Effect of Moisture Content of Carrot Slices on the Fat Content, Carotenoid Content, and Sensory Characteristics of Deep-fried Carrot Chips

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ABSTRACT: Our objective was to develop a reduced-fat deep-fried carrot chip. Moisture contents of the carrot slices were altered, and fat uptake and quality parameters were measured. Decreasing moisture content of carrot slices significantly decreased ($P < 0.05$) the yield, hue° value, and fat uptake, and increased the redness value, which correlated with increased carotenoid content, but did not influence chip lightness, yellowness, water activity, and moisture content. Removing 50% of the initial moisture content of the carrot slices decreased the chips' fat content from 57% to 38.5%. Adjusting the moisture level of the carrot slices appears to influence fat uptake and carotene content of deep-fried carrot chips.

Keywords: fat uptake, carotenes, carrot chips, moisture, vitamin A

Introduction

Deep-fried carrot chips have been developed as a good source of bioavailable provitamin A carotenoids as well as other carotenoids (Sulaeman and others 2001a). Deep-fried carrot chips contain the important nutrients α-, β-, and *cis*-9-β-carotene, and lutein (Sulaeman and others 2001a). The α-, β-, and *cis*-9-β-carotenes are provitamin A compounds, which can be converted into vitamin A in the human body (IMNAS 2000), whereas lutein functions merely as an antioxidant like other carotenes. The developed carrot chip effectively reversed vitamin A deficiency in gerbils (Sulaeman and others 2002a). Because of the antioxidant activity of provitamin A carotenoids, foods rich in these and other carotenoids may also help prevent major health problems (Kohlmeier and Hastings 1995; Törrönen and others 1996; Kritchevsky 1999). Carotenoids are believed to have a variety of different actions that are related to the decreased risk of some degenerative diseases (IMNAS 2000). The introduction of carrot chips to any population, therefore, would be a food-based vehicle for increasing the consumption of carotenoids.

Carrot chips have a pleasant taste and an appealing appearance according to trained panelists (Sulaeman and others 2001a, 2001b); consumer sensory evaluations indicated that this product was acceptable to both American and Southeast Asian consumers (Sulaeman and others 2002b). The retention of provitamin-A carotenoids

find an alternative processing method to decrease the fat content of the product.

The fat content of a deep-fried product depends on the oil uptake during frying. Some factors that have been reported to affect oil uptake are oil quality and composition, frying temperature and duration, product shape, moisture content, composition, prefrying treatments (for example, drying, blanching), surface roughness, porosity, and others (Pinthus and others 1993; Saguy and Pinthus 1995). The surface moisture of potatoes has been reported to influence fat uptake (Lamberg and others 1990). The oil content of potato slices was reduced when more moisture-loss sites were formed (Gamble and others 1987), and the loss of moisture during finish-frying influenced the fat uptake in potato French fries (O'Connor and others 2001). Because pre-fry drying and post-fry drying reportedly influence the fat content of fried potato slices, the same may be true for carrot slices.

The purposes of this study were to develop reduced-fat deep-fried carrot chips and to evaluate the effect of moisture contents of carrot slices before frying, on the fat content, as well as on the physicochemical and sensory values of deep-fried carrot chips.

Materials and Methods

from Sigma Chemical Co. (St. Louis, Mo., U.S.A.) and all-trans-α-carotene from Carolina Chemical Purities (Cary, N.C., U.S.A.). The identities and concentrations of the working standards were confirmed spectrophotometrically (Beckman DU 640; Beckman Instruments, Inc., Fullerton, Calif., U.S.A.) using previously reported extinction coefficients (Epler and others 1993). All high-performance liquid chromatography (HPLC)-grade solvents (acetonitrile, tetrahydrofuran, methanol, and hexane) were obtained from Fisher Scientific Co. (Fair Lawn, N.J., U.S.A.). The HPLC-grade solvents were degassed under vacuum and filtered through a 0.45-µm membrane filter (Pall Gelman Laboratory, Ann Arbor, Mich., U.S.A.) before use.

