Carotenoid content of fruits and vegetables: An evaluation of analytic data

ANN REED MANGELS, PhD, RD; JOANNE M. HOLDEN, MS; GARY R. BEECHER, PhD; MICHELE R. FORMAN, PhD; ELAINE LANZA, PhD

ABSTRACT: The test of the association between dietary intake of specific carotenoids and disease incidence requires the availability of accurate and current food composition data for individual carotenoids. To generate a carotenoid database, an artificial intelligence system was developed to evaluate data for carotenoid content of food in five general categories, namely, number of samples, analytic method, sample handling, sampling plan, and analytic quality control. Within these categories, criteria have been created to rate analytic data for β-carotene, α-carotene, lutein, lycopene, and β-cryptoxanthin in fruits and vegetables. These carotenoids are also found in human blood. Following the evaluation of data, acceptable values for each carotenoid in the foods were combined to generate a database of 120 foods. The database includes the food description; median, minimum, and maximum values for the specific carotenoids in each food; the number of acceptable values and their references; and a confidence code, which is an indicator of the reliability of a specific carotenoid value for a food. The carotenoid database can be used to estimate the intake of specific carotenoids in order to examine the association between dietary carotenoids and disease incidence. *J Am Diet Assoc. 1993; 93:284-296.*

J. M. Holden (corresponding author), A. R. Mangels, and G. R. Beecher are with the Beltsville Human Nutrition Research Center, US Department of Agriculture, Beltsville, MD 20705. M. R. Forman and E. Lanza are with the Division of Cancer Prevention and Control, National Cancer Institute, National Institutes of Health, Bethesda, MD 20892.

In numerous epidemiologic studies, an increased intake of fruits and vegetables is associated with a reduced risk of lung and other epithelial cancers (1-10). The odds ratios of lung cancer are higher among subjects with lower (vs higher) intakes of carrots, tomatoes, and dark-green vegetables, which are foods rich in specific carotenoids (4,5,11). Thus, consumption patterns of foods rich in carotenoids, such as lycopene, lutein, and β-carotene, need to be examined with a food composition database of specific carotenoid values. Food composition tables in current use provide data on total vitamin-A activity (eg, reference 12) or total carotenoid content (eg, reference 13) of foods. In the past, carotenoids were viewed primarily as vitamin-A precursors so analytic efforts centered on carotenoids with provitamin-A activity (14).

In addition to lacking data for individual carotenoids, most food composition tables contain carotenoid data generated by procedures similar to the official methods of the Association of Official Analytical Chemists (AOAC). These procedures, as described by Beecher and Khachik (15), quantify total carotenoid rather than individual carotenoids and tend to overestimate total carotenoid content and, subsequently, vitamin-A activity of plant foods (16). Although a few food tables express carotenoid data on a weight basis (micrograms per 100 g), most present carotenoid content of fruits and vegetables as international units, retinol equivalents, or β-carotene equivalents (15). The recent use of high-performance liquid chromatography (HPLC) for the separation and quantification of carotenoids has resulted in an increase in data quantifying the amount of individual carotenoids in foods. The quality of data varies by type and execution of the analytic method, by sample selection and handling, by the number of samples analyzed, and by the presence or absence of quality control procedures.

Fruits and vegetables are rich in carotenoids and are the most important contributors of carotenoids in the typical human diet (17). Multicomponent foods that contain notable amounts of vegetables or fruits may also be good sources of carotenoids; however, few reports of the carotenoid content of mixed dishes are available for foods commonly consumed in the United States. Limited data for dairy products, eggs, fats, and cereals indicate that these foods contain modest levels of carotenoids (17). Meats and fish contain low levels of carotenoids (18,19).

In this article, we describe the development of a carotenoid food composition database that contains values for the five most commonly occurring carotenoids in fruits and vegetables. These carotenoids are also among those found in human plasma. An artificial intelligence system was used to rate existing information on the carotenoid content of foods. The purpose of this article is to describe the components of the evaluation system, to document the carotenoid values of specific foods along with a range of acceptable values, and to indicate the extent to which the data are considered reliable.

