommended by Saltveit (1982). The procedure used a 20-l Plexiglas vacuum chamber filled to 90% capacity with degassed saturated solution of magnesium sulfate (Epsom salt, $MgSO_4.7H_2O$, with a solubility of 71 g/100 ml cold water). The saturated solution was acidified to pH 2.5 with HCl to further reduce carbon dioxide solubility before use. Degassing was done by holding the solution under vacuum for several hours before use. A 200-g sample of carrots was submerged in the degassed saturated solution and covered with a submerged inverted glass funnel whose tip was covered tightly with a rubber septum. Then, a partial vacuum (300 mm Hg) was applied to the chamber. Gas bubbling out of the carrots rose and accumulated at the top of the inverted funnel. The vacuum was released after 4 min and three 1-ml gas samples were collected for CO_2 and O_2 analysis.

3. Results and discussion

Effect of dehydration on white blush

Exposing peeled carrots to a 180 m/min flow of 55% RH at 20°C for 40 min resulted in a linear (r^2 = 0.999) weight loss at a rate of 0.194%/min. Weight loss is assumed to be mainly loss of water by evaporation.

After a 10-min lag, the whitish index increased from a minimum value of 32 to a maximum value of 50 at 30 min. Delay in W_i increase was probably due to the presence of excess surface water. The large standard deviation for W_i values indicated substantial variability in the color of different carrots and the necessity of having a large number of replications to determine statistical differences. Bruemmer (1988) found no significant difference in color of fresh-cut and stored carrot sticks using the same model chroma-meter, possibly because he measured the color of carrot juice instead on the carrot surface.

The W_i increased to a maximum of 50 as the water loss increased to 6%, but once the white blush formed, there was no correlation between W_i and further weight loss. White blush can be induced in one or two minutes by removing surface moisture with a tissue paper. These results confirm that white blush formation in peeled carrots is essentially a dehydration of the surface as reported by Den Outer (1990) and Tatsumi et al. (1991). Bolin and Huxsoll (1991) claimed that the white blush was due to lignin formation through an enzymatic reaction, but they may have confused cause and effect. Abrasion peeling may have caused both the white blush and lignification.

Effect of relative humidity on white blush

The W_i reached a maximum value of around 45 at different rates of drying during storage of peeled carrots at different RH (Fig. 1). The W_i reached a value of 40 after approximately 1, 2, and 3.5 days storage at 34%, 76% and 100% RH, respectively. The maximum W_i value of 45 was reached after only two days at 34% RH, while it took more than seven days to reach a similar W_i at 100% RH. This indicates

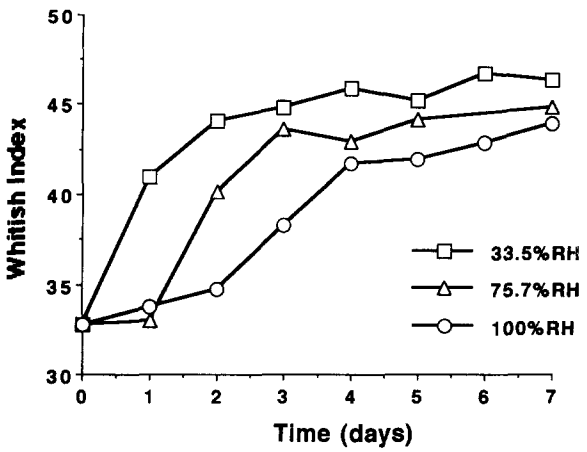

Fig. 1. Effect of % RH on whitish index on uncoated peeled carrots stored at 10°C.

the importance of maintaining a high RH during storage of peeled carrots. Such a high RH can be maintained by using low water vapor permeable polymeric bags and edible films (Den Outer, 1990), and also by reducing the water vapor gradient by storing packaged carrots in a high RH environment. Storage at 98% RH reduced the W_i to the same extent as 100% but not significantly lower than RH below 70–95% due to high standard deviations. Van den Berg and Lentz (1978) indicated that whole carrots should be stored at 98–100% RH to assure a shelf-life of 15–40 weeks, depending on cultivar.

A water loss as low as 0.5% was enough for the development of an unacceptable level of white blush. This white blush corresponds to a W_i of 40. The maximum W_i at each RH was reached in three days at 10°C. After three days the carrots had a constant W_i, although they continued to lose moisture.