Deep-fried carrot chip production

Fresh carrots were trimmed and cut into 55-mm lengths and mechanically peeled using a Hobart Peeler Machine (Hobart Manufacturing Co., Troy, Ohio, U.S.A.) at the lowest speed for 1 min and sliced into 1.5-mm thickness using a Dito Dean Slicer Model TR-22 (Dean Food Preparation, Los Angeles, Calif., U.S.A.). The carrot slices were steam-blanched (the equipment used was made and designed in our pilot plant) for 4 min, cooled under running tap water for 4 min, soaked in sodium metabisulfite solution 0.2% (w/v) for 15 min, and drained until surfaces were nearly dry. Our previous research (Sulaeman and others 2001b) showed that use of sodium metabisulfite was the preferred pretreatment. The following treatments were applied to the carrot slices:

C = control; after draining, the slices were deep-fried at 165 °C until there were no visible bubbles (4.75 min) in PHSO. After draining 1 min on the tray, the excess oil was removed using paper towels. This control treatment was developed earlier by our laboratory group (Sulaeman and others 2001a).

MH = high moisture; after draining, the slices were deep-fried as in treatment C for 4.75 min. After draining 1 min on the tray, the excess oil was removed using a series of paper towels while being blown with hot air. After draining, the carrot chips were put into a dehydrator (Model FD 1010; Nesco/American Harvest, Two Rivers, Wis., U.S.A.) at 40 °C for 2 h to improve crispness.

MM = medium moisture; after draining, the slices were put in a dehydrator at 40 °C for 4 h or until the moisture content reached 85%. The partially dried carrot chips were then conditioned in a refrigerator (5 °C) for 12 to 24 h. Conditioning involved the slices being placed in a tightened, closed plastic bag, and the bag was placed in a covered plastic jug. This conditioning treatment was intended to enable all slices to reach the predetermined moisture content evenly. Carrot slices were removed for frying when moisture values had equilibrated. The slices were deep-fried as in treatment C but for 2 min. Then the fried chips were drained and put in a dehydrator as in treatment MH.

ML = low moisture; after draining, the slices were put in a dehydrator at 40 °C for 8 h or until the moisture content reached 65%. The partially dried carrot chips were then conditioned as in treat-

Table 1—Profile of trained panelists and their general liking of chip products

Variable	Category	N	Percentage
Gender	Male	7	43.8
	Female	9	56.2
Age	19 to 24 y	3	18.8
	25 to 34 y	7	43.8
	35 to 45 y	6	37.4
Cigarette smoking	No	16	100.0
	Yes	0	0
Food allergy	No	15	93.8
	Yes	1	6.2
Special diet	No	16	100.0
	Yes	0	0
Kind of chip product liked	Potato chips	16	100.0
	Tortilla chips	15	93.8
	Corn chips	14	87.5
	Other chips	3	18.8
Degree of liking chip products in general	Like extremely	1	6.3
	Like very much	9	56.3
	Like moderately	6	37.4

chips were packaged in vacuum-sealed layered film (2.50 mil, or 0.0635-mm-thick metallized polyester, and linear low-density polyethylene) pouches, 16.5 cm × 20.3 cm outer dia (Kapak Co., Minneapolis, Minn., U.S.A.) using a Multivac AG 500/AG900 (Multivac Inc., Kansas City, Mo., U.S.A.) and put into a freezer at –40 °C for future analyses. Each treatment was replicated twice.

Analyses of carotenoids

Carotenoids were analyzed using an HPLC technique according to Sulaeman and others (2001a, 2001b). The HPLC system (Waters Associates, Inc., Milford, Mass., U.S.A.) consisted of the following equipment: 600E solvent delivery system, Rheodyne 7725 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 inner dia) C_{18} column (Rainin, Woburn, Mass., U.S.A.), which was protected with a guard column of C_{18} materials (3-cm length × 4.6-mm inner dia) 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 (1998), and the carotenoids were separated using acetonitrile:tetrahydrofuran:methanol:1% ammonium acetate (65:25:6:4), respectively, as the mobile phase under isocratic conditions (Nierenberg and Nann 1992), as previously described (Sulaeman and others 2001a, 2001b). 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 (IMNAS 2001). The true retention values (%) of carotenoids in the carrot chips as influenced by the carrot chip processing were calculated as described by Murphy and others (1975).