Categories	3	2	1	0
Analytic method	Published documentation with validation for foods analyzed, including use of appropriate reference material, with results within acceptable range or 95% to 100% recoveries on similar food and use of other method or laboratory on same sample with agreement within 10%; exemplary processing and saponification of sample and identification and quantification of carotenoid.	Some documentation; incomplete validation studies; including 90% to 110% recoveries on similar foods or use of other method or laboratory on same sample with agreement within 10%; adequate processing and saponification of sample and identification and quantification of carotenoid.	Some documentation; minimal validation; including <8% CV for repeatability or 8% to 20% CV for repeatability along with 80% to 120% recoveries on similar food to sample or use of other method or laboratory on related food with agreement within 10%; minimally acceptable processing and saponification of sample and identification and quantification of carotenoid.	No documentation of method, no reference or inacessible reference given; nonchromatographic method used; no validation studies or failure to achieve acceptable results with reference material, repeatability (≥20% CV), recovery (<80% or >120%), or comparison method or laboratory; inadequate processing or saponification of sample or identification or quantification of carotenoid.
Analytic quality control	Optimum accuracy and precision of method monitored and indicated explicitly by data.	Documentation of assessment of both accuracy and precision of method; acceptable accuracy and precision	Some description of minimally acceptable accuracy and/or precision.	No documentation of accuracy or precision; unacceptable accuracy and/or precision.
No. of samples	>10; SD, SE, or raw data reported	3 to 10	1 or 2; explicitly stated or not specified	—
Sample handling	Complete documentation of procedures, including analysis of edible portion only, validation of homogenization method, details of food preparation, and monitoring of storage and moisture changes.	Pertinent procedures documented, including analysis of edible portion only; procedures seem reasonable but some details not reported.	Limited description of procedures, including evidence of analysis of edible portion only.	Totally inappropriate procedures or no documentation of criteria pertinent to food analyzed.
Sampling plan	Multiple geographic sampling with description of and statistical basis for sampling and sample representative of brands/varieties consumed or commercially used.	At least two geographic regions sampled; sample is representative.	One geographic area sampled; sample is representative of what some eat.	Not described or sample is not representative.

FIG 1. Summary of data-quality criteria. Key: SD = standard deviation; SE = standard error; CV = coefficient of variation.

METHODS

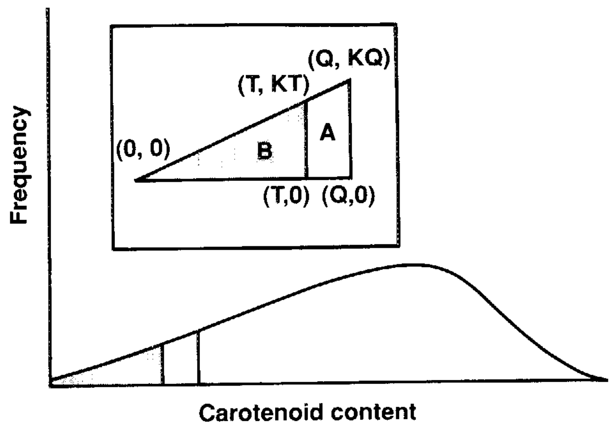
A system was developed for the evaluation of analytic data for levels of five carotenoids in foods: β-carotene, α-carotene, lutein + zeaxanthin, lycopene, and β-cryptoxanthin. This system was based on those previously described for the evaluation of selenium and copper data (20-22), but was modified to accommodate carotenoid data evaluation. Objective evaluation was aided by use of an artificial intelligence system that incorporated standardized questions and decision pathways (23).

Development of the Evaluation System

Data were evaluated in five general categories: analytic method, analytic quality control, number of samples, sample handling, and sampling plan. These categories represent the major determinants of data quality and inclusion in the database.

Specific criteria were developed for each category; ratings for each ranged from 0 (unacceptable) to 3 (highly acceptable) (Figure 1). Criteria for both analytic method and analytic quality control were developed to address the acceptability of methodology for carotenoid analysis and were based on extensive discussion with experts in carotenoid determination. Within analytic method, we evaluated the steps involved in sample processing; carotenoid separation, identification, and quantification; and validation of the chosen method. Analytic quality control rated both day-to-day accuracy and precision of carotenoid determination. Criteria for number of samples and sample handling were the same as those used for evaluation of selenium (21) and copper (22). Sampling-plan criteria were modified from those used for selenium and copper, based on knowledge of appropriate sampling strategies for food, to incorporate the international nature of the carotenoid database. After the criteria were established, decision trees were developed for each category to simulate the human decision-making process that takes place in data-quality evaluation. (Further details related to data-quality criteria and decision trees can be requested from the authors.)

The category-specific criteria and decision trees were incorporated into artificial intelligence software. The user-friendly system queried for specific information in each category. Questions probed for specific details of steps such as sample processing, saponification, carotenoid identification and quantification, and validation of the analytic method to determine the most appropriate rating. Most questions required a yes or



The distribution of possible analytic values for a given component can assume several shapes (eg, normal, skewed). The curve represents the frequency distribution of values for the component of interest. Therefore, the area under the curve is related to the frequency of occurrence of individual values. The quantitation limit (Q) bisects the curve of the distribution.

To quantify trace, it was necessary to determine the point on the x-axis at which the area under the curve from 0 to that point is half the area under the curve from 0 to the quantitation limit. Thus, half the values in this region lie below this point (T).

Although the curve is not linear, it can be approximated, below the quantitation limit, by the hypotenuse of a right triangle (A). The vertical line through the quantitation limit (Q) is the height of the triangle while the base is the distance from 0 to Q on the x-axis. The area of right triangle A is $1/2KQ^2$ when the equation of the line representing the hypotenuse is $y=Kx$ and $x=Q=$ quantitation limit.

