Carotenoid Content, Physicochemical, and Sensory Qualities of Deep-Fried Carrot Chips As Affected by Dehydration/Rehydration, Antioxidant, and Fermentation

Ahmad Sulaeman,[†] Laurie Keeler,[§] Steve L. Taylor,[‡,§] David W. Giraud,[†] and Judy A. Driskell*[,†]

Department of Nutritional Science and Dietetics, Department of Food Science and Technology, and Food Processing Center, University of Nebraska, Lincoln, Nebraska 68583

Carrot slices were subjected to one of the following experiments prior to deep-frying: (A) dehydration/rehydration, (B) soaking in different antioxidants, and (C) fermentation with/without blanching. There were no significant differences ($P \geq 0.05$) in carotenoid contents among carrot chips treated with/without dehydration. Soaking in sodium metabisulfite resulted in the highest carotenoid content and lightness (*L*), redness (*a*), and yellowness (*b*) values among the antioxidant treatments. Fermentation without blanching significantly decreased ($P < 0.05$) carotenoid content, vitamin A activity, and fat content. Dehydration and fermentation with blanching significantly increased ($P < 0.05$) the lightness (*L*), redness (*a*), and yellowness (*b*) values of the chips. Dehydration/rehydration, but not antioxidant and fermentation, significantly decreased ($P < 0.05$) the water activity of the chips. The textural values of carrot chips prepared using sodium metabisulfite, without dehydration and without fermentation, were the lowest among other treatments which suggests the crispiest. Carrot chips prepared using sodium metabisulfite, without dehydration and without fermentation, had the highest carotenoid content and retention, and the highest overall acceptability score.

Keywords: *Carrots; chips; carotenoids; color; sensory qualities; fermentation*

INTRODUCTION

Vitamin A deficiency is the leading cause of blindness in children in developing countries. Dietary intervention with foods rich in provitamin A carotenoids has been suggested as one solution to this problem (*1*). In addition, due to its antioxidant activity, foods rich in provitamin A carotenoids and other carotenoids may also be beneficial in preventing major health problems in developed countries such as cancer, cardiovascular/coronary heart diseases, and other diseases (*2*, *3*).

Carrots have the highest carotene content among human foods (*4*). In the U.S., carrots are a principle vegetable crop, contributing 14% of the total vitamin A consumption (*5*). Efforts have been made to prepare high carotenoid food product from carrots. Dried carrot slices (*6*), carrot juice (*7*, 8), and carrot chips (9−*11*) have been produced. However, the carotenoid bioavailability from plant sources depends, among other factors, on the dietary fat concentration (*12*, *13*) and on the type and extent of processing (*14*). Skrede et al. (*15*) and Sulaeman et al. (*11*) reported that the carotenoid levels of carrots were well retained during the processing of deep-fried carrot chips, and the chips contained high levels of fat which may further improve the ability of carrot chips to serve as a source of provitamin A for humans.

A previous study in our laboratory (*11*) demonstrated that deep-frying of carrot slices in partially hydrogenated soybean oil at 165 °C resulted in the highest carotenoid content and the most preferred carrot chip product. However, to further improve and to find other alternative methods in preparing deep-fried carrot chips, additional research was undertaken. Several promising pretreatments were investigated including dehydrating the carrot slices prior to frying, which has been applied with potato chips (*16*), a fermentation step to reduce the sugar content (9), and the soaking of carrot slices in different types of antioxidants.

The purpose of the present study was to evaluate the influence of the following pretreatments prior to deep-frying of the carrot slices: dehydration/rehydration, the soaking in different antioxidants (sodium metabisulfite, erythorbic acid, L-cysteine, and salt brine), and fermentation (with *Lactobacillus sakei* and *L. plantarum*) with or without blanching, on carotenoid content, physicochemical, and sensory qualities of deep-fried carrot chips.

MATERIALS AND METHODS

Materials. Fresh jumbo carrots (*Daucus carota* cv. Navajo) harvested in Bakersfield, CA, were purchased from Grimmway Farms (Bakersfield, CA). The roots were stored in plastic bags in the dark at 0−2 °C (*17*) and 98% relative humidity (RH) for 1−2 months prior to processing. The oil utilized was partially hydrogenated soybean oil (PHSO) (Bunge Food, Bradley, IL). *L. sakei* (ATCC 15521) (ATCC, Manassas, VA) and *L. plantarum* (ATCC 4008) were used in the fermentation experiment. Cells were grown in Lactobacilli MRS Broth (Difco Laboratories, Detroit, MI) harvested in logarithmic growth phase by centrifugation (10000*g* for 5 min) and resuspended in 0.9% saline to obtain 10^7 cells/mL, as indicated by an absorbance equal to 0.1 at 600 nm in a spectrophotometer (Beckman DU 640, Beckman Instruments Inc., Fullerton, CA) (*18*).

* To whom correspondence should be addressed. Dr. Judy A. Driskell, Department of Nutritional Science and Dietetics, University of Nebraska, Lincoln, NE 68583-0806 U.S.A. Phone: 402-472-8975. Fax: 402-472-1587. E-mail: jdriskell@unl.edu.

[†] Department of Nutritional Science and Dietetics.

[§] Food Processing Center.

[‡] Department of Food Science and Technology.

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All-trans-β-carotene was purchased from Sigma (St. Louis, MO) and *all-trans*-α-carotene, from Carolina Chemical Purities (Cary, NC). The identities and concentrations of the working standards were confirmed spectrophotometrically (Beckman DU 640, Beckman Instruments Inc., Fullerton, CA) using previously reported extinction coefficients (*19*). All HPLC grade solvents (acetonitrile, tetrahydrofuran, methanol, and hexane) were obtained from Fisher Scientific Co. (Fair Lawn, NJ). The HPLC grade solvents were degassed under vacuum and filtered through a 0.45-μm membrane filter (Pall Gelman Laboratory, Ann Arbor, MI) prior to use.

Carrot Chip Production. Carrots were trimmed and cut into 55 mm lengths and mechanically peeled using a Hobart Peeler Machine (Hobart Manufacturing Co., Troy, OH) at the lowest speed for 1 min and then sliced into 1.5 mm thickness using a Dito Dean Slicer model TR-22 (Dean Food Preparation, Los Angeles, CA). The carrot slices were then subjected to the following experiments.

Experiment A: Effect of Dehydration and Rehydration. The purpose of this experiment was to determine if dehydration and rehydration prior to deep-frying will beneficially influence the quality of carrot chips, reduce the frying time, and minimize the loss of carotenoids. The carrot slices were steam-blanched for 4 min, cooled under running tap water for 4 min, soaked in 0.2% (w/v) sodium metabisulfite solution for 15 min, drained, and then were subjected to the following treatments:

(i) Control, not dehydrated but fried directly.

(ii) Partially dehydrated (40 °C for 2 h) and then fried.

(iii) Dehydrated in cabinet drier (40 °C until moisture content was <10%) and rehydrated in distilled water at room temperature for 5 min prior to frying.

(iv) Dehydrated in cabinet drier (40 °C until moisture content was <10%) and rehydrated in boiling distilled water for 1 min prior to frying.

