OPTIMIZATION OF EDIBLE COATINGS ON MINIMALLY PROCESSED CARROTS USING RESPONSE SURFACE METHODOLOGY


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ABSTRACT. Formation of a whitish, dried appearance (white blush) on the surface of peeled carrot pieces is a major factor reducing consumer acceptance of minimally processed carrot products. The optimization of sodium caseinate/stearic acid emulsion coating formulations was studied using response surface methodology. Optimization was based on the ability of edible coatings to increase water vapor resistance and reduce white blush measured by sensory and instrumental analysis. The effect of different sodium caseinate/stearic acid emulsion coatings on three different response parameters (water vapor resistance, whitish index, and sensory ranking of white blush) indicated that storage stability of peeled carrots can be improved with an optimized 1.4 to 1.6% sodium caseinate/0.1 to 0.2% stearic acid emulsion coating formulation. Keywords. Baby carrots, Whitish index, Water vapor resistance.

Minimal processing has been defined as the handling, preparation, packaging, and distribution of agricultural commodities in a fresh-like state (Shewfelt, 1987). Minimally processed fruits and vegetables often are exposed to substantial mechanical injury and wounding (Rolle and Chism, 1987). Mechanical wounding may induce increased respiration, accumulation of secondary metabolites, increased ethylene synthesis, and cellular disruption (Rolle and Chism, 1987). Maintenance of cell membrane integrity and reduction of chemical and enzymatic reactions are some of the major problems to extending the shelf-life of minimally processed fruits and vegetables (Klein, 1987; Rolle and Chism, 1987).

Peeled carrots are raw carrot sections that have been selected, washed, cut into 5-cm-long pieces, peeled, cooled to 1.5°C by hydro-cooling with chlorinated water, and packaged in low-density polyethylene (LDPE) bags as a ready-to-eat product (Avena-Bustillos et al., 1993). 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 (Tatsumi et al., 1991; Avena-Bustillos et al., 1993) and an enzymatic reaction (Bolin and Huxsoll, 1991).

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, 1988), and Krochta (1991, 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.

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. Avena-Bustillos et al. (1993) demonstrated that a sodium caseinate/stearic acid emulsion coating formulation appeared to be very successful in increasing water vapor resistance and reducing white blush on peeled carrots.

Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for analyzing problems in which several independent variables influence a dependent variable or response. The goal of RSM is to optimize the response (Montgomery, 1984). For simplicity, the number of independent variables is usually limited to two or three. Response surface methodology is a powerful tool in experimental product development design (Dziezek, 1990) and has been applied to optimize several food processing operations (Mudahar et al., 1989; Gontard et al., 1992).

The objective of this study was to investigate the optimization of sodium caseinate/stearic acid emulsion coating formulations using response surface methodology based on ability of the coating to increase water vapor resistance, reduce whitish index, and reduce sensory white blush ranking.

MATERIALS AND METHODS
EDIBLE COATINGS

Packaged peeled carrot sections were obtained from a commercial processing plant in Bakersfield, California. Samples were transported under crushed ice in insulated chests and received at the University of California, Davis, on one day after packaging. Edible coating formulations consisted of 1 to 3% total solids emulsions incorporating sodium caseinate (SC) (Alanate-110™ from New Zealand...
Table 1. Edible coating formulations for baby carrots

<table>
<thead>
<tr>
<th>Code</th>
<th>% Total Solids</th>
<th>Sodium Caseinate</th>
<th>Stearic Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>1.0</td>
<td>0.25%</td>
<td>0.75%</td>
</tr>
<tr>
<td>T2</td>
<td>1.0</td>
<td>0.50%</td>
<td>0.50%</td>
</tr>
<tr>
<td>T3</td>
<td>1.0</td>
<td>0.75%</td>
<td>0.25%</td>
</tr>
<tr>
<td>T4</td>
<td>2.0</td>
<td>0.50%</td>
<td>1.50%</td>
</tr>
<tr>
<td>T5</td>
<td>2.0</td>
<td>1.00%</td>
<td>1.00%</td>
</tr>
<tr>
<td>T6</td>
<td>2.0</td>
<td>1.50%</td>
<td>0.50%</td>
</tr>
<tr>
<td>T7</td>
<td>3.0</td>
<td>1.00%</td>
<td>2.00%</td>
</tr>
<tr>
<td>T8</td>
<td>3.0</td>
<td>1.50%</td>
<td>1.50%</td>
</tr>
<tr>
<td>T9</td>
<td>3.0</td>
<td>2.00%</td>
<td>1.00%</td>
</tr>
<tr>
<td>T10</td>
<td>Control, Uncoated</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Milk Products, Inc., Santa Rosa, CA), with stearic acid (SA) (Aldrich Chemical Co., Inc., Milwaukee, WI) at nine different formulations (table 1). These substances are food-grade approved and used for emulsification and coating of diverse food products. Emulsions were prepared by dissolving SC in distilled water at room temperature. The solution was heated to 60°C and SA added. After melting with constant stirring and heating to 70°C, the mixture was then emulsified using an Ultra-Turrax T25 homogenizer (IKA-Works, Inc., Cincinnati, OH) at 13,500 rpm for one minute. Formulations were selected according to an experimental design appropriate for applying response surface analysis (Montgomery, 1984). A 100-ppm chlorine solution was first sprayed on contact surfaces and working areas. Carrots were handled with gloves and sanitary masks. Emulsion coatings were then sprayed at 20°C on 2.2-kg batches of carrots. Drainage of excess coating was aided by blowing 20°C air for 5 min over the carrots. Emulsions had a milky appearance; but after drying, films and coatings were transparent.

