Using Edible Coating to Enhance Nutritional and Sensory Qualities of Baby Carrots

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ABSTRACT: Xanthan gum coating was used to carry 5% Gluconal Cal, a mixture of calcium lactate and gluconate, and 0.2% α–tocopheral acetate (vitamin E) by weight, respectively. Peeled baby carrots were dipped in the coating solutions, dried, and then stored at 2 °C and 85% relative humidity for up to 3 wk. Calcium and vitamin E contents of the coated samples, per serving (85g), increased from 2.6% to 6.6%, and from 0 to about 67% of the Dietary Reference Intakes (DRI) values respectively. Edible coatings ($p<0.05$) improved the desirable surface color of carrots without effects ($p<0.05$) on the taste, texture, and fresh aroma and flavor except for a slightly slippery surface. The β–carotene level in the baby carrots ($p<0.05$) was not affected by edible coating.

Keywords: calcium, α–tocopheral, baby carrots

Introduction

WHITE DISCOLORATION ON THE SURFACE OF PEELED BABY CARROTS is the result of reversible surface dehydration and irreversible formation of lignin, which reversibly affect their storage quality and shelf life (Bolin and Huxsoll 1991; Howard and Griffin 1993; Cisneros-Zevallos and others 1995). Edible coatings have been applied to the surface of fresh carrots to control white surface discoloration by acting as moisture barrier or surface moisturizer (Avena-Bustillos and others 1993a,b; Howard and Dewi 1995, 1996; Cisneros-Zevallos and others 1997; Li and Barth 1998). An edible coating can also be used as an effective carrier of many functional ingredients, including antimicrobial agents, antioxidants, flavorings, and colorants (Chen, 1995). Integration of these minor ingredients can enhance food stability, quality, functionality, and safety. While an edible coating served as carrier of nutritional ingredients, it will provide an excellent vehicle to enhance the nutritional value of foods by adding nutrients that are present in low quantity.

There has been increased consumer interest in the health-enhancing role of specific foods or physiologically-active food components, so–called nutraceuticals or functional foods (Hasler 1998). Nutraceuticals are natural, bioactive chemical compounds that have health promoting, disease preventing, or medicinal properties. Calcium and vitamins have been identified as important nutraceuticals and play a significant role in the human body to prevent certain diseases (Pszczola 1998; Elliott 1999). Calcium is a common intracellular messenger, a cofactor for extracellular enzymes and proteins, and also is essential for the development of bone and teeth (Weaver and Heaney 1998). Deficiencies in calcium result in bone and tooth diseases, and increased risk of hypertension, preeclampsia, and colon cancer. The Dietary Reference Intakes (DRI) for calcium are 1300 mg/d for individuals aged 9-18 years, 1000 mg/d for adults aged 19 to 50 years old, and 1200 mg/d for individuals over the age of 51 years (FNB 1999).

Vitamin E functions in vivo as a chain-breaking antioxidant that prevents propagation of free radical damage in biologic membranes, and is believed to protect the human body against certain types of cancers, cardiovascular disease, cataracts, arthritis, diabetes, and Alzheimer's disease (Elliott 1999). The most recent Dietary Reference Intake (DRI) for vitamin E is 15 mg/d (220 IU/d) for both men and women (FNB 2000). High intakes and high serum vitamin E levels have been associated with reduced risk for coronary heart disease in men and women, reduced risk of prostate cancer, and may slow progression of Alzheimer's disease (Meydani and Hayes 1999). Vitamin E is relatively safe compared to other fat-soluble vitamins.

Peeled baby carrots are high in nutrients, such as vitamin A and carotene, vitamin C, and dietary fiber, but a poor source of calcium and vitamin E. According to USDA Nutrient Database for Standard Reference Release 14 (2001) (http://www.nal.usda.gov/fnic/foodcomp/Data/SR14/sr14.html), 100 g of edible baby carrots contains about 23 mg of calcium and a negligible amount of vitamin E. A serving of carrots only affords about 2% DRI for calcium and 0% DRI for vitamin E, respectively. The use of edible coatings as carriers of calcium and vitamin E on fresh baby carrots is a natural extension of their barrier property, and would further enhance and expand the functionality of edible coatings by providing additional health benefits to consumers. The objectives of this study were to develop the formulation of edible coatings for incorporating calcium and vitamin E, and to demonstrate the feasibility of applying these coatings on peeled baby carrots.

