β-Carotene from Red Carrot Maintains Vitamin A Status, but Lycopene Bioavailability Is Lower Relative to Tomato Paste in Mongolian Gerbils\(^1,2\)

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**Abstract**

Red carrots contain lycopene in addition to \(α\) - and \(β\) - carotene. The utility of red carrot as a functional food depends in part on the bioavailability of its constituent carotenoids. Lycopene bioavailability was compared in Mongolian gerbils (Meriones unguiculatus) fed freeze-dried red carrot and tomato paste (Study 1, \(n = 47\)) and whole food extracts dissolved in cottonseed oil (Study 2, \(n = 39\)). Diets and supplements were equalized for lycopene and intakes did not differ. Both studies utilized negative (oil) and positive (purified lycopene [Lyc]) controls. In Study 1, vitamin A liver stores (0.68 ± 0.13 μmol/liver) of the red carrot group did not differ from baseline (0.63 ± 0.13 μmol/liver) and were greater than those of the tomato paste (0.43 ± 0.12 μmol/liver), Lyc (0.51 ± 0.14 μmol/liver), and control (0.38 ± 0.17 μmol/liver) groups (\(P < 0.003\)). A similar pattern was observed in Study 2. In both studies, hepatic lycopene was higher in the tomato paste (82.7 ± 26.7 and 80.7 ± 20.2 nmol/liver) groups compared with red carrot groups (59.3 ± 21.9 and 39.5 ± 14.1 nmol/liver, \(P < 0.0001\)). Hepatic lycopene from tomato paste was higher than Lyc in Study 1, but tomato paste extract and Lyc did not differ in Study 2, when both were dissolved in oil. Red carrot maintains vitamin A status, but constituent \(β\) - carotene may interfere with lycopene bioavailability. These results confirm prior studies in humans on the relative bioavailability of lycopene from red carrots and tomato paste and expand them by suggesting the mechanism and determining vitamin A value. J. Nutr. 137: 1395–1400, 2007.

**Introduction**

In the multidisciplinary field of carotenoid research, relatively few groups have examined the nutritional aspects of the carrot (Daucus carota L.), the ancient progenitor of the term "carotenoid." Before the emergence of the conventional orange carrot ~400 y ago, carrot color was yellow or purple. Some time after the appearance of orange carrots, other colors were developed including red strains containing abundant lycopene in addition to the provitamin A carotenoids, \(α\) - and \(β\) - carotene. Red carrots are thought to have originated in China and India in the eighteenth century and still grow in these locations today (1,2). The red carrot qualifies as a functional food because, in addition to providing essential vitamin A, it may offer protection against chronic disease through the putative benefits of lycopene. Lycopene is a potent antioxidant in vitro (3) and is associated with decreased risk of certain cancers in epidemiological studies (4). The fiber in red carrots may provide additional health benefits, but does negatively impact lycopene bioavailability (5).

Previous work with red carrots in humans suggests that lycopene from tomato paste is more bioavailable than from red carrots (5). Differences in food processing and fiber content were suggested as reasons for the greater lycopene bioavailability of tomato paste. Although these factors are well supported (6,7), other possibilities include carotenoid interaction during, before, and after absorption. Carotenoids may compete for incorporation into micelles prior to absorption causing decreased bioavailability (8). The characterization of theoretical carotenoid transporters at the enterocyte apical surface (9,10) also presents a feasible mode of carotenoid interaction through potential competition for transporter facilitation or binding. Another site of carotenoid interaction may lie within the enterocytes, where the carotenoid cleavage monoxygenases initiate carotenoid metabolism (11–13).