The slices were deep-fried in PHSO using a Toastmaster Fryer model 1427 (Elgin, IL) at 165 °C for 5 min (*11*) or until there were no visible bubbles due to residual water (*9*). The fried carrot chips were drained on paper towels and shaken with 1.0% (w/w) NaCl. On the basis of the carotenoid, physicochemical, and sensory findings of this experiment, the decision was made to neither dehydrate nor rehydrate the carrot slices in experiment B.

Experiment B: Effect of Soaking in Different Antioxidants. The purpose of this experiment was to determine the best antioxidant to be used in soaking the carrot slices prior to deep-frying. The carrot slices were steam-blanched for 4 min, cooled under running tap water for 4 min, and soaked in either: 0.2% (w/v) sodium metabisulfite for 15 min; 1.5% (w/v) salt brine for 30 min; 0.3% (w/v) erythorbic acid for 15 min; 5.0 mM L-cysteine for 30 min.

After draining, the slices were then deep-fried in PHSO as described above, drained on paper towels, and shaken with 1.0% (w/w) NaCl. On the basis of the carotenoid, physicochemical, and sensory findings, the decision was made to use sodium metabisulfite for soaking the carrot slices in the control treatment in experiment C.

Experiment C: Effect of Lactic Acid Fermentation with or without Blanching. The purpose of this experiment was to evaluate if a lactic acid fermentation and blanching prior to deep-frying is beneficial in improving the quality of carrot chips. In this investigation, the carrot slices were subjected to the following treatments:

(i) Control, steam-blanched for 4 min, soaked in 0.2% (w/v) sodium metabisulfite, drained, and deep-fried as described before.

(ii) Carrot slices in 10 L bucket were covered with 0.9% saline (w/v) at ratio of 1:1.5 and held at 25 °C for 24 h. The slices were rinsed with running tap water, drained, and then deep-fried as described previously.

(iii) Carrot slices in 10 L bucket were covered with 0.9% saline (w/v) at ratio of 1:1.5 preinoculated with *L. sakei* (10^7 cells/mL) and fermented at 25 °C for 24 h. After rinsing with running tap water and draining, the carrot slices were deep-fried as previously described.

(iv) Carrot slices in 10 L bucket were covered with 0.9% saline (w/v) at ratio of 1:1.5 preinoculated with *L. plantarum* (10^7 cells/mL) and fermented at 25 °C for 24 h. After rinsing with running tap water and draining, the carrot slices were deep-fried as previously described.

(v) Carrot slices were steam-blanched, cooled in running tap water, put in 10 L bucket, covered with 0.9% saline (w/v) at ratio of 1:1.5, and fermented at 25 °C for 24 h. After rinsing with running tap water and draining, the carrot slices were deep-fried as previously described.

(vi) Carrot slices were steam-blanched, cooled in running tap water, put in 10 L bucket, covered with 0.9% saline (w/v) at ratio of 1:1.5 preinoculated with *L. sakei*, and fermented at 25 °C for 24 h. After rinsing with running tap water and draining, the carrot slices were deep-fried as previously described.

(vii) Carrot slices were steam-blanched, cooled in running tap water, put in a 10 L bucket, covered with 0.9% saline (w/v) at ratio of 1:1.5 preinoculated with *L. plantarum*, and fermented at 25 °C for 24 h. After rinsing with running tap water and draining, the carrot slices were deep-fried as previously described.

The carrot chips produced in the three experiments were weighed, and the total yields of carrot chips (%) were calculated as percentages of weight of fresh sliced carrots before and after deep-frying. The products were then packaged in layered film (2.50 mil, metallized polyester and linear low-density polyethylene) pouches (16.5 cm × 20.3 cm o.d.) (Kapak Co., Minneapolis, MN) using Multivac AG 500/AG900 (Multivac Inc., Kansas City, MO). The moisture and oxygen permeability of this pouch were 0.837 g/m^2/24 h (at 37.8 °C, 100% RH) and 1.2 cm^3/m^2/24 h (at 22.8 °C, 0% RH and 100% O_2), respectively, according to the manufacturer. A vacuum was pulled on the pouches that were back flushed with Nitrogen gas until the O_2 concentration of the pouches was <1% (*20*). The packaged products were stored at −50 °C until used for carotenoid, physicochemical, and sensory analyses.

HPLC Analyses of Carotenoids. The HPLC system consisted of the following Waters Associates, Inc. (Milford, MA) equipment: 600E solvent delivery system, U6K injector, 484 UV detector and 745B data integrator. The separation was carried out using a reversed-phase Microsorb-MV (5 μm, 250 × 4.6 mm) C_{18} column (Rainin, Woburn, MA) which was protected with a guard column of C_{18} materials (3 cm length × 4.6 mm i.d.) packed with spheri-5-C_{18} (5 μm particle size). The extraction of carotenoids was carried out using the modified method of Barua and Olson (*21*), and the carotenoids were separated using acetonitrile/THF/methanol/1% ammonium acetate (65:25:6:4) as the mobile phase under isocratic conditions (*22*, *23*), as previously described (*11*). Vitamin A activity was calculated as retinol activity equivalents (RAE) using 12 μg per RAE for *all-trans β*-carotene and 24 μg per RAE for *all-trans* α-carotene (*24*). The true retention values (%) of carotenoids in the carrot chips as effects of carrot chip processing were calculated as described by Murphy et al. (*25*).

Physicochemical and Sensory Analyses. Physicochemical parameters of carrot chips were measured as described previously (*11*). Color was evaluated with regard to lightness (*L*), redness (*a*), yellowness (*b*), and Hue^o ($\tan^{-1}$ *b*/*a*) using a Minolta CR300 chromameter (Minolta Co., Ramsey, NJ). The texture, based on maximum force (*F*) and work (*W*) required to break the chips, was measured using a TAXT2 Texture Analyzer (Texture Technologist Corp., Scardale, NY). An AquaLab (Decagon Devices, Inc., model CX-1, Pullman, WA) was used to measure the water activity. Fat content was measured using a Soxtec System HT6 (Tecator Inc., Herndon, VA). Moisture content was measured using an oven at 105 °C for 20−22 h. Sensory analyses were performed as previously described (*11*) using 14 trained panelists to evaluate the color, crispness, odor, sweetness, flavor, and overall acceptability of these carrot chip products.