To determine a value for point T, or trace, we chose a second triangle (B) so that the area of B was half the area of A. Thus, the area of $B=1/2(1/2KQ^2)=1/2KT^2$. Simplifying, $T=1/(2^{1/2})Q$. Trace can be approximated by 0.71 times the quantitation limit.

FIG 2. Quantitation of "trace" level of a carotenoid.

no response; a few were multiple choice or required a numeric response. Responses were based on information from published or selected internal reports containing carotenoid values for foods. Decision paths were dependent on the user's response so that only pertinent questions were asked. Decisions and scoring limiters were invisible to the user, thus eliminating much of the subjectivity associated with manual evaluation.

Data Compilation

Only those studies that used a chromatographic procedure were evaluated. We reviewed more than 180 articles published from 1971 to 1991, including articles on methodology and composition. When published information was limited, especially regarding method validation and analytic quality control, we contacted authors to obtain additional details. We reviewed 34 responses to 60 queries; 23 of these led to an improvement in the rating in one or more categories. However, there are no assurances that similar improvements would have resulted from the 26 remaining nonrespondents.

Several calculations were performed as needed on published data. Dry-weight values with accompanying moisture values were converted to wet weight and considered for inclusion in the database. Results that were expressed on a dry-weight basis without accompanying moisture values were excluded from the database. Values expressed as carotenal fatty-acid esters were converted to the amount of the individual carotenoid present using a ratio of the molecular weight of the carotenoid to the molecular weight of the carotenal fatty acid ester, multiplied by the amount of the carotenal fatty acid ester.

If a carotenoid was reported as not detected, a value of zero for that carotenoid was assumed. Preliminary assessment of collected data sources indicated that some authors reported a value of "trace." We collaborated with statisticians to quantify "trace" and used a technique adapted during our study. The trace value was estimated as the product of the quantitation limit of the analytic method and a factor, 0.71. The quantitation limit for a specific assay is the lowest point at which the method can quantify the amount of a component in the sample. In practice, the quantitation limit is some multiple of the analytic detection limit. Among analysts that multiple is determined by convention for the specific instrumentation used and component of interest. For HPLC, the quantitation limit is generally defined as 2.5 times the detection limit. If the detection limit (or quantitation limit) was not cited by authors in the same or another reference, we used the convention of 1 µg/100 g for the detection limit. This convention is based upon our review of stated detection limits from acceptable studies (24-27). Figure 2 illustrates the derivation of 0.71 as the multiplier for the quantitation limit.

The procedure used by a number of investigators did not permit separation of lutein and zeaxanthin so we decided to report lutein + zeaxanthin. In the few references where lutein and zeaxanthin were independently measured, their values were summed and reported as lutein + zeaxanthin. Because green vegetables, green fruits, pumpkin, winter squash, and carrots contain essentially no zeaxanthin (28), the values for lutein + zeaxanthin for these foods represent primarily lutein. Peaches and corn contain both lutein and zeaxanthin in varying ratios (24,29).

Data Evaluation

In the evaluation process, we rated each carotenoid value for a food in a specific reference by answering questions in each category posed by the artificial intelligence system. Table 1 provides an example of ratings assigned to various references for β-carotene in winter squash. Next, a Quality Index, an indicator of the overall data quality for a carotenoid value in a food from a single reference or study, was calculated. In general, the mean of the five ratings was designated the Quality Index, as shown in Table 1. When the rating for analytic method was zero or when any three ratings were zero, the Quality Index for that value was set to zero. A Quality Index of one or more indicated an acceptable value and was retained.

Initially, similar foods were grouped into preliminary aggregates. For example, as shown in Table 1, the aggregate titled "squash, winter, cooked, canned, frozen" includes microwaved fresh acorn squash, frozen cooked butternut squash, and unspecified canned winter squash. After all available data were evaluated, acceptable values were reviewed to assess the suitability of the preliminary aggregations. For similar forms of a single food, all acceptable data were grouped together under the general food description. If data were widely divergent and clearly stratified by distinct forms of the food, then the forms of that food were separated into two or more new aggregates. For example, pink and white grapefruit were initially aggre-

Table 1
Worksheet for β-carotene in winter squash (cooked, canned, frozen)

Description	Reference[a]	Data quality criteria ratings: No. of samples — Actual no.	No. of samples — Rating	Analytic method	Sample handling	Sampling plan	Quality control	Quality[b] Index	β-Carotene value
									μg/100g
Acorn, fresh, microwaved 8 min	o	3	2	2	1	1	1	1.4	490[c]
Frozen, commercial	p	4	2	1	1	1	1	1.2	2,670 ± 6[d]
Butternut, cooked 20 or 40 min	q	4	2	1	1	1	1	1.2	4,570 ± 12
Canned	r	2	1	1	1	1	1	1.0	923
Pressure cooked	s	2	1	1	1	1	1	1.0	2,800
Canned	t	3	2	1	1	0	0	0.8	1,250 ± 180
Frozen, cooked	u	3	2	1	1	2	0	1.2	2,400 ± 570
Frozen, cooked	v	3	2	1	1	2	0	1.2	1,400 ± 600
Acorn, frozen	w	1	1	1	1	1	0	0.8	300
Butternut, frozen, cooked	x	2	1	1	1	2	0	1.0	850 ± 350
Butternut, frozen, cooked	y	3	2	1	1	2	0	1.2	3,600 ± 1,600
Frozen, cooked	z	2	1	0	1	1	1	0[e]	800