Effect of coating on water vapor resistance

A simple linear regression analysis of weight loss versus time was performed for ten replicates for each treatment. Water loss followed a linear relationship with time ($P < 0.001$) and its slope in g/h provided the water vapor transmission rate. Water vapor resistances (in s/cm) were calculated for the coated and uncoated carrots (Fig. 2). As expected for a peeled vegetable, water vapor resistance was very low compared with unpeeled vegetables (Cameron and Reid, 1982). Analysis of variance and Duncan's multiple range test (SAS, 1990) indicated that all coating treatments, except T6, had significantly higher water vapor resistance than the control at the 5% level. These results are consistent with measurements of water vapor permeability of cast-alone caseinate-based edible films (Avena-Bustillos and Krochta, 1993), where permeability was lower for calcium caseinate/beeswax (T1) films than for sodium caseinate/acetylated monoglyceride (T6) films.

Comparing resistance values for coated and uncoated carrots indicated that it was possible to increase by 45% the water vapor resistance of peeled carrots using the

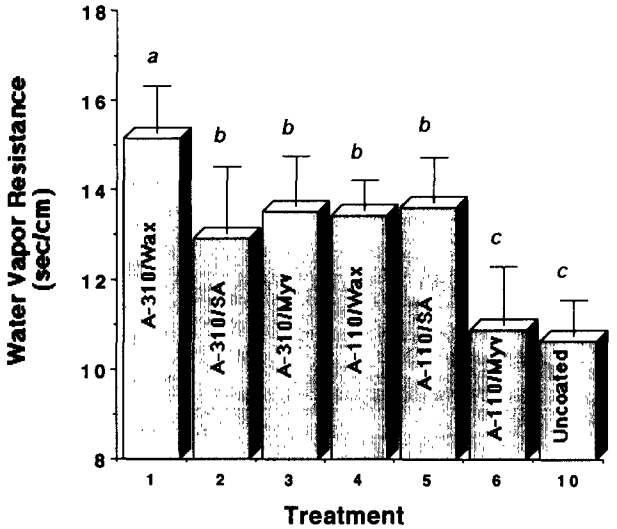

Fig. 2. Water vapor resistance on coated and uncoated peeled carrots (2.5°C, 70% RH and 20 m/min). Letters indicate significant difference at $P < 0.05$. Bars are standard deviations.

1.0% sodium caseinate : 1.0% beeswax formulation. However, beeswax-based edible coating contributed to the white blush appearance due to a possible crystallization of the beeswax. An alternative would be to use an edible coating formulated with sodium and stearic acid (T5). This coating formulation provided a good moisture barrier and reduced the rate of white blush formation.

Effect of coating on whitish index

Carrots coated with the 1% sodium caseinate and 1% stearic acid (T5) developed a significantly lower ($P < 0.05$) W_i than control and rest of coated carrots during storage in LDPE bags at 10°C (Fig. 3). White blush was evident in 24 h in some uncoated carrots, while most of the uncoated carrot pieces showed white blush spots after three days. The blush predominated on carrots facing the polymeric films, and was less evident on carrots positioned in the center of the bag. This difference is explained by a possible %RH gradient in the bag. The edible coating T5 approximately doubled the time it took for carrots stored at 10°C to reach W_i values between 35 and 44 compared to the uncoated carrots (Fig. 3). After 23 days, carrots with T5 coating had a lower W_i than carrots receiving the other treatments.

Sensory color analysis

Using the Newell-MacFarlane two-factor ranked non-parametric analysis of variance (Newell and MacFarlane, 1987) with critical rank sum differences for one-sided "treatments versus control" comparisons at 5% level of significance, we concluded that the edible coating T5 was consistently visually ranked lower ($P < 0.05$) in white blush than uncoated carrots (Fig. 4). The rest of the edible coating

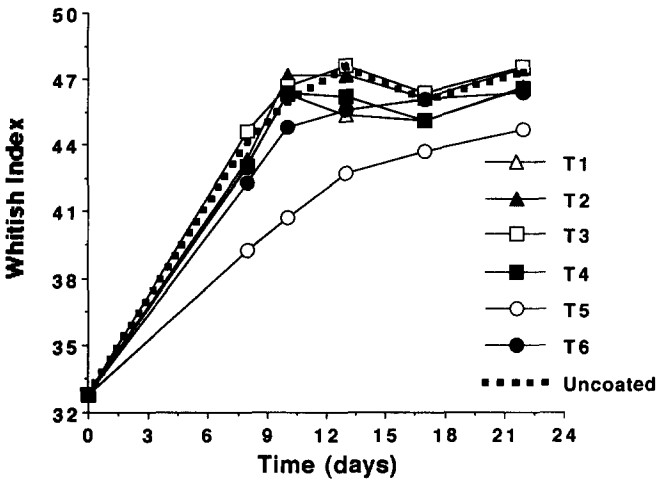

Fig. 3. Whitish index change during storage of coated peeled carrots packaged in 1.5-mil LDPE bags at 10°C.