Statistical Analyses. Carotenoid and physicochemical data from each experiment were subjected to analysis of variance (ANOVA) and a least significant difference (LSD) test to determine significant differences between treatments. A two-

Table 1. Mean Yield (%), Carotenoid Content (μg/100 g), and Vitamin A Activity (μg of RAE/100 g) of Carrot Chips As Influenced by Dehydration/Rehydration, Soaking in Different Antioxidants, and Fermentation[a]

experiment/treatment	yield	α-carotene	β-carotene	tentatively identified *cis*-9-β-carotene	total carotenes[b]	vitamin A activity
Experiment A: Effect of Dehydration/Rehydration						
raw		3558	7639	nd[c]	11197	785
not dehydrated	14.54[a]	15439[b]	40035[ab]	14205[ns]	69673[b]	3980[b]
partially dehydrated	12.23[b]	17773[ab]	39042[b]	15338[ns]	72153[ab]	3994[ab]
dehydrated rehydrated 5 min 25 °C	10.00[c]	18191[ab]	43386[a]	14536[ns]	76113[ab]	4374[a]
dehydrated rehydrated 1 min 100 °C	9.40[c]	19672[a]	42720[ab]	18283[ns]	80174[a]	4380[a]
Experiment B: Effect of Soaking in Different Antioxidants						
raw		3893	8119	nd[c]	12012	839
sodium metabisulfite	14.36[a]	15020[a]	36416[ns]	13386[ns]	64822[a]	3661[a]
saline	14.80[a]	11144[b]	27906[ns]	10084[ns]	49133[ab]	2790[ab]
erythorbic acid	13.63[b]	10800[b]	31771[ns]	11920[ns]	54491[ab]	3098[ab]
L-cysteine	13.10[b]	8831[b]	27477[ns]	8384[ns]	46071[b]	2658[b]
Experiment C: Effect of Fermentation						
raw		3671	7667	nd[c]	11338	792
not fermented	14.18[bcd]	14758[a]	43804[a]	11487[a]	70048[a]	4266[a]
not blanched/saline	19.92[a]	6692[c]	25196[d]	4448[c]	36336[d]	2379[d]
not blanched/*L. sakei*	15.87[bc]	8621[bc]	28214[cd]	4880[c]	41715[cd]	2711[cd]
not blanched/*L. plantarum*	17.13[ab]	12508[abc]	34112[bc]	8033[bc]	54653[bc]	3364[bc]
blanched/saline	12.79[d]	14578[ab]	39237[ab]	12062[a]	65877[ab]	3878[ab]
blanched/*L. sakei*	13.06[cd]	18015[a]	39788[ab]	13514[a]	71315[a]	4067[ab]
blanched/*L. plantarum*	13.14[cd]	15977[a]	36194[b]	12407[a]	64577[ab]	3681[ab]

[a] Values within a column and experiment with the same letters are not significantly different ($P \geq 0.05$). ns, not significant ($P \geq 0.05$). [b] Total carotenes = α-carotene + β-carotene + tentatively identified *cis*-9-β-carotene. [c] nd, nondetectable.

way analysis of variance (ANOVA) with treatment and judges as sources of variation and LSD tests were carried out on sensory data to determine differences among the treatments (*26*). Correlations between observed parameters were also determined. For all analyses, differences were considered significant at $P < 0.05$. All statistical analyses were conducted using SAS version 6 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Yield, Carotenoid Content, and Vitamin A Activity of Carrot Chips. The mean yield of carrot chips in all treatments and experiments ranged from 9.4 to 19.9% (Table 1). Dehydration and rehydration of carrot slices significantly decreased ($P < 0.05$) the yield of carrot chips. The lower yield of carrot chips pretreated with dehydration/rehydration may be due to the high loss of moisture during dehydration and loss of soluble solids during rehydration. Little difference occurred in yield among antioxidant treatments used in soaking carrot slices prior to deep-frying. Soaking in sodium metabisulfite and in salt brine resulted in significantly higher ($P < 0.05$) yields than with erythorbic acid or L-cysteine. Fermentation without blanching tended to result in higher yield in carrot chips as compared to those treated either with blanching but without fermentation, or with fermentation and blanching. This is reasonable as the blanching may cause the loss of soluble solids and that may decrease the yield.

The yields of carrot chips in the present study were generally higher than those reported by Baardseth et al. (*18*) using lactic acid fermentation (10.07−11.7%). Aukrust et al. (*9*), also using the fermentation technique, found the yield to be between 12.5 and 16%, depending on the initial concentration of NaCl in the brine used during fermentation. Differences in varieties of carrots, as well as in the processing methods, and the *Lactobacillus* culture used may be responsible for the differences in the carrot chip yield.

The mean carotenoid content of deep-fried carrot chips prepared by the treatments in the present study were

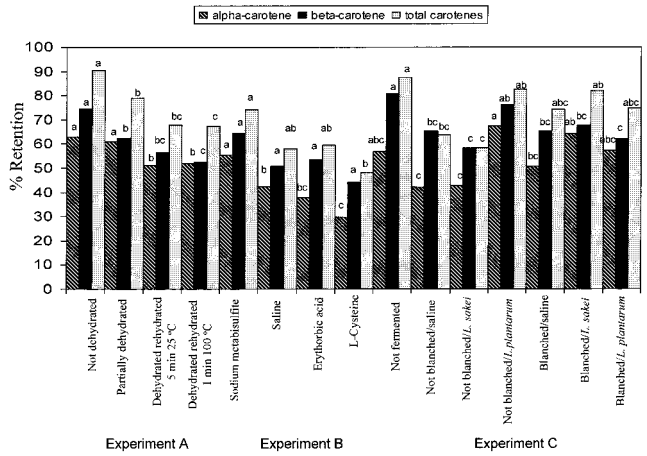

Figure 1. Mean carotenoid retention of carrot chips as influenced by dehydration/rehydration (experiment A), soaking in different antioxidants (experiment B), and fermentation (experiment C). Values within the same experiment with the same letters are not significantly different ($P \geq 0.05$).

(μg/100 g w/w) α-carotene, 6692−19672; β-carotene, 25196−43804; tentatively identified *cis*-9-β-carotene, 4448−18283 and total carotenes, 36336−80174 (Table 1). The vitamin A activity of carrot chips in the present study ranged from 2379 to 4380 μg of RAE/100 g of chips, indicating the high vitamin A potency. Dehydration, including partial dehydration at low temperature (40 °C), did not significantly decrease ($P \geq 0.05$) α-carotene, β-carotene, *cis*-9-β-carotene, total carotene content, and vitamin A activity of the carrot chips. A slight increase was noted. However, due to the lower yield, the retention of carotenoids in carrot slices treated with dehydration/rehydration were slightly lower (Figure 1). Dehydration, regardless of the drying method, significantly reduced carotene in carrots, broccoli, and spinach (*27*). Lin et al. (*6*) reported that the losses of α- and β-carotene during drying were 19.2% for air-dried samples and 3.2% for the vacuum microwave dried samples.

Carrot slices treated with sodium metabisulfite had higher, sometimes significantly, α-carotene, total carotenes, and vitamin A activity than those treated with other antioxidants and saline. Sodium metabisulfite retained the highest α-carotene, *β*-carotene, total carotenes, and vitamin A activity in the carrot chips in the present study (Figure 1). With regard to the preparation of dried carrot slices, Mohammed and Hussein (*28*) treated carrots with sodium metabisulfite and obtained a retention twice as high when compared with no metabisulfite. Zhao and Chang (*29*) found that the *β*-carotene content of 0.2% sodium bisulfite-treated carrots was higher than 2.5% corn starch-treated carrots. Krokrida et al. (*30*) used 2% sodium bisulfite solution for soaking steam-blanched carrots for 5 min prior to freeze-drying. However, the use of sulfites in food has been criticized due to some adverse reactions in sulfite-sensitive individuals (*31*). Erythorbic acid *(32*) and L-cysteine (*33*) were proposed as sulfite substitutes for the prevention of enzymatic browning in foods. No adverse effects were reported with regard the use of erythorbic acid in food (*31*). The present study indicated that erythorbic acid had a similar effect in protecting *β*-carotene, total carotene, and vitamin A activity as in carrot chips treated with sodium metabisulfite. L-Cysteine is supposed to be safe since it is a naturally occurring amino acid and has GRAS status (*33*). However, L-cysteine provided the lowest carotenoid and vitamin A protection as compared to other antioxidants in the present study. Thus, for individuals needing or wanting to avoid sulfites, the carrot chips produced using erythorbic acid may be more appropriate.