Summary: Quality Sum[f] = 10.4; confidence code[g] = A; median[h] = 2,400 μg/100 g; minimum-maximum[h] = 490 to 4,570 μg/100g

[a]Although the data, including ratings, are authentic, the references are coded.
[b]A Quality Index ≥1 is required for data to be considered acceptable.
[c]Mean.
[d]Mean ± standard deviation.
[e]Because of zero rating for analytic method, Quality Index is zero.
[f]The sum of the Quality Indexes for acceptable references; it serves as the basis of the confidence code.
[g]The confidence code is derived from the Quality Sum.
[h]The median, minimum and maximum are based on the acceptable means. In this case, acceptable values are from references o-s, u, v, x, y.

gated as "grapefruit, raw." Lycopene and β-carotene consistently appeared to be markedly higher in pink grapefruit; therefore, pink grapefruit and white grapefruit were listed separately.

However, if the acceptable data for a single food were highly variable but no logical pattern of variance could be identified, the data were retained under the single description. Frequently, both cooked and raw forms of a food were aggregated because insufficient data existed to support their separation. Although season, geographic location, harvest conditions, and many other factors can influence carotenoid levels, the amount of available data per food is insufficient at present to permit aggregation based on these factors. In general, the final aggregation of data was chosen on the basis of approximate similarity of food descriptions within the aggregate.

Table 2
Assignment and meaning of confidence codes

Sum of Quality Indexes	Confidence code	Meaning of confidence code
>6.0	A	The user can have considerable confidence in this value.
3.4 to 6.0	B	The user can have confidence in this value; however, some problems exist regarding the data on which the value is based.
1.0 to <3.4	C	The user can have less confidence in this value because of limited quantity and/or quality of data.

Development of Tables on Individual Carotenoids in Foods

For each aggregate, we calculated the median and mean for each carotenoid. After comparisons of the mean and median for individual aggregates, the median was selected as a measure of central tendency because of the skewed nature of some data. Use of the median tends to reduce the impact of a single observation (30). Some foods had divergent means and medians, which supported the rationale for reporting medians rather than means. For example, for the seven β-cryptoxanthin values for orange juice reported in acceptable studies (14.3, 14.9, 16.4, 23.7, 24.7, 460, and 488.7 μg/100 g), the grand mean is 150 μg/100 g whereas the median is 24 μg/100 g. For the four α-carotene values reported for raw winter squash (0, 0, 23.7, and 935 μg/100 g), the grand mean is 240 μg/100 g whereas the median is 12 μg/100 g. (Zero represents values reported as not detected at a detection limit specified in the acceptable references.)

We used reported values to calculate the median of each carotenoid for an aggregate, with equal weighting of each value. Because 1 μg/100 g is the common detection limit for HPLC determination of carotenoids (24-27), medians with digits to the right of the decimal point were rounded using standard procedures (30). The median was also rounded to reflect the least number of significant digits in any value contributing to the median.

Variability of data (as expressed by minimum and maximum values) and the number and citations of acceptable references were documented for each food aggregate and carotenoid. After all studies were evaluated, and Quality Indexes were assigned, a Quality Sum, that is, the sum of the acceptable Quality Indexes for a food aggregate, was determined. The Quality Sum is an indicator of the relative strength of a data set for a food. Finally, a confidence code was assigned on the

a. The consensus of experts in carotenoid analysis is that this food does not contain detectable levels of this carotenoid. Impute the carotenoid level as 0.

b. Carotenoid present in similar food. For imputation purposes, cooked broccoli was used to estimate missing values for asparagus; guava for guava juice; white cabbage for iceberg lettuce; raw peach for raw nectarine; cucumber for okra; orange juice for oranges; green pepper for red pepper; tangerine juice for tangerines; tomato for tomato juice, tomato paste, and tomato sauce; and a mixture of greens (mustard greens, kale, parsley, raw spinach, and cooked spinach) for beet greens, chicory, cress leaf, endive, collard greens, romaine lettuce, and swiss chard. Impute carotenoid using the ratio of the missing carotenoid to β-carotene in similar food multiplied by the β-carotene content of the food with missing carotenoid.

c. Impute using unpublished preliminary data for guava from Nutrient Composition Laboratory, Beltsville Human Nutrition Research Center, Agriculture Research Service, Beltsville, Md.

d. Impute value from similar food with highly similar levels of other carotenoids. For imputation purposes, carotenoid content of cloud berries (29) was used to replace missing values for blueberries, raw broccoli for cooked broccoli, and raw carrots for cooked carrots.

e. Impute based on unpublished preliminary data, 1988, for blueberries from Arthur D. Little, Inc, Cambridge, Mass.