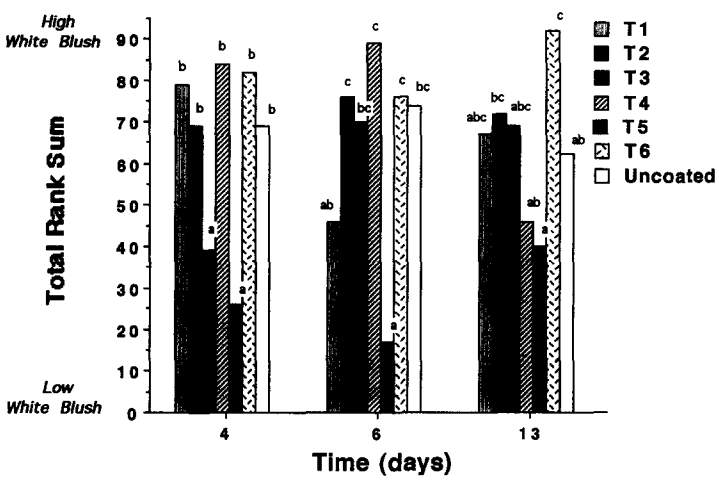

Fig. 4. Color ranking of coated peeled carrots stored in LDPE bags at 10°C and 85% RH. Letters indicate significant difference at $P < 0.05$.

treatments were not ranked significantly different from the uncoated carrots in a consistent fashion during the different testing sessions. An "acceptable appearance" by the visual color ranking was achieved each time a coated sample had significantly lower total rank sum values than uncoated carrots (Fig. 4).

There was no significant correlation between subjective evaluation of white blush and the computed W_i (Fig. 5). According to the coefficient of determination (r^2), only 57% of W_i values were linearly correlated with total rank sum after 13 days

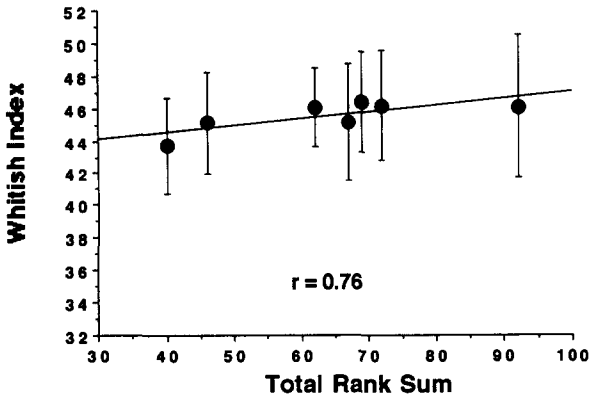

Fig. 5. Correlation between sensory and instrumental analysis of color of coated peeled carrots stored at 10°C for 13 days.

of storage. Similar results occurred at the different testing sessions. Due to the large standard deviations within each sample, as a result of position of the carrot in the bags, degree of abrasion, and normal color variability, we concluded that sensory color analysis could be more sensitive and reliable for assessing white blush conditions than the calculated W_i for peeled carrots.

Respiration rate

The control and coated carrots all followed a decreasing, non-climacteric respiration pattern. This decreasing respiration rate pattern is characteristic for many commodities recuperating from wound injuries. Bruemmer (1988) indicated that carrots processed into carrot sticks had an abrupt but temporary 10-fold increase in respiration. A one-way analysis of variance showed that the respiration rate for coated peeled carrots was significantly lower ($P < 0.05$), except for T1 and T4, at the start of the experiment compared to the control. This difference was taken as evidence of a temporary increase in CO_2 mass transfer resistance caused by the application of the emulsion coating. Respiration decreased from an initial 7.8 ± 0.6 to 3.6 ± 0.2 ml CO_2 kg^{-1} h^{-1} after 45 days. Coatings T3 and T6 significantly reduced respiration for most of the storage period, a desirable effect to increase shelf-life. The data also suggests that respiration may have continued to decline after 45 days. Such a low respiration rate is consistent with the long storage life observed for carrots in this study, up to 60 days of storage at 2.5°C in 100% RH air.

Head space gases and internal gases

There was not a significant difference in head space and internal gas composition for the different coating treatments and the uncoated carrot stored in LDPE bags (data not shown). Carrots stored at 2.5°C for 45 days in LDPE bags had a head space gas concentration of 8% CO_2 and 1.5% O_2 and an internal gas composition of 9% CO_2 and 1% O_2. Sealed LDPE bags collapsed as a consequence of selective gas exchange, a phenomenon reported by Mannapperuma and Singh (1990).

Product stability

Evidence of visual microbial spoilage was noticeable during storage of packaged coated and uncoated carrots at 10°C after 3 weeks. However, packaged coated and uncoated carrots stored at 2.5°C were stable at least for 45 days.