A functional food can only exert its beneficial effects if its constituent compounds can be utilized in vivo. To further evaluate the utility of red carrots as a dietary source of lycopene, Mongolian gerbils were used to assess bioavailability and distribution within the body. Gerbils have demonstrated an excellent congruency to humans in the bioavailability of \(α\) - carotene...
(14), β-carotene (15–17), and β-cryptoxanthin (18), but not lutein (19). It is unknown if they are useful for assessing the bioavailability of lycopene. The current studies were designed to: 1) determine whether gerbils are useful models for the evaluation of lycopene bioavailability, 2) compare the relative lycopene bioavailability of freeze-dried tomato paste and red carrots, 3) assess the interaction of β-carotene and lycopene in vivo using whole-food extracts dissolved in cottonseed oil, 4) determine the vitamin A value of red carrot, and 5) analyze testes and adrenals to determine if Mongolian gerbils distribute lycopene more like humans or rats. With the food matrices removed in one study, bioaccessibility was not a factor, leaving lycopene more like humans or rats. With the food matrices and adrenals to determine if Mongolian gerbils distribute lycopene in vivo using whole-food extracts dissolved in cottonseed oil, 4) determine the vitamin A value of red carrot, and 5) analyze testes and adrenals to determine if Mongolian gerbils distribute lycopene more like humans or rats. With the food matrices removed in one study, bioaccessibility was not a factor, leaving lycopene more like humans or rats. With the food matrices and adrenals to determine if Mongolian gerbils distribute lycopene in vivo using whole-food extracts dissolved in cottonseed oil, 4) determine the vitamin A value of red carrot, and 5) analyze testes and adrenals to determine if Mongolian gerbils distribute lycopene more like humans or rats. With the food matrices and adrenals to determine if Mongolian gerbils distribute lycopene more like humans or rats. With the food matrices and adrenals to determine if Mongolian gerbils distribute lycopene more like humans or rats.

Materials and Methods

Animals. Male 40-d-old Mongolian gerbils (n = 87) were obtained from Charles River Laboratories. Gerbils were individually housed in plastic shoebox cages and fed a carotenoid- and vitamin A-free diet ad libitum during the studies. Treatments were either mixed in the diets or dissolved in cottonseed oil and given orally. Gerbils were weighed daily and monitored for health until all were thriving, at which time, they were weighed every 2 d. One gerbil developed a noncontiguous inner-ear infection of Pseudomonas aeruginosa and was euthanized. Gerbils were killed by exsanguination while under isofluorane anesthesia. Blood samples were centrifuged at 2200 × g for 15 min in BD Vacutainer Gel and Clot Activator tubes (Becton Dickson) for serum isolation. Livers in both studies, and testes and adrenals in Study 2, were excised and stored at −80°C until vitamin A and carotenoid analyses. All animal handling procedures were approved by the College of Agriculture and Life Sciences Animal Care and Use Committee of the University of Wisconsin-Madison.

Diet. With the assistance of Harland Teklad, gerbil feeds were designed using white, carotenoid-free maize as the principle energy source. For the vitamin A-depletion phase, the basal diet was a 45% white maize feed (17). For the treatment phase of Study 1, treatments were the basal diet with added freeze-dried red carrot powder (1.2%) or tomato paste powder (0.7%) and twice daily oral cottonseed oil doses (3 mL). Blood samples were centrifuged at 1380 × g for 15 min in BD Vacutainer Gel and Clot Activator tubes (Becton Dickson) for serum isolation. Livers in both studies, and testes and adrenals in Study 2, were excised and stored at −80°C until vitamin A and carotenoid analyses. All animal handling procedures were approved by the College of Agriculture and Life Sciences Animal Care and Use Committee of the University of Wisconsin-Madison.

Carotenoid analysis of diet composition. Red carrot or tomato paste diet was weighed (0.6 g), β-apo-8’-carotenal was used as an internal standard, and the mixture extracted 3 times with hexane (3 mL); phases were separated by centrifugation at 1380 × g for 1 min. Combined extracts were washed with water (3 mL). The organic phase was placed in a test tube and the aqueous phase was extracted twice more with hexane. Organic phases were combined and dried under argon, reconstituted in dichloroethane:methanol (100 μL, 50:50, v:v), and injected (50 μL) into a Waters HPLC system (Waters Corporation) previously described (14). Lutein, zeaxanthin, β-cryptoxanthin, lycopene, α-carotene, and β-carotene HPLC purified standards and absorption spectra were used for identification. Chromatograms were generated at 432 and 472 nm.

Preparation of purified lycopene and whole-food extracts. Lycopene was extracted from tomato paste with hexane, acetone, and ethyl acetate. The resultant extract was concentrated, dissolved in hexane, and purified on a 2% water-deactivated neutral alumina column to isolate all-trans lycopene. The organic solvents were removed by rotary evaporation and sparging with argon; complete removal was verified by weight analysis. The resulting crystals were dissolved in cottonseed oil using a sonicator. Whole-food extracts were prepared by extracting freeze-dried tomato paste and red carrot powders with hexane, acetone, and ethyl acetate; evaporating completely; and dissolving in cottonseed oil. The carotenoid profiles of each treatment were determined by HPLC. All supplements were stored at −80°C until use.