Table 2—Effect of moisture level of carrot slices on yield (%), carotene content, and vitamin A activity retention of carotene and vitamin A activity (%) of carrot chips[a]

Treat-ment	Moisture level of slices (%)	A_w of slices	Yield (%)	Carotene content (μg/100 g, w/w) α-carotene	β-carotene	*cis*-9-β-carotene	Total carotene	Vitamin A activity[b] (μg RAE/100 g w/w)	Retention (%) α-carotene	β-carotene	Total carotene	Vitamin A activity
C	93	1.01	14.55b	26776c	42478c	10480cd	79734c	4655.5c	60.03b	51.92b	63.07b	53.65b
MH	93	1.01	13.76bc	26954c	42058c	8530d	77542c	4626.4c	57.12bc	48.54bc	57.94bc	50.36bc
MM	86	1.00	12.63cd	25347c	42281c	10636cd	78264c	4579.6c	49.37bc	44.87cd	53.77cd	45.83cd
ML	68	0.98	11.24de	26374c	41919c	11404c	79696c	4592.1c	45.64c	39.54d	48.64d	40.84d
MVL	45	0.94	10.65e	33166b	52092b	16652b	101910b	5722.9b	54.62bc	46.54bc	59.01bc	48.27bc

[a]Values are means of 2 replications. Values within a column with the same letters are not significantly different ($P < 0.05$).
[b]μg retinol activity equivalent (RAE) = $\frac{\mu g\ \alpha\text{-carotene}}{24}$ % $\frac{\mu g\ \beta\text{-carotene}}{12}$.

U.S.A.). Moisture content was measured by weight before and after the food matrix was in an air oven at 105 °C for 20 to 22 h (Baardseth and others 1995a). Fat and moisture data are expressed on a wet weight basis.

Sensory analyses

Sensory analyses were performed as previously described (Sulaeman and others 2001a) using 16 trained panelists to evaluate the color, crispness, odor, sweetness, flavor, and overall acceptability of these carrot-chip products. The profile of the panelists is presented in Table 1. Before the testing, the panelists (7 males and 9 females, aged 19 to 45 y) were trained (Carpenter and others 2000) to evaluate the attributes of the chips measured in this study. Several training sessions were included so that the panelists became proficient. Carrot chips were removed from the freezer 18 h before testing (Melton and others 1993), and the chips were at room temperature when tested. Testing was conducted twice for each panelist, morning and afternoon, in individual booths equipped with white fluorescent lights.

Statistical analyses

Physicochemical data from each experiment were subjected to analysis of variance (ANOVA) and least significant difference (LSD) tests to determine significant differences between treatments. A 2-way ANOVA with treatment and judges as sources of variation and LSD tests were carried out on sensory data to determine differences among treatments (Steel and others 1997). 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 Inst., Cary, N.C., U.S.A.).

Results and Discussion

Yield, carotene content, and vitamin A activity of carrot chips

ences in the quality of the carrots as well as in the processing methods may be responsible for the differences in carrot-chip yield.