Materials and Methods

Materials

The materials used for coating were xanthan gum (Supra, Rhodigel, Rhodia, Cranbury, N.J., PA., U.S.A.), α–tocopheral acetate (Sigma, St. Louis, Mo., U.S.A.), acetylated monoglyceride (Danisco, New Century, Kans., U.S.A.) and Gluconal Cal (Glucona America Inc., Janesville, Wis., U.S.A.). Xanthan gum is an anionic polymer with cellulosic backbone substituted on alternate glucose residues with a trisaccharide side chain. Gluconal Cal is a mixture of calcium lactate and calcium gluconate, and has water solubility up to 40 g /100 mL with neutral taste. α–tocopheral acetate is a very stable form of vitamin E,

which exhibits vitamin E activity and in vivo antioxidant effects as the result of enzymatic cleavage of the acetate ester (Gregory III, 1996).

Preparation of coating solutions

Xanthan gum coating was prepared by dissolving 0.3% xanthan gum into distilled water. Xanthan gum/vitamin E coating was manufactured by the following steps: 1) heating 1 liter of 0.3% xanthan gum solution to 60 °C; 2) dissolving 0.2% α–tocopherol acetate into 0.8% of acetylated monoglyceride based on the weight of xanthan gum solution prepared as above; and 3) integrating dissolved α–tocopheral acetate into xanthan gum solution, and homogenizing the mixture using a homogenizer (Brinkman Model PT10/35, Westbury, N.Y., U.S.A.) for 1 min with the speed setting of 5. Xanthan gum/calcium coating was prepared by dissolving 5% Gluconal Cal into the xanthan gum solution prepared in step 1). All ratios in this study were on the weight basis.

Sample preparation

Peeled baby carrots (unknown cultivar) packaged in polyethylene bags were purchased from a local supermarket when it arrived immediately from the supplier. It was confirmed from the supplier that no prior treatments had been applied on the carrots except washing. Carrot samples were carefully selected for uniformity and randomly assigned for 4 dipping treatments: distilled water used as control, 0.3% xanthan gum solution, 0.3% xanthan gum carrying 0.2% α–tocopheral acetate, and 0.3% xanthan gum carrying 5% Gluconal Cal. Carrot samples were dipped in above solutions for 30 s, drained on a stainless steel grill for 1 h at ambient condition, and then packaged in perforated low density polyethylene bags (S.C.Johnson and Sons, Inc.) Racine, Wis., U.S.A.). All samples were stored on racks of a cooler at 2 °C and 85% RH without light. Samples were removed at the end of 7, 14, and 21 d for color measurement and sensory evaluation, and also were removed on 1, 7, 14, and 21 d for β–carotene and α–tocopheral acetate analyses. As calcium is a stable mineral, calcium determination was only conducted on 1 and 21 d. Four replications for each measurement were conducted where each replication used 2 to 10 carrot subsamples based on specific measurement described below.

Color measurement

A Minolta Spectrophotometer (model CM-508d, Minolta Co., Ltd., Ramsey, N.J., U.S.A.) was used for color evaluation on L (lightness), a (redness), and b (yellowness) values. Two readings on different sites of each carrot were averaged for color measurement of 1 carrot. Ten carrots from each treatment were used for 1 replication. The severity of surface white coloration was estimated by Whiteness Index (WI, in the range of 0 to 100), which is expressed as (Bolin and Huxsoll, 1991):

$$WI = 100 - ((100 - L)^2 + a^2 + b^2)^{0.5}$$

The numerical scale of WI is from 0 to 100, where higher WI values represent more severe white surface discoloration.

Sensory evaluation

Sensory quality of carrots was conducted at 1, 2, and 3 wk of storage. The sensory panel utilized was composed of 10 trained panelists from the faculty, staff, and graduate students of the Nutritional Science Department, University of Connecticut. Panelists were selected and trained by a procedure as described by Lawless and Heymann (1999). Sensory quality attributes applied in this study include white surface discoloration, orange color intensity, fresh aroma, fresh flavor, bitterness, sweetness, crispness, and slipperiness. An unstructured 10 points scale was used with 0 = none, and 10 = intense. Carrots from each treatment were coded with different 3-digit random numbers and placed at room temperature under fluorescent light for evaluation. Panelists were served with 8 carrots at each session, 2 from each treatment. Panelists were asked to rinse their mouths with distilled water and use crackers between tasting different samples. Four replicates were performed for sensory quality evaluation.