To decrease the amount of reducing sugars in carrot slices, and thus to obtain more acceptable deep-fried carrot chips, fermentation using *Lactobacillus* strain NCIMB 40450 was proposed as pretreatment before deep-frying (*11*, *19*, *36*). In the present study, alternatives to replace or improve this fermentation step were sought. Alternatives were using blanching and soaking in an appropriate antioxidant, and blanching the slices before fermentation. Our study indicated that carrot slices treated with just blanching and soaking in sodium metabisulfite (without fermentation) resulted in carrot chips with usually higher, sometimes significantly ($P < 0.05$), *β*-carotene content than those treated with fermentation with or without blanching. The treatment of blanching and soaking in sodium metabisulfite provided a better carotenoid retention than the fermentation treatment.

Fermentation without blanching significantly decreased ($P < 0.05$) *β*-carotene, *cis*-9-*β*-carotene, and vitamin A activity in the carrot chips. However, fermentation with blanching resulted in carotenoid content (i.e., α-carotene, *β*-carotene, *cis*-9-*β*-carotene, and total carotenes) and vitamin A activities which were not significantly different ($P \geq 0.05$) than the treatment of blanching and soaking in sodium metabisulfite (without fermentation). This fact showed that the blanching step improved the fermentation process, perhaps by reducing the initial microflora in the carrot slices so that the activity and the growth of inoculated *Lactobacillus* was better. Blanching also produces a gradual breakdown in the protoplasmic structure organization, with subsequent loss of turgor pressure, the release of pectic substances (*35*), and a final softening effect which facilitate the *Lactobacillus* fermentation. In addition, blanching may cause the denaturation of the carotene-binding protein, which further releases the carotenoids so that they can be easily extracted (*36*). It is evident from the present study that blanching and sulfite treatment were effective in minimizing the loss of carotenoid and vitamin A activity during deep-frying of carrot chips (Table 1).

There was no significant difference ($P \geq 0.05$) between the carotenoid content of carrot chips prepared using the two *Lactobacillus* cultures. Carrot slices treated with fermentation and blanching but without a *Lactobacillus* culture resulted in carrot chips with carotenoid content that tended to be lower than those inoculated with *Lactobacillus* culture. However, carrot chips from slices treated with fermentation and inoculated with *Lactobacillus* culture, but without blanching, had slightly higher carotenoid content than those from slices treated with fermentation but no culture inoculated and without blanching. This phenomenon indicated that in carrot chips prepared by treatment with blanching and fermentation, the effect of blanching was much greater than the effect of fermentation itself.

Carotenoid levels of carrots were well retained during the processing of carrot chips in the current study (Figure 1). In general, it was found that the treatment with just blanching and soaking in sodium metabisulfite, without dehydration, and without fermentation resulted in carrot chips with the highest carotenoid and vitamin A activity retention. On the average, for this treatment, about 85.6% of the initial total provitamin A carotenoid of the carrots was retained in the carrot chips, either in the form of α-carotene, *β*-carotene, or tentatively identified *cis*-9-*β*-carotene. These results indicated that α- and *β*-carotene in carrots were relatively heat stable during the deep-frying process. This is probably due to the presence of α-tocopherol which functions as a natural antioxidant and other antioxidants in the oil used for deep-frying. The amount of α-tocopherol in carrots is reported to be about 0.11−0.50 mg/100 g (w/w) (*37*).

Color Values. Since the color of carrots was reported to be largely due to presence of carotenoids (*7*), the color of carrot chip product, as indicated by *L*, *a*, *b*, and Hue^o values, may also reflect its carotenoid content. It is also reported the presence of the lipoxygenase system in the carrot tissue (*38*) that may contribute to the color development during carrot chip processing. In the present study, the color values of carrot chips ranged from 31.2 to 45.7 (*L*), 13.0−28.4 (*a*), 12.4−25.8 (*b*), and 39.1−47.0 (Hue^o) (Table 2). Dehydration and rehydration significantly increased ($P < 0.05$) the lightness (*L*), redness (*a*) and yellowness (*b*) but not the Hue^o values (Table 2). Meanwhile, only partial dehydration significantly increased ($P < 0.05$) the redness (*a*) value. There were no differences ($P \geq 0.05$) in *L*, *a*, *b*, and Hue^o values between carrot slices rehydrated in distilled water at room temperature and those rehydrated in boiling water. Nevertheless, the slices treated without dehydration showed the highest Hue^o value. Dehydration as a step prior to chip-making has been investigated in potato chip preparation (*16*). This is one of the ways to prevent problems due to sugar accumulation during storage and eventually browning upon frying. Dehydration of potato slices prevents the action of amylolytic enzymes on starch. As a result, sugars do not accumulate in the slices, and thus the browning of chips during frying is prevented (*16*). Since carrots also contain a significant amount of starch, similar phenom-

Table 2. Hunter Color Values[a] of Carrot Chips As Influenced by Dehydration/Rehydration, Soaking in Different Antioxidants, and Fermentation[b]

experiment/treatment	*L*	*a*	*b*	Hue°
Experiment A: Effect of Dehydration/Rehydration				
not dehydrated	39.9[b]	22.3[e]	20.6[b]	42.8[a]
partially dehydrated	40.3[b]	25.9[b]	21.0[b]	39.1[b]
dehydrated rehydrated, 5 min 25 °C	43.4[a]	28.3[a]	23.2[a]	39.7[b]
dehydrated rehydrated, 1 min 100 °C	42.8[a]	28.4[a]	23.6[a]	39.4[b]
Experiment B: Effect of Soaking in Different Type of Antioxidant				
sodium metabisulfite	41.4[a]	22.3[ab]	21.8[ab]	44.3[a]
saline	39.3[b]	21.0[bc]	20.0[b]	43.6[a]
erythorbic acid	38.7[b]	20.6[c]	19.8[b]	43.9[a]
L-cysteine	42.0[a]	22.9[a]	22.8[a]	44.9[a]
Experiment C: Effect of Fermentation				
not fermented	41.4[cd]	22.7[b]	21.8[d]	43.9[ab]
not blanched/saline	31.2[f]	13.0[e]	12.4[f]	43.8[ab]
not blanched/*L. sakei*	34.5[e]	15.9[d]	15.9[e]	45.1[ab]
not blanched/*L. plantarum*	39.7[d]	19.9[c]	21.3[d]	47.0[a]
blanched/saline	43.0[bc]	24.0[ab]	23.3[c]	44.2[ab]
blanched/*L. sakei*	44.2[ab]	26.3[a]	24.4[b]	42.9[b]
blanched/*L. plantarum*	45.7[a]	26.4[a]	25.8[a]	44.3[ab]

[a] *L* = Lightness, *a* = redness, *b* = yellowness, Hue angle = $\tan^{-1}(b/a)$. [b] Values within the column and experiment with the same letters are not significantly different ($P \geq 0.05$).

ena might have happened. Other than the benefit on the prevention of browning, the dehydrated slices could be also used in the manufacture of ready-to-fry carrot chips.