Experimental design. Bioavailability of Lyc was compared with tomato paste and red carrot diets (Study 1) and oil extracts of freeze-dried tomato paste and red carrot (Study 2). After a 4-wk vitamin A-depletion phase in both studies, gerbils were sorted into weight-matched treatment groups (n = 10/group, except for control group in Study 2, n = 9) and placed on their respective treatments for 3 wk.

In Study 1 (n = 47), following depletion, a baseline kill (n = 7) established pretreatment tissue and serum vitamin A concentrations. Gerbils were divided into 4 groups and assigned to tomato paste diet, red carrot diet, basal diet + Lyc, or basal diet + oil. Red carrot and tomato paste diets were mixed to achieve an equalized lycopene concentration of 10 μg (18.6 nmol)/g feed. Gerbils consumed ~6 g feed/d, which was measured daily in the red carrot and tomato paste groups during the treatment phase; thus, ~60 μg lycopene/d was consumed. Lyc was given orally by pipette in 2 divided doses per day (~30 μg lycopene/45 μL oil). The amount of Lyc administered was based on the mean daily intake of the red carrot and tomato paste diet groups on the previous day. In Study 2 (n = 39), following depletion, the gerbils were divided into 4 groups, fed the basal diet, and dosed twice daily with red carrot extract, tomato paste extract, cottonseed oil, or Lyc. The oil doses (45 μL) were equalized for lycopene (30 μg lycopene/45 μL oil) to provide 60 μg lycopene/d.

Serum and tissue HPLC analyses. Modified published procedures were used for vitamin A and carotenoid analyses of serum and tissues (16). All samples were analyzed under gold fluorescent lights to prevent carotenoid photooxidation and isomerization. Retinyl butyrate was synthesized and used as an internal standard to determine extraction efficiency in serum and as an external standard to quantify retinol and retinyl esters. Serum (500 μL) was denatured with ethanol and extracted 3 times with hexane (1 mL) and dried under argon. Liver (0.6 g) was ground with ~3 g anhydrous sodium sulfate, extracted repeatedly with dichloromethane, and filtered into a 50-mL volumetric flask. An aliquot (3 mL) of the liver extract was dried under argon. For Study 2, pooled tests [n = 5 samples of 4 testes each, (2.3 ± 0.4 g)] and adrenal glands [n = 5 samples of 4 glands each, (0.090 ± 0.008 g)] were similarly extracted and the entire 50-mL extract was evaporated. Dried serum and tissue samples were reconstituted in methanol:dichloroethane (100 μL, 50:50, v:v) and injected (serum and liver, 50 μL; testes and adrenals, 75 μL) onto the HPLC (14).

Statistical analysis and calculations. Values are means ± SD. Data were analyzed using Statistical Analysis System software (SAS Institute, version 8.2). Outcomes of interest (i.e., gerbil weights, food and lycopene intakes, serum and tissue vitamin A, and lycopene concentrations) were evaluated using ANOVA at α < 0.05. Post hoc differences between treatment groups were determined using Fisher’s Least Significant Difference test at α < 0.05. Orthogonal contrasts were used to determine exact P-values for specific differences. Retinol utilization rates were calculated for the oil control group compared with the baseline group, and the vitamin A value of red carrot was estimated.

Results

Gerbil weights and intakes. Final gerbil weights did not differ between groups, except in Study 1, in which the younger baseline group weighed less (66.0 ± 3.6 g) compared with other groups (70.2 ± 5.4 g). Liver weights were not different in either study. Feed intake (6.0 ± 1.0 g/d) did not differ among groups.
Lycopene in diets, extracts, and purified supplements consisted primarily of the all-trans form (>96%), showing low variation among treatments (data not shown). Lycopene dosage for the Lyc group was based on feed intake in Study 1, and thus did not differ; total lycopene consumed during the 21-d feeding period was 1241 mg from tomato paste, 1265 mg from red carrot, and 1263 mg from Lyc. In Study 2, lycopene concentrations of food extracts and Lyc were equalized with cottonseed oil and delivered 1260 µg during the 21-d period.