The carotene contents of deep-fried carrot chips in the present study were as follows: (μg/100 g w/w) α-carotene, 25347-33166; β-carotene, 41919-52092; *cis*-9-β-carotene, 8530-16652; and total carotene, 77542-101910 (Table 2). Except for MVL, there were no significant differences between treatment groups in α-, β-, and total carotene contents. The carotenoid content of MVL was significantly higher ($P < 0.05$) than other treatments, perhaps due to the very short frying time compared with that of the other treatments. The very short frying time caused the increased retention of carotenes as indicated by the high *cis*-9-β-carotene content that may have protected the other carotenes. Boileau and others (1999) reported that the carotenoid *cis*-isomers may play a role in radical chain-reaction termination. *Cis*-9-β-carotene has been shown in vivo and in vitro to be a better free radical scavenger than the all-trans form (Levin and others 1997). Sulaeman and others (2003) indicated that *cis*-9-β-carotene appeared to be a better free radical scavenger than the trans-isomer, thus protecting the other carotenes. The shorter frying time caused the increased retention of carotenes; however, for some treatments, the mean values were lower, although mainly nonsignificantly lower, than the control. This is reasonable because there was no drying treatment applied to the control before and after frying and, therefore, carotene retention was influenced only by the blanching, soaking, and frying.

The vitamin A activity of the carrot chips (w/w) ranged from 4579.6 μg to 5722.9 μg RAE/100 g chips, respectively. The carotene concentrations and vitamin A activities of carrot chips reported in the present study were higher than those reported by Skrede and others (1997) and our previous studies (Sulaeman and others 2001a, 2001b), but this may be due to differences in initial carrot quality and processing methods.

The carotene levels of carrots were well retained during the processing of carrot chips in the current study. The retention of carotenes and vitamin A activity tended to decrease with the decrease

Table 3—Effect of moisture levels of carrot slices on color values, moisture content, water activity, fat content, and fat reduction of deep-fried carrot chips[a]

Treatment	Initial moisture (%)	Initial A_w	L^*	a^*	b^*	Hue°	Chip A_w	Moisture (%)	Crude fat (%)	Fat reduction (%)
C	93a	1.01a	39.85a	24.05bc	20.91a	41.00a	0.25a	2.43a	57.15a	0e
MH	93a	1.01a	32.81b	21.64c	19.03a	41.37a	0.25a	2.46a	53.68b	6.06d
MM	86b	1.00ab	41.14a	27.89a	22.75a	39.20b	0.22a	1.96a	49.26c	13.81c
ML	68c	0.98b	39.01a	25.20ab	21.47a	40.44a	0.24a	2.68a	44.29d	22.50b
MVL	45d	0.94c	40.33a	28.11a	21.61a	37.56c	0.23a	2.44a	38.53e	32.58a

[a]Values are means of 2 replications. Values within a column with the same letters are not significantly different ($P < 0.05$). A_w = water activity

Table 4—Significant correlations between parameters of deep-fried carrot chips[a]

	Yield	Fat content	Color a^*	Hue°	α-Carotene	β-Carotene	*cis*-9-β-carotene	Total carotene	Vitamin A activity
Initial moisture	$r = 0.89$ $P = 0.0006$	$r = 0.95$ $P = 0.0001$	$r = -0.85$ $P = 0.0020$	$r = 0.86$ $P = 0.0014$	$r = -0.77$ $P = 0.0098$	$r = -0.80$ $P = 0.0053$	$r = -0.94$ $P = 0.0001$	$r = -0.87$ $P = 0.0011$	$r = -0.81$ $P = 0.0044$
Initial A_w	$r = 0.80$ $P = 0.0053$	$r = 0.88$ $P = 0.0009$	$r = -0.82$ $P = 0.0040$	$r = 0.88$ $P = 0.0009$	$r = -0.80$ $P = 0.0059$	$r = -0.85$ $P = 0.0018$	$r = 0.94$ $P = 0.0001$	$r = -0.90$ $P = 0.0004$	$r = -0.86$ $P = 0.0015$

[a]Values are means of 2 replications.

4579.6 µg to 5722.9 µg RAE per 100 g w/w chips. The consumption of 1 serving of carrot chips (30 g) is likely more than enough to meet the vitamin A requirement of an adult (IMNAS 2001). This means that this reduced-fat carrot chip is still a rich source of carotene either as a vitamin A precursor or an antioxidant.