4. Conclusions

White blush formation on peeled carrot sections is caused by surface dehydration. White blush is reduced, although not significantly, by keeping carrots at 98–100% RH. Instrumental color evaluation of the whitish index should take into account the high degree of variability in white blush. Sensory color ranking appears to be more sensitive to small differences in white blush on peeled carrots than instrumental evaluation as determined by W_i.

White blush and respiration rate were reduced and water vapor resistance was increased using edible coatings. A sodium caseinate/stearic acid emulsion coating formulation appeared to successfully reduce white blush.

References

ASTM, 1985. Standard practice for maintaining constant relative humidity by means of aqueous solutions. Annual Book of ASTM Standards, Designation, E 104-85.

Avena-Bustillos, R.J. and Krochta, J.M., 1993. Water vapor permeability of caseinate-based edible films as affected by pH, calcium crosslinking and lipid content. J. Food Sci., 58: 904–906.

Avena-Bustillos, R.J., Krochta, J.M., Saltveit, M.E., Rojas-Villegas, R.J. and Sauceda-Pérez, J.A., 1993. Optimization of edible coating formulations on zucchini to reduce water loss. J. Food Eng. (in press).

Ben-Yehoshua, S., Burg, S.P. and Young, R., 1985. Resistance of citrus fruit to mass transport of water vapor and other gases. Plant Physiol., 79: 1048–1053.

Bolin, H.R. and Huxsoll, C.C., 1991. Control of minimally processed carrot (*Daucus carota*) surface discoloration caused by abrasion peeling. J. Food Sci., 56: 416–418.

Bruemmer, J.H., 1988. Quality changes of carrot sticks in storage. Proc. Fla. State Hortic. Soc., 101: 207–210.

Cameron, A.C. and Reid, M.S., 1982. Diffusive resistance: importance and measurement in controlled atmosphere storage. In: D.G. Richardson and M. Meheriuk (Editors), Controlled Atmosphere for Storage and Transport of Perishable Agricultural Commodities. Timber Press, Beaverton, Oreg., pp. 171–180.

Carlin, F., Nguyen-The, C., Hilbert, G. and Chambroy, Y., 1990. Modified atmosphere packaging of fresh, "ready-to-use" grated carrots in polymeric films. J. Food Sci., 55: 1033–1038.

Chirife, J. and Ferro-Fontan, C., 1982. The water activity of fresh foods. J. Food Sci. 47: 661–663.

Den Outer, R.W., 1990. Discoloration of carrot (*Daucus carota* L.) during wet chilling storage. Sci. Hortic., 41: 201–207.

Guilbert, S., 1986. Technology and application of edible protective films. In: M. Mathlouthi (Editor), Food Packaging and Preservation. Theory and Practice. Elsevier, Amsterdam, pp. 371–394.

Judd, D.B., 1963. Color in Business, Science and Industry. John Wiley, New York, N.Y., pp. 299–300.

Kester, J.J. and Fennema, O.R., 1986. Edible films and coatings: a review. Food Technol., 12: 47–59.

Krochta, J.M., 1992. Control of mass transfer in foods with edible coatings and films. In: R.P. Singh and M.A. Wirakartakusumah (Editors), Advances in Food Engineering. CRC Press, New York, N.Y., pp. 517–538.

Krochta, J.M., Pavlath, A.E. and Goodman, N., 1990. Edible films from casein-lipid emulsions for lightly-processed fruits and vegetables. In: W.E.L. Spiess and H. Schubert (Editors), Engineering

and Food, Vol. 2. Preservation Processes and Related Techniques. Elsevier, Amsterdam, pp. 329–340.

Mannapperuma, J.D. and Singh, R.P., 1990. Modeling of gas exchange in polymeric packages of fresh fruits and vegetables. Presented at the Annual Meeting of the Institute of Food Technologists, June 16–20, 1990, Anaheim, Calif.

Newell, G.J. and MacFarlane, J.D., 1987. Expanded tables for multiple comparison procedures in the analysis of ranked data. J. Food Sci., 52: 1721–1725.

Saltveit, M.E., 1982. Procedures for extracting and analyzing internal gas samples from plant tissues by gas chromatography. HortScience, 17: 878–881.

Saltveit, M.E., 1989. A rapid method for accurately measuring oxygen concentrations in milliliter gas samples. HortScience, 24: 145–147.

SAS, 1990. SAS/STAT User's Guide. Version 6, 4th ed., Vol. 2, GLM-VARCOMP. SAS Institute Inc., Cary, N.C.

Tatsumi, Y., Watada, A.E. and Wergin, W.P., 1991. Scanning electron microscopy of carrot stick surface to determine cause of white translucent appearance. J. Food Sci., 56: 1357–1359.

Van den Berg, L. and Lentz, C.P., 1978. High humidity storage of vegetables and fruits. HortScience, 13: 565–569.