**Vitamin A and carotenoid concentrations.** In Study 1, liver vitamin A in the red carrot group was higher than in the tomato paste, Lyc, and control groups (P < 0.003) and did not differ from baseline (Fig. 1). Surprisingly, liver vitamin A was slightly higher in the Lyc group than in the control group (P < 0.04) but did not differ from the tomato paste group. Liver lycopene in the tomato paste group was greater than the red carrot and Lyc groups (P < 0.0001). Liver lycopene was not different between the red carrot and Lyc groups. β-Carotene was found only in the livers of gerbils that received red carrot at low concentrations (2.27 ± 0.91 nmol/g), due to preferential conversion to vitamin A.

In Study 2, the effects of the food matrix were removed by using whole-food extracts dissolved in oil. Liver vitamin A was higher in the red carrot extract group than in the tomato-paste extract, Lyc, and control groups (P < 0.0001, Fig. 2). Liver lycopene was lower in the red carrot extract group than in the tomato-paste extract and Lyc groups (P < 0.0001), which did not differ from each other. As in Study 1, β-carotene was found only in livers from gerbils fed red carrot extract (3.76 ± 1.46 nmol/g).

The Study 1 control group had higher serum retinol concentrations than all other groups, whereas the opposite finding was observed in Study 2 (Table 1). In both studies, serum lycopene concentrations followed the same pattern as hepatic storage (Table 1), correlating with liver lycopene in Study 1 (r = 0.54, P < 0.003) and Study 2 (r = 0.64, P < 0.0001).

**Determination of utilization rate and vitamin A value of red carrot.** The retinol utilization rate during the treatment phase of Study 1 was determined for the control group and compared with the baseline group. A total of 0.249 µmol (71.2 µg) retinol disappeared from liver storage during this 21-d period. This corresponds to 0.012 µmol/d (3.4 µg/d for 70 g gerbils) or 4.9 µg/100 g body weight. The mean intake of the red carrot group was 551 µg (1.03 µmol) β-carotene during the treatment phase, which resulted in 86.9 µg retinol increase in the liver of the red carrot group compared with the control group. Considering the amount of retinol utilized and accumulated (i.e., 71.2 µg + 86.9 µg = 158.1 µg), the vitamin A value of the red carrot was 3.5 µg β-carotene to 1 µg retinol (i.e., 551 µg β-carotene consumed/158.1 µg retinol) in this vitamin A-depleted gerbil model. This does not take into account the α-carotene intake from the red carrot, which was low (26.7 µg during the treatment period).

The β-carotene consumed in the red carrot extract group was 448 µg (0.834 µmol) in Study 2 during the treatment phase and resulted in 121.3 µg retinol accumulation in the liver. Using the utilized retinol from the 21-d period in Study 1 and the retinol accumulated for Study 2 (i.e., 192.5 µg), the vitamin A value of the red carrot extract dissolved in oil was ~2.3 µg β-carotene to 1 µg retinol.

**Extrahepatic vitamin A and lycopene concentrations.** In study 2, adrenal lycopene concentrations in the tomato paste and Lyc groups were higher than in the red carrot group.
(P < 0.03). In the testes, lycopene was higher in the tomato paste group than in the red carrot and Lyc groups (P < 0.003), which were not different from each other. Retinol concentration in the testes did not differ between the groups, whereas for the adrenals, the red carrot group had more retinol than the tomato paste, Lyc, and control groups (P < 0.0001; Table 1).

**Discussion**

These studies show that lycopene is bioavailable in Mongolian gerbils and confirm previous findings in humans characterizing the relative bioavailability of carotenoids from red carrots and tomato paste (5). By removing the food matrix in Study 2, this work further suggests a possible interaction between β-carotene and lycopene that decreases lycopene bioavailability. This presumes that no other extracted compounds interacted with lycopene bioavailability. Finally, the vitamin A value of red carrot in this vitamin A-depleted model was estimated.

Tomato paste consumption from diet or an oil extract resulted in abundant liver lycopene, whereas red carrot or oil extract consumption resulted in less. When mixed into feed, red carrot resulted in slightly higher liver lycopene than Lyc, but red carrot extract resulted in lower liver lycopene than Lyc. These results may be partially explained by differences in lycopene delivery and gerbil eating patterns. The red carrot diet was consumed ad libitum and the absorption of lycopene was more incremental than the absorption from twice-daily lycopene doses. In addition, β-carotene supplements are quickly cleared in gerbils with 45 ± 19% of the recovered dose reaching the cecum at 3 h (20), indicating that the administration of carotenoids as a single bolus is less efficient than grazing patterns of intake.