FIG 3. Methods for imputing missing carotenoid data.

basis of the Quality Sum (Table 2).

The confidence code—either "A", "B", or "C"—is an indicator of the relative quality of the data and of the confidence a user can have in each median. Confidence codes of "A", "B", or "C" all indicate that data were acceptable for inclusion in the database of carotenoids in foods. A confidence code of "A" indicates considerable confidence, due either to a few exemplary studies or to a large number of studies of varying quality. Unacceptable data were not included in the database but were archived as a record of their evaluation.

Missing carotenoid values were estimated for some foods using composition data for similar foods. For example, only a limited number of foods are known to contain β-cryptoxanthin; after we consulted experts in the area of carotenoid analysis, if no data were available for the β-cryptoxanthin content of a food and the food was botanically similar to foods not containing β-cryptoxanthin, we imputed a value of 0 for this component. Figure 3 lists the imputation procedures that were used. (Full details of the imputation process are available from the authors.)

RESULTS

Tables 3 and 4 provide information on the carotenoid content of fruits and vegetables, the most important food sources of carotenoids. These tables include a median for each food as well as minimum and maximum values where more than one acceptable study was reported. A confidence code, based on both the quality and quantity of existing data, is associated with each carotenoid value. All values in Tables 3 and 4 derive from analytic data.

Table 5 includes the number of acceptable values and a listing of acceptable references for each entry. These references provide the user with helpful information concerning the source of acceptable values for a food and permit independent review of individual references by interested users.

Imputed data for carotenoids in fruits and vegetables can be found in Table 6. The method by which these values were determined is indicated.

DISCUSSION

The preceding tables represent the most comprehensive estimates of individual carotenoids in fruits and vegetables. These estimates are derived from critically evaluated published and unpublished sources. Users can review the specific criteria to better understand the rating process and the meaning of the confidence codes assigned to the data. Heinonen and others (18,19,27,31,32) have published limited data for meats, grains, dairy products, fats and oils, and other foods that suggest that these foods are relatively poor sources of carotenoids. Information on the carotenoid content of these products in the United States is not available and represents an area for future research.

Results in Tables 3 and 4 present a median based on all acceptable studies. We used minimum and maximum values to illustrate variability of food carotenoid levels because all acceptable citations did not provide standard deviations, which are essential for calculation of variance across studies. Additionally, the limited number of acceptable values for many foods would give little meaning to the concept of a standard deviation or other measure of variability.

Note that the minimum and maximum values for a food are really the minimum and maximum means reported by the sources cited. Unless a study contained only one analytic value for a food, reported values are means of several determinations (range 1 to 60, typically 4 or 5). Therefore, the minimum and maximum values presented in this report do not reflect the full variability that might be observed if we had access to individual values.

We considered various schemes for weighting acceptable values in computation of the median. Weighting based on the number of samples in each study was rejected because this would attach greater significance to the number of samples category than to the other categories that affect data quality. A lack of standard reference materials and quality-control procedures precluded rating based on analytic method or quality control category scores. Weighting based on Quality Index score was also rejected because of the narrow range of Quality Indexes and the resulting lack of resolution. In the future, as the amount of acceptable data increases, a weighting strategy could be devised based on the overall quality of the data, the quality of the sampling plan used, the number of samples, or some other as yet undetermined factor.

Although we believe the carotenoid values in these tables are the best available estimates of carotenoids in fruits and vegetables, there are specific limitations in the quantity and quality of data. For example, 9% of the foods in the carotenoid database had an "A" confidence code compared with 25% and 14% of foods in the selenium (21) and copper (22) databases, respectively, that had confidence codes of "A." The limited quantity of the data is illustrated by the following: 61% of foods

Table 3
Carotenoid content of fruits and vegetables derived from analytic data[a,b]