**WATER VAPOR RESISTANCE**

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

\[ r = \left( Aw \times \frac{\% RH}{100} \right) \frac{P_{wv}}{RT} \left( \frac{\Delta}{J} \right) \]

where

- \( r \) = water vapor resistance (s/cm)
- \( Aw \) = 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 (3464.6 mm Hg cm²/g·°K)
- \( T \) = storage room temperature [275.5°C K (2.5°C)]
- \( A \) = surface area of carrot sections (cm²)
- \( J \) = slope of curve of weight loss vs. storage time for carrots (g/s)

**WHITISH INDEX**

Change of color (white blush formation) during storage of baby carrots was evaluated using a Minolta chromometer CR200 (Minolta Camera Co., Japan) by determining L, a, and b (Hunter) from the CIE (Commission Internationale de l'Eclairage) color scale (Gardner, 1975) after calibration before each testing session with a standard orange tile. A whitish index (Wi) was estimated according to Judd (1963):

\[ Wi = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \]

Whitish index was evaluated every two days for two weeks on coated and uncoated (control) carrots packaged in batches of 500 g in 1.5-mil LDPE bags stored at 10°C. Packaged carrots were sealed using an impulse heat sealer. Bags were stored in such a way that each bag was exposed to the open atmosphere in a dark room, not piled on other bags. Color was measured on the surfaces of carrots facing the package film. Twenty carrots were taken out of bags for each treatment at each storage time, averaging three color measurements on the surface of each carrot. Opened bags of carrots were discarded after each measurement.

**SENSORY ANALYSIS**

Visual ranking of white blush intensity was performed by two judges in nine replications at each testing session. The judges evaluated samples of carrots by ranking nine 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 (10) to the sample with the most white blush. Ranking was performed on coated and uncoated carrots packaged in LDPE bags stored in a room at 10°C and 85% RH. Color ranking was performed on packaged carrots positioned facing the package film.

**RESPONSE SURFACE METHODOLOGY**

On the basis of response surface methodology (Montgomery, 1984), quantitative data was used to build empirical models to describe the relationships between the amount of sodium caseinate and stearic acid on water vapor resistance, whitish blush, or sensory ranking of whitish blush in coated carrots. The RSREG procedure from SAS/STAT (SAS, 1990) was used to fit the second-order polynomial regression to experimental data. Three-dimensional surfaces were generated using the G3D procedure from SAS/GRAPH (SAS, 1985). Levels of sodium caseinate and stearic acid were presented on horizontally perpendicular axes; the response variable (water vapor resistance, whitish blush or ranking of whitish blush) was presented on the vertical axis.
RESULTS AND DISCUSSION

WATER VAPOR RESISTANCE

A simple linear regression analysis of weight loss versus time was performed for 10 replicates for each treatment. Water loss followed a linear relationship with time at \( P < 0.001 \) and its slope in g/h provided the water vapor transmission rate. Water vapor resistance, in s/cm, was calculated for the coated and uncoated carrots (fig. 1). As expected for a peeled vegetable, water vapor resistance was very low compared with unpeeled vegetables (Cameron and Reid, 1987). Analysis of variance and Duncan’s multiple range test (SAS, 1990) indicated that all coating treatments except T9 (2% SC/1% SA) had significantly higher water vapor resistance than the control at the 5% level.

Comparing resistance values for coated and uncoated carrots indicated that it was possible to increase by 65% the water vapor resistance of baby carrots using coating T3 (0.75% SC/0.25% SA) formulation.

A saddle-type response surface defines the effect of coating peeled carrots with different formulations of sodium caseinate/stearic acid emulsions on water vapor resistance (fig. 2). An estimated ridge of maximum response of 14.4 s/cm for water vapor resistance is predicted for a 1.4% SC/0.1% SA emulsion coating. RSM indicated that water vapor resistance can be increased 84% with this formulation. The surfactant nature of sodium caseinate is important to obtain a uniform emulsion coating on the peeled carrot surface and increase water vapor resistance.