One of the study aims was to assess the interaction of β-carotene and lycopene in vivo. Results from carotenoid interaction effects on bioavailability are ambiguous and sometimes contradictory (8). Negative interactions between lycopene and β-carotene have been observed in in vitro models (21) and in humans (5,22,23). By using an animal model with demonstrated utility for modeling human carotenoid bioavailability (14–18), we were able to determine hepatic storage of carotenoids, which is not possible in human studies or in vitro models. In Study 1, determinants of carotenoid bioavailability included differences in food matrix surrounding the carotenoids, differences in fiber content, and carotenoid interactions. After removal of the food matrix in Study 2 and equalizing lycopene among the supplements, the only apparent variable that differed between groups was the level of β-carotene intake, presuming that other extractable compounds did not differ between groups. Because liver lycopene storage was significantly lower in the red carrot group than in the tomato paste group, regardless of matrix (food matrix in Study 1 and oil in Study 2), we hypothesize that carotenoid interaction was the major factor reducing lycopene bioavailability from red carrots and extracts. Additionally, consumption of red carrot extract in oil resulted in lower liver lycopene compared with Lyc, further indicating a negative interaction of β-carotene and lycopene. However, red carrot and tomato extracts were not evaluated for other lipid-soluble compounds, which may have interfered with or enhanced lycopene bioavailability.

Whereas humans and rodents have unique storage patterns for lycopene, storage of vitamin A is fairly uniform, with 80–90% stored in the liver during vitamin A adequacy. As expected, liver vitamin A was highest in gerbils consuming β-carotene-rich red carrots. In Study 1, red carrot diet consumption maintained vitamin A status at baseline levels, and in Study 2, red carrot extract resulted in even higher liver vitamin A values. These results concur with the calculated conversion factors of 3.5 μg β-carotene to 1 μg retinol for red carrot and 2.3 μg β-carotene to 1 μg retinol for the oil extract in this vitamin A-depleted model. In a vitamin A-sufficient gerbil model (16), conversion factors for typical orange carrots were ~9–11 μg β-carotene to 1 μg retinol and ~23 μg β-carotene to 1 μg retinol for dark-orange carrots containing 2 times more β-carotene (24). These results are not conflicting but support our prior finding (17) that vitamin A status and the amount of carotenoid consumed are 2 major factors that affect bioefficacy of dietary β-carotene conversion to retinol.

Unlike liver storage, serum retinol concentration is not a useful indicator of vitamin A status because it is homeostatically

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**TABLE 1** Serum, testes, and adrenal retinol and lycopene concentrations in 2 studies of Mongolian gerbils

<table>
<thead>
<tr>
<th>Group</th>
<th>Retinol</th>
<th>Lycopene</th>
<th>Retinol</th>
<th>Lycopene</th>
<th>Retinol</th>
<th>Lycopene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>1.81 ± 0.09a</td>
<td>ND</td>
<td>1.65 ± 0.21a</td>
<td>40.0 ± 6.1b</td>
<td>0.70 ± 0.14</td>
<td>0.0092 ± 0.0023b</td>
</tr>
<tr>
<td>RC</td>
<td>1.26 ± 0.17b</td>
<td>34.0 ± 15.0b</td>
<td>0.70 ± 0.14</td>
<td>0.0092 ± 0.0023b</td>
<td>1.36 ± 0.56b</td>
<td>0.58 ± 0.30b</td>
</tr>
<tr>
<td>TP</td>
<td>1.31 ± 0.12b</td>
<td>51.7 ± 19.8a</td>
<td>0.67 ± 0.15</td>
<td>0.034 ± 0.015a</td>
<td>0.21 ± 0.068b</td>
<td>1.26 ± 0.35a</td>
</tr>
<tr>
<td>Lyc</td>
<td>1.30 ± 0.25a</td>
<td>17.5 ± 4.6c</td>
<td>0.62 ± 0.15</td>
<td>0.013 ± 0.0032b</td>
<td>0.20 ± 0.11b</td>
<td>1.38 ± 0.55a</td>
</tr>
<tr>
<td>Con</td>
<td>1.63 ± 0.17a</td>
<td>ND</td>
<td>0.64 ± 0.081</td>
<td>ND</td>
<td>0.093 ± 0.023b</td>
<td>ND</td>
</tr>
</tbody>
</table>

1 Values are means ± SD. Serum, n = 10 except for control group in Study 2 (n = 9); testes and adrenals, n = 5, with tissues pooled for analysis, i.e., pairs of adrenals and testes from 2 gerbils were combined for 1 sample analysis. Within a study, means in a column with superscripts without a common letter differ, P < 0.05.