β–carotene and α–tocopheral acetate analysis

The analyses of β–carotene and α–tocopheral acetate were conducted using a modified method from Howard and Dewi (1996). Fifty g of the carrot tissue from each treatment was ground in a Handy chopper (Black & Decker, Shelton, Conn., U.S.A.). A 10-g sample was then homogenized in 70 mL acetone containing 0.04 g BHT and 1 g $MgCO_3$. After filtering through Na2SO4 on Whatman #4 filter paper, the residue was re-homogenized and re-filtered until the remaining residue was colorless. Filtrates were concentrated using hexane on a rotary vacuum evaporator (Dietz and others 1988) where the temperature was set to be 40 °C to speed the concentration. The filtrates were then pooled and adjusted to 100 mL with hexane. Twenty-five mL of the filtrate was injected into a HPLC system for analysis. β–carotene and α–tocopheral acetate were simultaneously measured using external standards by reversed-phase HPLC utilizing isocratic elution with 2 detectors. The HPLC system used in this study included a Waters model 510 pump and an automated injection system (Model 717, Waters Associates, Milford, Mass., U.S.A.), connected in series to 2 absorbance detectors, 1 detector set at 450 nm for β–carotene and the other set at 285 nm for α–tocopheral acetate measurement. A C–18 5mm Varian column (Varian Analytical Instruments, Walnut Creek, Calif., U.S.A.) was used, and the mobile phase for chromatography was acetonitrile/dichloromethane/methanol/1–octanol (90:15:10:0.1, v/v/v/v), which was filtered through a 0.45mm nylon filter before use (Barua and others 1993). The flow rate was adjusted to 1.5 mL/min. For carotene analysis, only β–carotene was quantified since it is the predominant carotenoid present in the carrots.

Calcium determination

A representative sample of up to 0.5 g from each treatment was put in a fluorocarbon microwave vessel with 10 mL of concentrated nitric acid. The digestion was performed with the vessel capped and heated using microwave heating in a discreet flow automated microwave digestion unit (Qprep 5000, Ques-Tron Technologies Corporation, Mississauga, Ontario, Canada) for 30 min. After cooling, the vessel contents were filtered and adjusted to 100 mL for analysis by Inductively Coupled Plasma Optical Emission Spectrometer (Perkin Elmer Optima 3300XL, Shelton, Conn., U.S.A.), which measured characteristic emission spectra by optical spectrometry according to Method 6010B in SW-846 (EPA 2000)

Statistical analysis

Data were analyzed by analysis of variance (ANOVA) using SAS (SAS 1988). General linear model (GLM) procedures were performed ($p<0.05$) for all the treatments at different sampling times.

Results and Discussion

Nutritional enhancement

For 1 serving (equal to 85 g) of peeled baby carrots, coating treatment increased calcium content from 2.6% to 6.6% of DRI values (based on 1000 mg/d), and vitamin E content from 0 to more than 67% of DRI values (based on 15 mg/d) (Table 1). The calcium source used in this study is a mixture of calcium lactate and calcium gluconate, and contains about 10.75% pure calcium by weight. Calcium gluconate is recognized as GRAS (Generally Recognized As Safe 2001) by FDA for a Direct Food Additive. It is the preferred intravenous preparation for the treatment of hypocalcemia and available as an oral or intramuscular preparation (Levenson and Bockman 1994). Calcium lactate is listed as a nutrient supplement. It has good solubility and bioavailability in comparison with other organic calcium salts (Sheikh and others 1987).

Table 1—Calcium and vitamin E contents in 1 serving (=85 g) coated and uncoated carrots relative to the DRI value during storage.

Storage Time	Ca Contents (mg)	DRI (%) (1000mg/d)	VE Contents (mg)	DRI (%) (15mg/d)
0 wk	26[a]	2.6[a]	0.00[a]	0.0[a]
1st wk	66[b]	6.6[b]	11.75[b]	75.1[b]
2nd wk	66[b]	6.6[b]	10.05[b]	67.0[b]
3rd wk	66[b]	6.6[b]	12.15[b]	81.2[b]

[a–d] Mean values with different superscript letters in the same column are different ($p<0.05$).

Physiological changes

Edible coating treatment did not affect the β–carotene levels in mini-peeled baby carrots during storage (Figure 1). Statistical analysis did not reveal differences on different coating treatments or storage time (wet weight basis) ($p<0.05$). Howard and Dewi (1996) reported that β–carotene levels in carrots fell dramatically within 3 d after peeling, then stayed stable when carrots were stored at 2°C. Samples used in this study were obtained from a local supermarket where they had been peeled for a few days without using prior treatments according to the supplier and store. Similar results were observed on the dry weight basis, as the moisture loss was less than 1% during the entire storage period in this study.