EFFECT OF COATING ON WHITISH INDEX

According to whitish index results, edible coatings did not reduce white blush consistently compared to uncoated carrots during storage in LDPE bags at 10°C (fig. 3). Whitish index on day 3 was significantly lower for each treatment compared to day 5. For many treatments, the whitish index practically remained unchanged from day 5 to day 10. A higher Wi was measured on day 3 for most coated carrots compared to uncoated carrots, because the emulsion coatings were not dried and therefore imparted a milky appearance. After 10 days, carrots coated with emulsions T3 and T9 (0.75% SC/0.25% SA and 2% SC/1% SA, respectively) had a lower Wi than carrots receiving the other treatments, although not different from the uncoated carrots. Whitish index was highly variable for each treatment, including the control. Statistical difference among the different treatments was not consistent from day to day.

Response surface analysis indicated that an estimated ridge for a minimum Wi value of 38 at 10 days of storage
Figure 5—Ranking by white blush intensity of coated peeled carrots stored at 10°C for 3, 5, 7, and 10 days. High total rank sum indicates high white blush. Letters on columns indicate difference at $P < 0.05$ at each time.

Figure 7—Sensory ranking optimization for coated peeled carrots.

in LDPE bags at 10°C can be achieved using a 1.5% SC/0.15% SA emulsion coating (fig. 4).

**SENSORY ANALYSIS**

Using the Newell-MacFarlane two-factor ranked nonparametric analysis of variance (Newell and MacFarlane, 1987) with critical rank sum differences for one-sided "treatments versus control" comparisons were used at the 5% level of significance. Most of the edible coatings, except T1, T7, and T8, were consistently visually ranked significantly lower ($P < 0.05$) in white blush than uncoated carrots (fig. 5). The T2 to T6 and T9 coatings were ranked significantly with less white blush than uncoated peeled carrots in a consistent fashion during the entire testing period, except on day 3. Visual ranking on day 3 reflects the fact that the emulsion coating was not completely dried, resulting in a milky appearance. This disappeared on day 5, as is evident from the visual ranking and instrumental $W_i$ results.

There was a significant positive correlation at $P < 0.005$ (Montgomery, 1984) between subjective evaluation of white blush and the computed $W_i$ on the last two measurements (days 7 and 10). According to the coefficient of determination ($r^2$), 64% of $W_i$ values were linearly correlated with total rank sum after seven days of storage (fig. 6). Also, according to the fitting lines in figure 6, $W_i$ increased significantly from day 3 to day 5; but $W_i$ was not significantly different for day 5, compared to day 7 and day 10 of storage. Large standard deviations occurred within each treatment as a result of position of the carrot in the bags, degree of abrasion, and normal color variability. Also, because white blush was uneven on the surface of carrots, judges integrated overall color information of carrots more efficiently than instrumental analysis could have. Thus, we concluded that a properly performed sensory analysis could be more sensitive and reliable for assessing white blush conditions than the calculated $W_i$. Klein (1987) indicated that conditions that preserve sensory quality of minimally processed fruits and vegetables also maintain nutritional value.

Response surface analysis of total rank sum values at day 10 of storage for the different emulsion coating formulations indicated that an estimated ridge of minimum response for total rank sum can be achieved using a 1.6% SC/0.2% SA emulsion coating (fig. 7).

**CONCLUSIONS**

The effect of different sodium caseinate/stearic acid emulsion coatings on three different response parameters (water vapor resistance, whishit index and sensory ranking of white blush) indicated that storage stability of peeled carrots can be improved with an optimized 1.4 to 1.6% SC/0.1 to 0.2% SA emulsion coating formulation. Canonical analysis indicated a saddle-shaped response surface for optimization of coating formulations for peeled carrots based on the three different response variables. In a saddle-shaped response surface, ridge analysis for minimum response is not unique (SAS, 1990). It is possible that a coating formulated with pure caseinate could perform at least as well as the emulsion coatings tested.

It is hypothesized that hydrophilic coating materials, such as sodium caseinate, help to moisturize the carrot surface, reducing white blush formation. The working mechanism to achieve this objective could be related to the sorption properties of the hydrophilic coating materials rather than to their water-barrier properties.

Sensory ranking appears to be a powerful technique to evaluate white blush on peeled carrots. Instrumental color

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*Sensory ranking optimization for coated peeled carrots.*

*Response surface analysis of total rank sum values at day 10 of storage for the different emulsion coating formulations indicated that an estimated ridge of minimum response for total rank sum can be achieved using a 1.6% SC/0.2% SA emulsion coating (fig. 7).*
measurement of whitish index is less sensitive due to the large variability of color according to different degree of abrasion on carrot surfaces and the position of carrots in polymeric packages.

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REFERENCES