Aggregate	β-Carotene			α-Carotene			Lutein+zeaxanthin			Lycopene		
	Median	Min-max	Conf code[c]	Median	Min-max	Conf code	Median	Min-max	Conf code	Median	Min-max	Conf code
	← μg/100g →			← μg/100g →			← μg/100g →			← μg/100g →		
Apple, raw	26	12-39	C	0[d]	0-0	C	45	42-48	C	0	0-0	C
Apricot, canned, drained	1,500[e]	560-19,270	B	0	...	C	2	0-3.5	C	65	...	C
Apricot, dried	17,600[e]	551-34,630	C	...	...	...	0	...	C	864	...	C
Apricot, raw	3,524	615-6,433	C	0	...	C	0	...	C	5	...	C
Asparagus, raw	449	317-581	C	9	0-17	C	...	...	...	...	...	...
Avocado, raw	34	...	C	...	...	...	320	...	C	...	...	...
Banana, raw	0	0-14	C	0	0-12	B	0	0-3.3	C	0	0-0	C
Basil, not dried	350	266-510	B	...	...	...	...	...	...	...	...	...
Beet greens	2,560	2,181-5,028	B	3	0-14	B	...	...	...	...	...	...
Beet, canned	1	...	C	0	...	C	4	...	C	0	...	C
Bitter melon, raw	50	...	C	...	...	...	...	...	...	...	...	...
Blueberries	...	...	...	0	...	C	...	...	...	...	...	...
Bottle gourd, raw	4	...	C	...	...	...	...	...	...	...	...	...
Broccoli, cooked	1,300	1,000-2,600	A	...	...	...	1,800	830-4,300	A	...	...	...
Broccoli, raw	700	480-1,080	A	1[e]	0-73	B	1,900	1,800-2,060	C	0	...	C
Brussels sprouts	480	340-1,100	A	6	0-11	C	1,300	920-1,590	A	0	...	C
Cabbage, chinese, bok choy, raw	62	15-110	C	1	...	C	40	...	C	0	...	C
Cabbage, chinese, wild	530	100-970	B	...	...	...	...	...	...	...	...	...
Cabbage, red, raw	15	...	C	1	...	C	26	...	C	0	...	C
Cabbage, white	80[e]	0-410	A	0	0-1	C	150	0-310	C	0	0-0	C
Cantaloupe, raw	3,000[e]	1,643-25,496	A	35	9-61	C	0	...	C	0	...	C
Carrot, cooked, canned, frozen	9,800	4,760-26,900	A	3,700	2,200-7,800	A	...	...	...	0	...	C
Carrot, raw	7,900	1,830-14,700	A	3,600	530-8,500	A	260	...	C	0	...	C
Carrot, A+ variety, raw	18,250	...	C	10,650	...	C	...	...	...	0	...	C
Carrot, A+ variety, cooked	25,650	...	C	15,000	...	C	...	...	...	0	...	C
Cashew apple, raw	155	85-225	C	14	8.5-18	C	...	...	...	...	...	...
Cashew apple juice	80	...	C	...	...	...	...	...	...	...	...	...
Cassava leaf	3,000	2,820-3,100	C	...	...	...	...	...	...	...	...	...
Cauliflower	8[e]	0-430	B	0	0-0	B	33[e]	0-230	B	0	0-0	C
Celeriac, raw	0	...	C	0	...	C	1	...	C	0	...	C
Celery	710	0-2,900	B	0	0-0	C	3,600	0-7,200	C	0	0-0	C
Chicory leaf, raw	3,430	...	C	...	...	...	...	...	...	...	...	...
Coriander, not dried	2,000	1,692-4,700	C	...	...	...	...	...	...	...	...	...
Corn, yellow	51	8-74	C	50	...	C	780	500-2,300	A	0	...	C
Cranberries, raw	22	...	C	1	...	C	28	...	C	0	...	C
Cress leaf, raw	4,150	...	C	...	...	...	...	...	...	...	...	...
Cucumber pickle	180	...	C	0	...	C	510	...	C	0	...	C
Cucumber, raw	6[e]	0-130	C	0	0-0.9	C	240	0-470	C	0	0-0	C
Currants, raw	62	25-99	C	0	0-0.9	C	240	47-440	C	0	0-0	C
Dill, not dried	4,500	...	C	0	...	C	6,700	...	C	0	...	C
Eggplant	35	9-87	B	...	...	...	...	...	...	...	...	...
Endive	1,300	960-1,720	C	...	...	...	...	...	...	...	...	...
Fennel leaves	4,440	...	C	...	...	...	...	...	...	...	...	...
Grapefruit, pink, raw	1,310	279-2,343	C	0	...	C	0	...	C	3,362	...	C
Grapefruit, white, raw	14[e]	2.3-248	B	1[e]	0.9-8	B	10	...	C	0	...	C
Grapes, raw	33	...	C	1	...	C	72	...	C	0	...	C
Green beans	630	180-810	A	44	39-64	C	740	440-1,100	B	0	...	C
Greens, collard	5,400	5,400-5,510	B	...	...	...	...	...	...	...	...	...
Greens, fiddlehead	1,950	1,640-2,050	B	280	190-331	B	...	...	...	...	...	...
Greens, mustard	2,700	80-7,400	B	...	...	...	9,900	9,400-10,400	C	...	...	...
Guava juice	270	...	C	...	...	...	...	...	...	3,340	...	C
Guava, raw	812	435-1,190	C	...	...	...	...	...	...	5,400	5,340-5,500	C
Jackfruit, raw	23	...	C	...	...	...	...	...	...	...	...	...
Jellies, jams, preserves	16	...	C	1	...	C	6	...	C	0	...	C

Continued on next page

Table 3
Carotenoid content of fruits and vegetables derived from analytic data[a,b] (cont)