Whiteness index (WI) and moisture content retention

Whiteness Index indicates the development of white surface discoloration. The higher the WI score, the more severe the white discoloration. All coating treatments resulted in significantly lower WI scores than the controls (Figure 2). At the end of 3 wk storage, WI of the control samples increased from about 30 to 38.6, while the WI of xanthan gum/vitamin E coated samples increased to 31.5, xanthan gum alone treated samples increased to 30.2, and xanthan gum/calcium coated ones decreased to 29. White surface discoloration was significantly retarded by using edible coating to limit the surface moisture loss, which is consistent with our sensory study discussed later and with previous study (Li and Barth 1998).

Edible coating has been used as water barrier to retard the surface moisture loss on fresh fruits and vegetables. Difference in the moisture loss during storage among coated and control samples were not found in this study. Considering the main reason for white discoloration is surface dehydration, it can be concluded that edible coating retarded whitening by acting as surface moisturizer (Cisneros-Zevallos and others 1997) or by physically filling the air-filled surface tissue of the abraded carrots (Li and Barth 1998). Thus, the more surface moisture the coating holds, the higher the WI scores. Xanthan gum is a cellulose derivative, and Gluconal Cal is a calcium salt. Both of them can act as humectants because of their hydrophilic properties, thus keeping the peeled surface of carrots moist to retard white discoloration. Among the 3 coating treatments, xanthan gum/calcium treatment had the greatest moisture-holding capacity, and xanthan gum/vitamin E treatment had similar moisture-holding capacity to treatment with xanthan gum alone. As shown in this study, surface moisture content affected WI scores before surface white discoloration was noticed. Lower moisture content increased "a" and "b" values, but decreased "L" values, thus decreased WI scores eventually. This explains why WI scores decreased on coated samples at the end of the 1st wk storage. Moisture-absorptive capacity of humectants is dependant upon the relative humidity and temperature (Cisneros-Zevallos and others 1997). With ambient relative humidity and temperature (about 50% RH, 23 °C), edible coating holds less moisture, thus

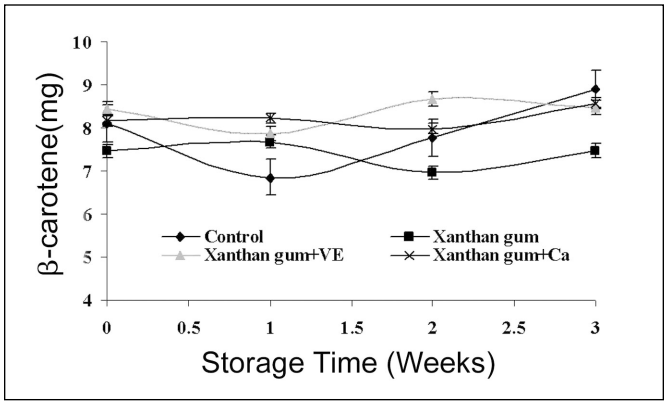

Figure 1—β–carotene retention on coated and uncoated carrots during storage at 2 °C and 85% RH. Data are average of 4 replications ± standard deviation.

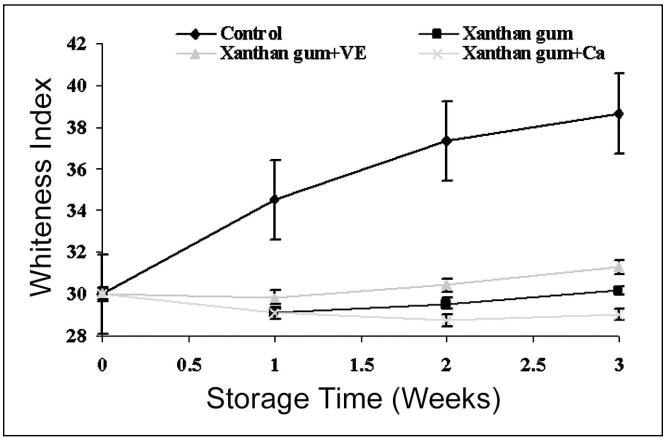

Figure 2—Whiteness Index changes in coated and uncoated carrots during storage at 2 °C and 85% RH. Data are average of 4 replications ± standard deviation.