Color of carrot chips

The color of the carrots has been reported to be largely due to the presence of carotenes (Bao and Chang 1994). The orange color of carrots and carrot chips was described by the lightness (L^*), redness (a^*), yellowness (b^*), and hue° parameters. The color values of carrot chips in the present study ranged from 32.81 to 41.14 (L^*), 21.64 to 28.11 (a^*), 19.03 to 22.75 (b^*), and 37.56 to 41.37 (hue°) (Table 3). Sulaeman and others (2001a), using 3 types of oil for frying at different temperatures, found the color values of carrot chips to be as follows: 32.3 to 46.1 (L^*), 14.7 to 20.4 (a^*), 13.4 to 26.5 (b^*), and 42.1 to 53.5 (hue °). The L^*, a^*, and b^* values reported by previous researchers using lactic acid fermentation were 44.9 to 51.3 (L^*), 10.1 to 12.6 (a^*), 15.8 to 26.5 (b^*) (Slinde and others 1993); 49.0 to 52.4 (L^*), 15.1 to 16.3 (a^*), 26.2 to 29.0 (b^*) (Baardseth and others 1995); and 15.9 to 20.4 (b^*) (Aukrust and others 1995).

Decreasing the initial moisture content tended to increase the redness (a^*) and tended to decrease the hue° values of the carrot chips; meanwhile, the yellowness (b^*) of the carrot chips was not affected. MVL had significantly lower ($P < 0.005$) hue° values than all other treatments. MVL had higher, sometimes significantly, redness values, percentage reduced-fat content, and lower, sometimes

Water activity, moisture content, and fat content

The water activity (a_w) and moisture content of deep-fried carrot chips in the present study ranged from 0.22% to 0.25% and 1.96% to 2.68%, respectively (Table 3). The low water activity and moisture content may help the carrot chips maintain their carotenoid content during storage. Arya and others (1982) reported that carotenoids were relatively stable when water activity ranged from 0.32 to 0.57, equivalent to a moisture content of 8% to 12% in freeze-dried carrots.

Decreasing the moisture level of carrot slices did not affect the water activity and moisture content of the carrot chips, but it significantly ($P < 0.0001$) affected the fat uptake during frying as indicated by the decreased fat content of the carrot chips (Table 3). The fat reduction increased significantly ($P < 0.001$) with the decreasing moisture level of the carrot slices. Lowering the moisture level to 45% resulted in a decrease in the fat content of 33% and resulted in a product which could be labeled as reduced-fat (USFDA 2003). However, we were unable to decrease the moisture level to below 45% because it resulted in darker chips and lower yields.

Correlations between the parameters measured on the deep-fried carrot chips and the initial moisture of the carrot slices, and thus the initial water activity, of the carrot slices are given in Table 4. Significant correlations were observed between the initial moisture content, and thus the initial water activity, of the carrot slices and yield, chip fat content, chip color a^* values, chip color hue °, carotene (α-, β-, *cis*-9-β-, and total) content, and vitamin A activity (Table 4). Table 4 demonstrates that altering the initial moisture to tubers is considered as a major factor. Besides the lower moisture level of the slices before frying, other factors that might contribute to the lower fat content include the post-treatment after frying. Blowing with hot air and drying in a dehydrator at 40 °C significantly decreased ($P < 0.05$) the fat content of the chips. This post-frying treatment helped to remove the fat that was absorbed during frying as indicated by comparing chips in treatment MH that received the post-frying treatment with chips having the same initial moisture content in treatment C which did not; the fat content was 6% lower in chips in treatment MH than in C.

Decreasing the initial moisture of the carrot slices in the current study decreased the yield likely due to the chip having lower water content. The decreased initial moisture of the slices resulted in a carrot chip product that was more red in color, contained more total carotenoids, and had more vitamin A activity likely due to these becoming more concentrated.