Sodium metabisulfite and L-cysteine showed the highest activity in preventing the browning reaction in the carrot chip processing. Carrot slices treated with sodium metabisulfite or L-cysteine resulted in carrot chips with the highest *L* and a values. However, there were no significant ($P \geq 0.05$) differences in the *b* and Hue° values among the carrot slices treated with different antioxidants and saline. Fermentation with blanching significantly increased ($P < 0.05$) the lightness (*L*), redness (*a*), and yellowness (*b*) but not the Hue° values of the carrot chips (Table 2). However, fermentation without blanching resulted in significantly lower ($P < 0.05$) *L*, *a*, and *b* values. The carrot chips treated with fermentation and inoculated with a *Lactobacillus* culture had higher, sometimes significantly ($P < 0.05$), *L*, *a*, and *b* values than those not inoculated with *Lactobacillus*. The effect of *Lactobacillus* inoculation was more obvious on carrot slices treated with fermentation without blanching than on those treated with fermentation with blanching.

Carrot chips treated with just blanching and soaking with sodium metabisulfite (without fermentation) had comparable *L*, *a*, and *b* values to those treated with fermentation and blanching and were even significantly higher ($P < 0.05$) than those treated with fermentation but without blanching. This finding indicated that blanching improved the effect of fermentation with/without *Lactobacillus*. Blanching followed by cooling under running tap water can result in removal of sugars and might be an effective way to control color development during frying since the reducing sugar content is normally the limiting factor which influences color development (*39*). There were no significant differences ($P \geq 0.05$) in *L*, *a*, and *b* values in carrot chips treated with blanching and fermented with *L. sakei* or *L. plantarum*; however, there were significant differences ($P < 0.05$) in those fermented without blanching. These facts demonstrated that blanching, sulfiting, as well as fermentation may minimize the browning reaction, either by decreasing the reducing sugars or by inactivating the carotenoid-destroying enzymic system (lipoxygenase).

The yellow and red color of carrot slices is attributed to the presence of carotenes (*40*), mainly *all-trans* α- and β-carotenes (*41, 42*). These two pigments account for more than 90% of the overall carotenoids in carrots (*5*). In the present study, there were positive correlations between the *L*, *a*, and *b* values of carrot chips and α-carotene content ($r_L = 0.76$, $P < 0.05$; $r_a = 0.90$, $P < 0.05$; $r_b = 0.74$, $P < 0.05$), β-carotene content ($r_L = 0.67$, $P < 0.05$; $r_a = 0.77$, $P < 0.05$; $r_b = 0.65$, $P < 0.05$), *cis*-9-β-carotene content ($r_L = 0.72$, $P < 0.05$; $r_a = 0.89$, $P < 0.05$; $r_b = 0.70$, $P < 0.05$), total carotene content ($r_L = 0.75$, $P < 0.05$; $r_a = 0.88$, $P < 0.05$; $r_b = 0.73$, $P < 0.05$), and vitamin A activity ($r_L = 0.70$, $P < 0.05$; $r_a = 0.82$, $P < 0.05$; $r_b = 0.68$, $P < 0.05$). In contrast, the Hue° value negatively correlated with α-carotene content ($r = -0.66$, $P < 0.05$), β-carotene content ($r = -0.55$, $P < 0.05$), *cis*-9-β-carotene content ($r = -0.72$, $P < 0.05$), total carotene content ($r = -0.65$, $P < 0.05$), and vitamin A activity ($r = -0.58$, $P < 0.05$) of the carrot chips. These data agree with the findings of Skrede et al. (*15*) on carrot chips and of Lin et al. (*6*) on dried carrot slices. This means that the lower the Hue value, i.e., the more redness in the color of the chips, the higher the carotenoid content and vitamin A activity.

Water Activity, Moisture Content, Fat Content, and Textural Values. The mean water activity (a_w) and moisture content of carrot chips in the various treatments in the present study ranged from 0.28 to 0.45 and from 1.80 to 5.44%, respectively (Table 3). This lower water activity and moisture content may help the carrot chips maintain carotenoid content during storage. Arya et al. (*43*) reported that carotenoids were relatively stable when water activity ranged from 0.32 to 0.57, equivalent to a moisture content of 8−12% in freeze-dried carrots. There were significant differences ($P < 0.05$) in water activity and moisture content in the carrot chips treated with or without dehydration/rehydration. Dehydration and rehydration decreased significantly ($P < 0.05$) the water activity of the carrot chips. However, there was no significant difference ($P \geq 0.05$) in water activity among carrot chips treated with different antioxidants. The moisture content of carrot chips treated without blanching were significantly ($P < 0.05$) increased as compared to the control.

Absorption of β-carotene is affected by dietary fat concentration. Individuals placed on high-fat diets showed significant increases in plasma β-carotene as compared with those placed on low-fat diets (*12*). Carrot chips in the present study contained high fat ranging from 48.1 to 66.0% (Table 3). Fermentation without blanching significantly decreased ($P < 0.05$) the fat content down to a level of 48.1%. Partial dehydration also significantly decreased ($P < 0.05$) the fat content down to a level of 50.3%. However, in contrast to fermentation without blanching, fermentation with blanching significantly increased ($P < 0.05$) the fat content of carrot chips up to a level of 66.0%. Blanching, as reported by previous researchers (*35, 43*), produces a gradual breakdown in the protoplasmic structure organization and induces more disruption of the carrot cells, making the fat more easily absorbed and retained during deep-frying.

Table 3. Mean Water Activity (a_w), Moisture Content (% w/w), Crude Fat Content (% w/w), Maximum Force (g), Work (g-mm) of Carrot Chips As Influenced by Dehydration/Rehydration, Soaking in Different Antioxidants, and Fermentation[a]

experiment/treatment	water activity	moisture content	crude fat content	maximum force	work
Experiment A: Effect of Dehydration/Rehydration					
not dehydrated	0.45[a]	2.7[ab]	57.6[a]	485.8[b]	304.3[b]
partially dehydrated	0.45[a]	4.2[a]	50.3[b]	648.8[a]	609.2[a]
dehydrated rehydrated, 5 min 25 °C	0.41[b]	2.3[b]	57.6[a]	610.2[a]	400.5[ab]
dehydrated rehydrated, 1 min 100 °C	0.41[b]	1.8[b]	57.7[a]	597.1[a]	378.4[b]
Experiment B: Effect of Soaking in Different Antioxidants					
sodium metabisulfite	0.29[ns]	2.7[b]	59.9[ns]	478.3[ns]	336.7[b]
saline	0.30[ns]	3.5[a]	57.8[ns]	500.5[ns]	530.4[a]
erythorbic acid	0.36[ns]	2.4[b]	58.5[ns]	465.2[ns]	349.5[b]
L-cysteine	0.28[ns]	2.5[b]	59.4[ns]	502.0[ns]	358.1[b]
Experiment C: Effect of Fermentation					
not fermented	0.35[ab]	3.1[b]	59.9[b]	430.4[b]	318.8[bc]
not blanched/saline	0.30[b]	4.4[a]	48.2[c]	426.7[b]	228.8[c]
not blanched/*L. sakei*	0.36[ab]	5.4[a]	48.1[c]	541.2[a]	585.2[a]
not blanched/*L. plantarum*	0.35[ab]	4.8[a]	48.2[c]	517.0[a]	491.8[ab]
blanched/saline	0.41[a]	2.6[bc]	66.0[a]	489.0[ab]	463.9[ab]
blanched/*L. sakei*	0.37[ab]	2.6[bc]	64.1[a]	445.3[b]	380.2[bc]
blanched/*L. plantarum*	0.33[ab]	1.8[c]	65.8[a]	437.6[b]	413.5[abc]

[a] Values within a column and experiment with the same letters are not significantly different ($P \geq 0.05$). [ns] Not significant ($P \geq 0.05$).