Table 2—Effects of edible coatings on sensory attributes of baby carrots during storage*

Time	Treat+	White Discoloration	Orange Intensity	Crispness	Sweetness	Bitterness	Fresh Aroma	Fresh Flavor	Slipperiness
1stweek	1	3.83^{a}	4.54^{c}	5.88^{a}	5.13^{a}	1.92^{a}	5.76^{a}	5.7^{a}	1.91^{c}
	2	1.68^{bc}	6.45^{ab}	5.92^{a}	4.52^{ab}	1.99^{a}	4.83^{ab}	5.25^{a}	5.14^{b}
	3	2.48^{b}	6.03^{b}	6.06^{a}	4.48^{ab}	2.23^{a}	4.43^{b}	4.89^{ab}	6.58^{a}
	4	0.92^{c}	7.27^{a}	6.13^{a}	4.03^{b}	2.98^{a}	3.83^{b}	3.89^{b}	7.57^{a}
2ndweek	1	6.11^{d}	3.82^{d}	5.67^{a}	6.16^{c}	1.71^{b}	4.78^{ab}	4.82^{ab}	1.12^{d}
	2	2.36^{b}	6.49^{ab}	5.42^{a}	5.31^{a}	1.93^{ab}	5.68^{a}	5.71^{a}	3.10^{c}
	3	2.29^{b}	6.19^{b}	5.61^{a}	4.48^{ab}	1.95^{ab}	5.41^{ab}	4.66^{ab}	5.27^{b}
	4	1.40^{c}	7.44^{a}	6.01^{a}	4.41^{ab}	2.83^{a}	4.39^{b}	3.91^{b}	6.76^{a}
3rdweek	1	6.19^{d}	3.52^{c}	5.69^{a}	5.40^{ac}	2.20^{a}	4.72a^{b}	4.33^{ab}	1.22^{d}
	2	2.41^{b}	6.44^{ab}	6.06^{a}	5.53^{ac}	2.17^{a}	4.51^{b}	6.39^{a}	3.23^{c}
	3	2.39^{b}	6.40^{ab}	6.02^{a}	5.24^{a}	2.07^{a}	5.72^{a}	5.08^{bc}	5.10^{b}
	4	0.90^{c}	7.39^{a}	5.59^{a}	4.90^{ab}	2.93^{a}	5.52^{ab}	5.54^{a}	6.62^{a}

a–d Mean values with different superscript letters in the same column differ ($p<0.05$).
* Sensory scale: 0 = none, 10 = intense.
+ Treatment: 1 = control, 2 = xanthan gum alone, 3 = xanthan gum/vitamin E, 4 = xanthan gum/calcium.

can't improve moisture loss. Packaging samples in low density polyethylene (LDPE) bags and storage in a cooler with high relative humidity are essential to keep the high moisture retention on the surface of the carrots because of the adequate performance of the hygroscopic materials.

Sensory quality attributes

Results on the sensory quality attributes of coated and control samples are shown in Table 2. All coated samples had lower scores on white surface discoloration and higher scores on orange color intensity. Xanthan gum/calcium coating resulted in best color attributes. No differences on crispness were identified among coated and control samples. During the 1st wk storage, xanthan gum/calcium coating resulted in lower sweetness score than other coating treatments. During the 2nd wk storage, control samples had higher sweetness scores than samples subjected to edible coatings. But there were no difference by the 3rd wk storage. There were no differences in the score of bitterness among all the treatments except during the 2nd wk. Coated samples had similar fresh aroma and flavor to control ones during 3 wk storage, but had relatively higher slipperiness scores due to the hydrophilic properties of xanthan gum and calcium salts. The order of the slipperiness scores for different treatments is: xanthan gum/calcium > xanthan gum/vitamin E > xanthan gum > control.

Considering panelists' comments about the severe adverse affects of slipperiness, future work is needed to improve this property. Improving drying process or modifying coating formula may do this. For example, drying at high RH for long time may better control the surface moisture of coated samples, thus decreasing the surface moisture without presence of white discoloration. Modifying coating formula to adjust the amount of each ingredient or include other ingredients may also help reduce the slipperiness.

Conclusions

EDIBLE COATINGS CAN BE USED AS CARRIERS OF CALCIUM AND vitamin E to enhance the nutritional value of fresh mini-peeled carrots in addition to their primary moisture barrier or surface moisturizer function. The integration of calcium and vitamin E into edible coating didn't affect its basic functional properties. All coating treatments maintained high moisture at the abraded carrots' surface, thus effectively controlled dehydration and white surface discoloration. Coating treatments did not significantly affect fresh aroma, fresh flavor, sweetness, crispness, and β–carotene level of the carrots. Coating treatment increased the slipperiness of the carrots, which can be reduced by improving the surface drying technique or modifying formula.

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