Aggregate	β-Carotene			α-Carotene			Lutein+zeaxanthin			Lycopene		
	Median	Min-max	Conf code[c]	Median	Min-max	Conf code	Median	Min-max	Conf code	Median	Min-max	Conf code
	← μg/100g →			← μg/100g →			← μg/100g →			← μg/100g →		
Kale	4,700	2,840-14,600	A	...	...	...	21,900	14,700-39,550	B	...	...	...
Kale, chinese	140	55-230	C	...	...	...	...	...	...	...	...	...
Kiwi fruit, raw	43	...	C	0	...	C	180	...	C	0	...	C
Leek, raw	1,000	...	C	0	...	C	1,900	...	C	0	...	C
Lemon, raw	3	...	C	0	...	C	12	...	C	0	...	C
Lettuce, iceberg	480	330-630	C	4	...	C	...	...	...	...	...	...
Lettuce, leaf	1,200	980-1,450	C	1	...	C	1,800	...	C	0	...	C
Lettuce, romaine	1,900	1,200-3,000	B	...	...	...	...	...	...	...	...	...
Lima beans, cooked	...	...	...	0	...	C	...	...	...	...	...	...
Loofah fruit, raw	47	...	C	...	...	...	...	...	...	...	...	...
Mango, raw	1,300	23-3,700	A	0	0-0	C	0	...	C	0	...	C
Mint, not dried	730	...	C	...	...	...	...	...	...	...	...	...
Mushroom	0	0-0	C	0	0-0	C	0	0-0	C	0	0-0	C
Mushroom, chanterelle, raw	1,300	...	C	1	...	C	0	...	C	0	...	C
Nectarine, raw	103	0-0	C	0	0-0	C	...	...	...	...	...	...
Okra, raw	170	54-432	C	28	...	C	...	...	...	...	...	...
Olive, green	280	...	C	0	...	C	510	...	C	0	...	C
Onion, yellow, raw	160	6.9-210	C	0	...	C	16	...	C	0	...	C
Orange juice	7	0-67	A	6	0-49	A	74	0-240	A	0	0-0	B
Orange, raw	39[e]	0-500	B	20[e]	0-400	B	14	0-27	C	0	...	C
Papaya, raw	99	38-160	C	0	...	C	...	...	...	0	...	C
Parsley, not dried	5,300	5,040-5,600	C	0	...	C	10,200	...	C	0	...	C
Peach, canned, drained	100	0-625	B	0	0-0.9	C	28	0-33	B	0	0-0	C
Peach, dried	9,256	...	C	...	...	...	188	...	C	0	...	C
Peach, raw	99	40-420	B	1	0-2.9	C	14	9.6-43	B	0	...	C
Pear, raw	17	...	C	0	...	C	110	...	C	0	...	C
Peas, green	350	110-1,300	A	16	0.9-26	C	1,700	1,100-2,400	A	0	...	C
Pepper, green, raw	230	81-276	B	11	0-34	B	700	...	C	0	...	C
Pepper, red	2,200	2,220-2,900	B	60	59-62	C	...	...	...	...	...	...
Pepper, yellow, raw	150	...	C	92	...	C	770	...	C	0	...	C
Pigeon peas	40	...	C	...	...	...	...	...	...	...	...	...
Pineapple, canned, drained	18	...	C	1	...	C	2	...	C	...	...	...
Plum, raw	430	...	C	...	...	...	240	...	C	0	...	C
Potato salad	12	...	C	2	...	C	...	...	...	0	...	C
Potato, white, cooked	0	...	C	0	...	C	0	...	C	0	...	C
Potato, white, raw	6	3.2-7.7	C	0	0-0.9	C	36	13-60	C	0	0-0	C
Prune, dried	140	...	C	31	...	C	120	...	C	0	...	C
Pumpkin	3,100	490-20,000	A	3,800	0.9-16,000	A	1,500	630-2,300	C	0	0-0	B
Radish, raw	9	...	C	0	...	C	12	...	C	0	...	C
Raisins	0	...	C	0	...	C	1	...	C	0	...	C
Raspberries, raw	6	...	C	6	0-13	C	76	...	C	0	...	C
Rhubarb, raw	61	...	C	0	...	C	170	...	C	0	...	C
Roquette, raw	3,460	...	C	...	...	...	...	...	...	...	...	...
Rose hip puree, canned	420	...	C	0	...	C	...	...	...	780	...	C
Rutabaga, raw	1	...	C	0	...	C	0	...	C	0	...	C
Scallion, raw	850	391-1300	C	6	...	C	2,100	...	C	...	...	...
Spinach, cooked, drained	5,500	3,300-9,200	A	...	...	...	12,600	5,000-20,300	A	...	...	...
Spinach, raw	4,100	3,043-6,710	A	0	0-0	B	10,200	4,400-15,940	C	0	...	C
Squash, summer	420	178-670	C	12	...	C	1,200	500-1,800	C	...	...	...
Squash, winter, cooked	2,400	490-4,570	A	12[e]	0-935	B	38	...	C	...	...	...
Squash, winter, raw	820[e]	49-5,780	A	12[e]	0-935	B	38	...	C	...	...	...
Strawberries	9	...	C	2	0-4.5	C	31	...	C	0	...	C
Sweet potato, cooked	8,800	5,620-19,000	A	0	0-0	C	...	...	...	0	0-0	C
Sweet potato, raw	8,900	7,620-16,000	B	0	...	C	...	...	...	0	...	C