Table 4. Mean Scores of Sensory Qualities of Carrot Chips As Influenced by Dehydration/Rehydration, Soaking in Different Antioxidants, and Fermentation[a]

experiment/treatment	color[b]	crispness[c]	odor[d]	sweetness[e]	flavor[f]
Experiment A: Effect of Dehydration/Rehydration					
not dehydrated	5.71[a]	7.54[a]	4.65[a]	5.69[a]	6.50[a]
partially dehydrated	5.50[a]	4.52[d]	4.13[ab]	4.54[b]	5.06[b]
dehydrated rehydrated 5 min 25 °C	4.21[b]	5.33[c]	3.56[bc]	3.75[c]	4.44[b]
dehydrated rehydrated 1 min 100 °C	4.60[b]	6.17[b]	3.44[c]	3.69[c]	4.46[b]
Experiment B: Effect of Soaking in Different Antioxidants					
sodium metabisulfite	4.73[b]	6.84[a]	4.61[b]	5.39[a]	6.05[a]
saline	5.16[b]	3.80[c]	4.36[b]	4.14[bc]	4.75[b]
erythorbic acid	5.82[a]	6.70[a]	4.45[b]	4.70[ab]	5.80[a]
L-cysteine	4.09[c]	5.95[b]	5.18[a]	3.59[c]	5.66[a]
Experiment C: Effect of Fermentation					
not fermented	4.43[d]	7.66[a]	4.75[bc]	5.64[a]	6.25[b]
not blanched/saline	8.68[a]	7.23[a]	5.98[a]	4.27[bc]	7.50[a]
not blanched/*L. sakei*	7.80[b]	3.59[d]	4.93[b]	4.05[bc]	5.61[b]
not blanched/*L. plantarum*	6.66[c]	4.61[c]	4.36[bc]	4.80[b]	5.61[b]
blanched/saline	3.68[e]	4.48[c]	4.18[c]	3.73[c]	4.59[c]
blanched/*L. sakei*	3.30[ef]	5.41[b]	3.52[d]	4.14[bc]	4.36[c]
blanched/*L. plantarum*	3.07[f]	5.95[b]	3.34[d]	4.14[bc]	4.64[c]

[a] Values within a column and experiment with the same letters are not significantly different ($P \geq 0.05$). [b] 1 = very light, 9 = very dark. [c] 1 = very tough, 9 = very crispy. [d] 1 = very bland, 9 = very intense. [e] 1 = not sweet at all, 9 = very sweet. [f] 1 = very bland, 9 = very intense.

The textural values may reflect the crispness of the chips. The peak force (F), work (W), or cohesiveness were found to be indicators of crispness for puffed corn curls (*44*). Table 3 shows the F and W values of carrot chips in the present study. Dehydration, including partial dehydration, significantly increased ($P < 0.05$) F and W values, which suggests a decrease in crispness. Dehydration caused the shrinkage of the carrot cell, reduced its porosity, and perhaps reduced the oil uptake during frying. There was no significant difference ($P \geq 0.05$) in F values among carrot chips treated with different types of antioxidants. However, the W values of carrot chips treated with sodium chloride were significantly higher ($P < 0.05$) than those treated with other antioxidants which means less crispy. *Lactobacillus* fermentation without blanching, significantly increased ($P < 0.05$) F and W values of carrot chips which suggests a decrease in crispiness. This decreased crispiness was related to the higher moisture content of these chips (Table 3). As mentioned above, blanching produces a gradual breakdown in the protoplasmic structure organization, induces more disruption of the carrot cells and perhaps increase the porosity of carrot slices after frying.

Sensory Qualities. The sensory qualities of carrot chips are presented in Table 4. There were significant differences ($P < 0.05$) in color, crispness, odor, and sweetness of carrot chips treated with dehydration/rehydration. The color score of carrot chips treated with dehydration and rehydration was lower than those treated without dehydration and rehydration which indicates that these chips had a lighter color. This is expected since these chips had higher lightness, redness, and yellowness values (Table 2). However, since these chips had a lower score in crispness, sweetness, odor, and flavor, the overall acceptability (Figure 2) of these chips was lower than those treated without dehydration/rehydration.

The carrot chips treated with sodium metabisulfite and erythorbic acid scored higher in crispness and

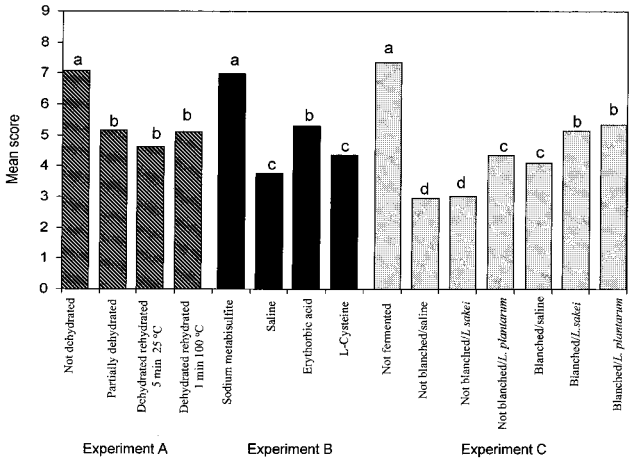

Figure 2. Mean overall acceptability of carrot chips as effect of dehydration/rehydration (experiment A), soaking in different antioxidants (experiment B), and fermentation (experiment C). Score 1 = dislike extremely, 5 = not like nor dislike, 9 = like extremely. Values within the same experiment with same letters are not significantly different ($P \geq 0.05$).

sweetness than those treated with saline and L-cysteine. This may have caused these chips to get a higher score in overall acceptability (Figure 2). As also indicated by the *L*, *a*, and *b* values (Table 2), carrot chips treated with fermentation and blanching scored lower in color, which means that these chips were less dark than those of other treatments. Fermentation, except for fermentation without blanching and without *Lactobacillus* inoculation, in general significantly decreased ($P < 0.05$) the crispness, odor, sweetness, and flavor scores, and this likely resulted in a lower overall acceptability score.

From the three experiments, positive correlations were found between the scores of crispness ($r = 0.69$, $P < 0.05$) and sweetness ($r = 0.75$, $P < 0.05$) with the overall acceptability of the carrot chips. This meant that the crispier and sweeter carrot chips were the most acceptable. There were negative correlations between the color score from the sensory analyses with the color values *L* ($r = -0.96$, $P < 0.05$), *a* ($r = -0.86$, $P < 0.05$), and *b* ($r = -0.94$, $P < 0.05$). A negative correlation ($r = -0.90$, $P < 0.05$) between textural value (*W*) from the texture analyses with the crispness score from sensory analyses was also observed in the present study. The lower *W* values were associated with higher crispness scores. A trend was observed that higher *F* (maximum force) values correlated with lower crispness scores from sensory analyses. These findings agree with those of Seymour and Hamann (*45*) that maximum force and work done to break the food, respectively, correlated inversely with crispness and crunchiness of low-moisture foods.