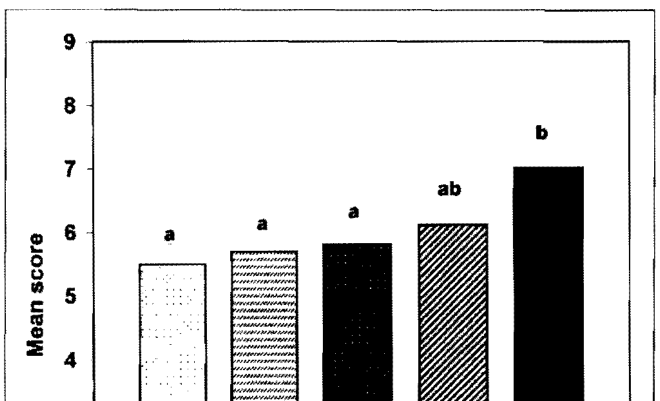
Table 5—Effect of initial moisture content of carrot slices on sensory characteristics of the deep-fried carrot chips[a]

Treatment	Color[b]	Crispness[c]	Oiliness[d]	Odor[e]	Sweetness[f]	Flavor[g]
C	5.4h	5.5j	4.7h	4.1h	3.8h	4.6i
MH	5.8h	6.2ij	4.3h	4.0h	4.2h	4.9hi
MM	6.1h	6.4ij	4.1h	3.9h	4.4h	4.9hi
ML	6.2h	6.8i	3.5h	4.0h	4.7h	5.8h
MVL	6.1h	8.0h	3.5h	3.7h	4.3h	5.8h

[a]Values are means of 2 replications with sensory evaluations completed twice by 16 panelists. Values within a column 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 = not oily at all; 9 = very oily.
[e]1 = very bland; 9 = very intense.
[f]1 = not sweet at all; 9 = very sweet.
[g]1 = very bland; 9 = very intense.

Sensory characteristics

The effect of initial moisture content of carrot slices on sensory characteristics of deep-fried carrot chips are presented in Table 5. The color, oiliness, odor, and sweetness values were not significantly different ($P \geq 0.05$) among groups; however, significant differences ($P < 0.05$) were observed in the crispness and flavor values. The overall acceptability of the chips increased with the decrease of moisture levels of the slices (Figure 1). Though not significantly different, the oiliness and odor scores of chips tended to decrease (judged less oily or less intense) with the decreased initial moisture content and water activity. This may be caused by the decreased fat content of carrot chips. Based on Pearson correlation analyses, there were positive correlations between the oiliness and odor scores with the fat content of the chips ($r = 0.956$, $P = 0.011$ and $r = 0.847$, $P = 0.0702$, respectively). The decrease in the oiliness and odor scores correlated ($r = -0.824$, $P = 0.0866$ and $r = -0.907$, $P = 0.024$, respectively) with the higher scores of overall acceptability. The crispness and flavor of carrot chips were significantly increased ($P < 0.05$) (judged crispier and more intense) with the decreased initial moisture content and water activity of the carrot slices. Positive correlations were observed between crispness and flavor score and overall acceptability ($r = 0.980$, $P = 0.003$ and $r = 0.839$, $P = 0.0757$, respectively). Seymour and Hamann (1988) found that maximum force and work done to break the food, respectively, correlated inversely with crispness and crunchiness of low-moisture foods. Sulaeman and others (2001b) found that the flavor scores of carrot chips were correlated with the sweetness, odor, and crispness scores.



Conclusions

Reduced-fat deep-fried carrot chips can be developed by adjusting the initial moisture content of the carrot slices before frying. Decreasing moisture content and water activity of carrot slices significantly decreased ($P < 0.05$) the yield and fat uptake, tended to decrease the hue° value, and tended to increase the redness value that was correlated with the increased carotene content, but did not significantly affect the lightness, yellowness, water activity, and moisture content of the carrot chips. Removing 50% of the initial moisture content of the carrot slices decreased the fat content of carrot chips from 57% to 38.5%. Blowing the chips with hot air after frying also helped to decrease the fat content of the chips by 6%. These results suggest that adjusting the moisture level of the carrot slices may control the fat uptake during carrot chip frying. This reduced-fat carrot-chip product has potential for use as a functional food and could be marketed as a relatively nutritious snack food because of its high carotenoid content.

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