2 Includes retinol and retinyl esters.

3 Base, baseline; Con, control; Lyc, purified lycopene; ND, not detectable; RC, red carrot diet; RCE, red carrot extract; TP, tomato paste diet; TPE, tomato paste extract.

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controlled and decreases only under severe vitamin A deficiency (25,26), defined as 0.07 μmol/l liver. In the current study, the lowest liver vitamin A values were twice as high as the cutoff for deficiency, thus serum retinol concentrations were not outside of the homeostatically controlled range. Although differences between groups were significant within a study, serum retinol concentrations were all normal in these gerbils. Serum lycopene concentrations reflected liver lycopene, despite a previous void of serum-liver correlations for other carotenoids (16,17,19). Serum lycopene concentrations may serve as an indicator of liver lycopene storage or intake in Mongolian gerbils, despite differences in the lipoprotein profiles of gerbils and humans (27). However, the correlations were found within each study and Study 2 had higher serum lycopene concentrations than Study 1, despite similar intakes. Carotenoids in general are quickly cleared in gerbils (20) and they were killed ≥17 h after the final dose. Future studies should evaluate lycopene distribution in gerbils in the context of other carotenoids.

The liver and serum lycopene values differed for the Lyc groups between Study 1 and Study 2. Identical extraction and purification procedures were followed in preparing the Lyc doses. In Study 1, the lycopene content of Lyc was quantified from spectrophotometric analysis using the E 1 cm1% . In Study 2, Lyc was analyzed on HPLC and a lycopene standard was used for quantification using the same spectrophotometric analysis. In Study 1, the dose was adjusted daily to the prior day’s intake and in Study 2 the dose was standard each day. The difference found between the studies for total liver lycopene storage represents a mere 1.4% of the supplemental lycopene administered during the 21-d period. This is experimentally acceptable considering the vast difference both within and between humans when fed identical carotenoid supplements (28). Moreover, the 2 studies were done at different times of the year, making environmental influences a possible cause of the difference across studies. Even with climate control, we observed that gerbils can appear more stressed during some studies than in others.

Recent work has demonstrated intriguing connections between lycopene and androgen metabolism in rats (29). In men, androgens are synthesized in the testes, modified by the prostate, and required for growth and development. However, perturbations in androgen signaling may be associated with the development of prostate cancer (30). Indeed, serum concentrations of testosterone, dihydrotestosterone, and testosterone metabolites are associated with prostate cancer risk (31). Lycopene intake influences androgen metabolism and signaling in the prostate and may offer protection against carcinogenesis (32). Whether the effects of lycopene are mediated by its antioxidant activity or the actions of its lycopene derivatives is under investigation (33). We collected 2 steroidogenic tissues (testes and adrenals) to further investigate this phenomenon by determining extrahepatic compartmentalization of lycopene in Mongolian gerbils. Humans can store up to 9 times more lycopene in the adrenals and testes compared with liver (34), whereas hepatic storage dominates in rats. Similar to rats, these data indicate that gerbils compartmentalize more lycopene in the liver, storing 60 times more than in the adrenals and several thousand times more in testes.

In a sensory evaluation of different colored carrots with Americans, red carrots were well accepted and compared favorably to other varieties in flavor, sweetness, and crispness (35). Additional investigation of sensory characteristics and acceptance of red carrots in other populations, especially where vitamin A deficiency exists, will determine whether this food is a viable complement to help solve this daunting nutritional problem. Red carrot promotion as a functional food may be a sustainable whole-food-based approach (36), providing other health benefits in addition to resolving the sequelae of vitamin A deficiency. Because dietary sources of lycopene are few and the red carrot offers bioavailable β-carotene and lycopene, it is a potential functional food, similar to tomato (37), in the arena of preventing both nutritional deficiency and chronic disease in carrot-consuming countries.

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