Relationships between sensory attributes and chemical components in 10 genotypes of strained processed carrots were determined by Talcott and Howard (*46*). They reported that fresh carrot flavor, aroma, and aftertaste were associated with high total sugar-to-terpinolene ratios. Sweet taste and sweet aftertaste were associated with high levels of total sugar-to-terpinolene ratios. Cooked flavor and cooked aftertaste were associated with high terpinolene content (*47*). Fried-food flavor intensity was the best indicator of overall flavor quality in fresh potato chips (*48*). In the present study, the flavor of carrot chips positively correlated with the sweetness ($r = 0.58$, $P < 0.05$), odor ($r = 0.88$, $P < 0.05$), and crispness ($r = 0.59$, $P < 0.05$) scores.

On the basis of the sensory qualities, as well as the carotenoid content and physicochemical properties of the carrot chips, those treated with just blanching and soaking in sodium metabisulfite, without dehydration and without fermentation were judged as the best in the present study. The carrot chips prepared with this method had the highest score in the overall acceptability (ranged from 7.0 to 7.3 on the 9 point scale), the highest total carotene retention (ranged from 77.2 to 90.1%), and contained the highest vitamin A activity (ranged from 3661 to 4266 μg of RAE/100 g). Although these chips did not have the best color, they were still acceptable. This means that if a processor selected this method, steps could be eliminated in carrot chip preparation, thus saving time and money.

Although the step of fermentation with blanching improved the color of the carrot chips, the panelists did not score these chips high for overall acceptability because the chips tasted less sweet, had less aroma, and were less crispy. To improve the overall acceptability, other steps such as adding flavoring agents may be required. The step of dehydration may be required if the producers intend to produce ready-to-fry carrot chips. From this study, we also found that erythorbic acid may be used as an alternative to sodium metabisulfite in carrot chip preparation, especially for individuals needing or wanting to avoid sulfites. However, the α-carotene content of the carrot chips produced using erythrobic acid is significantly lower ($P < 0.05$) than that of chips produced using sodium metabisulfite, the content of β-carotene, *cis*-9-β-carotene, and total carotenes as well as calculated vitamin A activity of the two are similar. Erythorbic acid may be used as an alternative to sodium metabisulfite in carrot chip preparation. Other processing steps may still be needed, however, to improve the carotenoid content, physicochemical, and sensory quality of the chips.

In summary, certain pretreatments prior to deep-frying of carrot slices may be needed to improve either the carotenoid retention, physicochemical properties, or the sensory qualities of carrot chips. Some treatments may be superior in improving physical properties such as color, but not the carotenoid content or the overall acceptability. Nevertheless, blanching and soaking in sodium metabisulfite seems to result in the optimum product. However, labeling information should indicate that the product contains sulfite to protect sulfite-sensitive individuals.

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LITERATURE CITED

(1) Lee, C. M.; Lederman, J. D.; Hofmann, N. E.; Erdman, J. W., Jr. The Mongolian gerbil (*Meriones unguiculatus*) is an appropriate animal model for evaluation of the conversion of β-carotene to vitamin A. *J. Nutr.* **1998**, *128*, 280−286.

(2) Törrönen, R.; Lehmusaho, M.; Häkkinen, S.; Hänninen, O.; Mykkänen., H. Serum β-carotene response to supplementation with raw carrots, carrots juice or purified β-carotene in healthy nonsmoking women. *Nutr. Res.* **1996**, *16*, 565−575.
(3) Kritchevsky, S. B. β-carotene, carotenoids and the prevention of coronary heart diseases. *J. Nutr.* **1999**, *129*, 5−8.
(4) Desobry, S. A.; Netto, F. M.; Labuza, T. P. Preservation of β-carotene from carrots. *Crit. Rev. Food Sci. Nutr.* **1998**, *38*, 381−396.
(5) Simon, P. W.; Wolff, X. Y. Carotenes in typical and dark orange carrots. *J. Agric. Food Chem.* **1987**, *35*, 1017−1022.
(6) Lin, T. M.; Durance, T. D.; Scaman, C. H. Characterization of vacuum microwave, air and freeze-dried carrot slices. *Food Res. Int.* **1998**, *31*, 111−117.
(7) Bao, B.; Chang, K. C. Carrot juice color, carotenoids and nonstarchy polysaccharides as affected by processing conditions. *J. Food Sci.* **1994**, *59*, 1155−1158.
(8) Chen, H. E.; Peng, H. Y.; Chen, B. H. Stability of carotenoids and vitamin A during storage of carrot juice. *Food Chem.* **1996**, *57*(4), 497−503.
(9) Aukrust, T.; Blom, H.; Slinde, E. Influence of brine composition on yield and quality of deep fried fermented carrot chips. *Lebensm. Wiss. Technol.* **1995**, *28*, 100−104.
(10) Baardseth, P.; Rosenfeld, H. J.; Sundt, T. W.; Skrede, G.; Lea, P.; Slinde, E. Evaluation of carrot varieties for production of deep-fried carrot chips − II. Sensory aspects. *Food Res. Int.* **1996**, *28*, 513−519.
(11) Sulaeman, A.; Keeler, L.; Giraud, D. W.; Taylor, S. L.; Wehling, R. L.; Driskell, J. A. Carotenoid content and physicochemical and sensory characteristics of carrot chips deep-fried in different oils at several temperatures. *J. Food Sci.* **2001**, in press.
(12) Dimitrov, N. V.; Meyer, C.; Ullrey, D. E.; Chenoweth, W.; Michelakis, A.; Malone, W.; Boone, C.; Fink, G. Bioavailability of β-carotene in humans. *Am. J. Clin. Nutr.* **1988**, *48*, 298−304.
(13) Jalal, F.; Nesheim, M. C.; Agus, Z.; Sanjur, D.; Habicht, J. P. Serum retinol concentrations in children are affected by food sources of β-carotene, fat intake, and antihelmintic drug treatment. *Am. J. Clin. Nutr.* **1999**, *68*, 623−629.
(14) Castenmiller, J. J. M.; West, C. E.; Linssen, J. P.; van het Hof, K. H.; Voragen, A. G. J. The food matrix of spinach is a limiting factor in determining the bioavailability of β-carotene and to a lesser extent of lutein in humans. *J. Nutr.* **1999**, *129*, 349−355.
(15) Skrede, G.; Nilson, A.; Baardseth, P.; Rosenfeld, H. J.; Enersen, G.; Slinde, E. Evaluation of carrot varieties for production of deep fried carrot chips: III. Carotenoids. *Food Res. Int.* **1997**, *30*, 73−81.
(16) Kulkarni, K. D.; Govinden, N.; Kulkarni, D. N. Crisp quality of two potato varieties: effects of dehydration and rehydration. *J. Sci. Food Agric.* **1994**, *64*, 205−210.
(17) Suslow, T. V.; Mitchell, J.; Cantwell, M. *Carrots: Postharvest Recommendations*. University of California Vegetable Research and Information Center: Davis, CA, 1998. Available from <http://vric.ucdavis.edu/vrichome/selectnewtopics.carrotph.htm)>. Accessed Aug 24.
(18) Baardseth, P.; Rosenfeld, H. J.; Sundt, T. W.; Skrede, G.; Lea, P.; Slinde, E. Evaluation of carrot varieties for production of deep-fried carrot chips − I. Chemical aspects. *Food Res. Int.* **1995**, *28*, 195−200.
(19) Epler, K. S.; Ziegler, R. G.; Craft, N. E. Liquid chromatographic method for the determination of carotenoids, retinoids and tocopherols in human serum and in food. *J. Chromatogr.* **1993**, *619*, 37−48.
(20) Emenheiser, C.; Watkins, R. H.; Simunovic, N.; Solomon, N.; Bulux, J.; Barrows, J.; Schwartz, S. J. Packaging preservation of β-carotene in sweet potato flakes using flexible film and an oxygen absorber. *J. Food Qual.* **1999**, *22*, 63−73.
(21) Barua, A. B.; Olson, J. A. Reversed-phase gradient high-performance liquid chromatographic procedure for simultaneous analysis of very polar to nonpolar retinoids, carotenoids and tocopherols in animal and plant samples. *J Chromatogr. Biol. Appl.* **1998**, *707*, 69−79.
(22) Nierenberg, D. W.; Nann, S. L. A method for determining concentrations of retinol, tocopherol, and five carotenoids in human plasma and tissue samples. *Am. J. Clin. Nutr.* **1992**, *56*, 417−426.
(23) Sun, J.; Giraud, D. W.; Moxley, R. A.; Driskell, J. A. β-carotene and α-tocopherol inhibit the development of atherosclerotic lesions in hypercholesterolemic rabbits. *Int. J. Vit. Nutr. Res.* **1997**, *67*, 197−205.
(24) Institute of Medicine, National Academy Sciences. Dietary references intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc (prepublication copy). National Academy Press: Washington, DC, 2001; p 4-1−4-61.
(25) Murphy, E. W.; Criner, P. E.; Gray, B. C. Comparisons of methods for calculating retention of nutrients in cooked foods. *J. Agric. Food Chem.* **1975**, *23*, 1153−1157.
(26) Steel, R. G. D.; Torrie, J. H.; Dickey, D. A. *Principles and Procedures of Statistics, A Biometrical Approach*, 3rd ed; The MacGraw-Hill Co., Inc: New York, 1997.
(27) Park, Y. W. Effect of freezing, thawing, drying, and cooking on carotene retention in carrots, broccoli and spinach. *J. Food Sci.* **1987**, *52*, 1022−1025.
(28) Mohammed, S.; Husein, R. Effect of low-temperature blanching, cysteine-HCl, *N*-acetyl-L-cysteine, Na-metabisulfite and drying temperature on the firmness and the nutrient content of dried carrots. *J. Food Process. Preserv.* **1994**, *18*, 343−348.
(29) Zhao, Y. P.; Chang, K. C. Sulfite and starch affect color and carotenoids of dehydrated carrots (*Daucus carota*) during storage. *J. Food Sci.* **1995**, *60*, 324−326, 347.
(30) Krokrida, M. K.; Karathanos, V. T.; Maroulis, Z. B. Effect of freeze-drying conditions on shrinkage and porosity of dehydrated agricultural products. *J. Food Eng.* **1998**, *35*, 369−380.
(31) Madhavi, D. L.; Salunkhe, D. K. Antioxidant. In *Food Additive Toxicology*; Maga, J. A., Tu, A. T., Eds.; Marcel Dekker: New York, 1995; pp 89−177.
(32) Lambrecht, H. S. Sulfite substitutes for the prevention of enzymatic browning in foods. In *Enzymatic Browning and Its Prevention*; Lee, C. Y., Whitaker, J. R., Eds.; American Chemical Society: Washington, DC, 1995; pp 313−322.
(33) Dudley, E. D.; Hotchkiss, J. H. Cysteine as an inhibitor of polyphenol oxidase. *J. Food Biochem.* **1989**, *13*, 65.
(34) Slinde, E.; Skrede, G.; Aukrust, T.; Blom H.; Baardseth, P. Lactic acid fermentation influence on sugar content and colour of deep-fried carrot chips. *Food Res. Int.* **1993**, *26*, 255−260.
(35) Fuchigami, M.; Hyakumoto, N.; Miyazaki, K. Programmed freezing effects texture, pectic composition and electron microscopic structure of carrots. *J. Food Sci.* **1995**, *60*, 137−141.
(36) Dietz, J. M.; Erdman, J. W. Effect of thermal processing upon vitamins and protein in foods. *Nutr. Today* **1989**, July/August, 6−15.
(37) Booth, V. H.; Bradford, M. P. Tocopherol content of vegetables and fruits. *Br. J. Nutr.* **1963**, *17*, 575−581.
(38) Rhee, K. S.; Watts, B. M. Evaluation of lipid oxidation in plant tissues. *J. Food Sci.* **1966**, *31*, 664−668.
(39) Marquez, G.; Anon, M. C. Influence of reducing sugars and amino acids in the colour development of fried potatoes. *J. Food Sci.* **1986**, *51*, 157−160.
(40) Wagner, L. A.; Warthesen, J. J. Stability of spray-dried encapsulated carrot carotenes. *J. Food Sci.* **1995**, *60*, 1048−1053.
(41) Bushway, R. J.; Wilson, A. M. Determination of α- and β-carotene in fruit and vegetables by High Performance Liquid Chromatography. *Can. Inst. Food Sci. Technol. J.* **1982**, *15*, 165−169.

(42) Heinonen, M. I. Carotenoids and provitamin A activity of carrot (*Daucus carota* L.) cultivars. *J. Agric. Food Chem*. **1990**, *38*, 609−612.
(43) Arya, S. S.; Netesan, V.; Premaavalli, K. S.; Vijayraghavan P. K. Effect of prefreezing on the stability of carotenoid in blanched air-dried carrots. *J. Food Technol*. **1982**, *7*(1), 109−113.
(44) Prestamo, G.; Fuster, C.; Risueno, M. C. Effect of blanching and freezing on the structure of carrots cells and their implications for food processing. *J. Sci. Food Agric*. **1998**, *77*, 223−229.
(45) Katz, E. E.; Labuza, T. P. Effect of water activity on the sensory crispness and mechanical deformation of snack food products. *J. Food Sci*. **1981**, *46*, 403−409.
(46) Seymour, S. K.; Hamann, D. D. Crispness and crunchiness of selected low moisture foods. *J. Text. Stud*. **1988**, *19*, 79−95.
(47) Talcott, S. T.; Howard, L. R. Chemical and sensory quality of processed carrot puree as influenced by stress-induced phenolic compounds. *J. Agric. Food Chem*. **1999**, *47*, 1362−1366.
(48) Warner, K.; Orr, P.; Glynn, M. Effect of fatty acid composition of oils on flavor and stability of fried foods. *J. AOCS* **1997**, *74*, 347−356.

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