Continued on next page

Table 3
Carotenoid content of fruits and vegetables derived from analytic data[a,b] (cont)

Aggregate	β-Carotene			α-Carotene			Lutein+zeaxanthin			Lycopene		
	Median	Min-max	Conf code[c]	Median	Min-max	Conf code	Median	Min-max	Conf code	Median	Min-max	Conf code
	← μg/100g →			← μg/100g →			← μg/100g →			← μg/100g →		
Swiss chard, raw	3,647	2,725-4,568	C	45	32-58	C	...	...	...	...	...	...
Tangerine, tangelo juice	8[e]	4.5-38	B	5	3-14	B	135	104-166	C	...	...	...
Tangerine, raw	38	...	C	20	...	C	20	...	C	...	...	...
Tomato catsup	5,000[f]	...	C	0[f]	...	C	210[f]	...	C	9,900[f]	...	...
Tomato juice, canned	900	...	C	...	...	...	...	...	...	8,580	50,000-11,600	B
Tomato paste, canned	1,700	...	C	...	...	C	...	...	...	6,500	5,400-15,000	B
Tomato sauce, canned	1,000	...	C	...	...	...	...	...	...	...	...	...
Tomato, raw	520	115-660	A	...	...	...	100	...	C	3,100	879-4,200	A
Turnip, raw	72	...	C	1	...	C	1	...	C	0	...	C
Watermelon, raw	230	...	C	1	...	C	14	...	C	4,100	2,300-7,200	B
Yard-long beans, raw	44	...	C	...	...	...	...	...	...	...	...	...

[a]Missing values for minimum and maximum (min-max) alone indicate that only one acceptable analytic value was found for that carotenoid in that food.
[b]Missing value for median, minimum, maximum, and confidence code indicate that no acceptable analytic values were found for that carotenoid in that food. Refer to Table 6 for imputed values.
[c]Conf code = Confidence code. See Table 2 for explanation of conf codes A, B, and C.
[d]Zeroes represent values reported as not detected at a detection limit specified in the acceptable references.
[e]Mean for acceptable foods more than two times median.
[f]Values based only on data for Finnish catsup containing carrots.

had more than one acceptable reference for β-carotene whereas 20% of foods had more than one acceptable reference for β-cryptoxanthin.

The Quality Indexes of acceptable data range from 1 to 1.8 out of a possible 3. These scores illustrate the idealistic nature of the criteria that were planned to have long-term relevance and to provide guidelines for the development of exemplary methodology and quality control materials for carotenoid determination. A score of 3 in the category of analytic method requires use of a standard reference material, characterized and certified for each carotenoid of interest, or other extensive validation of the chosen method. Because there is currently no standard reference material for carotenoids, it is difficult to achieve a score of 3 in the analytic method category. Given the recommendation of the Committee on the Nutrition Components of Food Labeling to develop additional standard reference materials for use in food analysis (33), we anticipate the development of standard reference materials for carotenoids in the near future.

A lack of published documentation of analytic quality-control procedures was another reason for low Quality Index scores. Analytic quality control is concerned with the day-to-day accuracy and precision of a measurement. Accuracy is monitored by routine analysis of a standard reference material or a secondary reference material developed especially for a study. Precision is usually evaluated by calculating a coefficient of variation of several replicates of the same sample or a quality-control material. Both acceptable precision and accuracy were required for a score of 3 in the analytic quality-control category. Few current studies report any assessment of day-to-day accuracy or precision; a report including both is rare. Limited quality control information makes it difficult to compare the relative quality of analytic data.

Despite the critical evaluation process, the carotenoid values for an aggregate presented in Tables 3 and 4 may or may not represent the carotenoid levels found in a given individual food sample because many factors influence the levels of carotenoids

Table 4
β-Cryptoxanthin content of fruits and vegetables derived from analytic data[a]

Aggregate	Median	Min-max	Conf[b] code
	← μg/100g →		
Apricot, canned, drained	0[c]	...	C
Apricot, dried	0	...	C
Apricot, raw	0	...	C
Cantaloupe, raw	0	...	C
Cashew apple juice	50	...	C
Grapefruit, pink, raw	0	...	C
Mango, raw	54	...	C
Olive, green	19	...	C
Orange juice	24[d]	14-489	A
Papaya, raw	470	...	C
Peach, canned, drained	47	...	C
Peach, dried	251	...	C
Peach, raw	42	12-71	C
Squash, winter, cooked	0	...	C
Squash, winter, raw	0	...	C
Tangerine, tangelo juice	214	15-304	B

[a]See Table 6 for imputed β-cryptoxanthin values for foods not found in this table.
[b]Conf code = confidence code. See Table 2 for explanation of confidence codes.
[c]Zeroes represent values reported as not detected at a detection limit specified in the acceptable references.
[d]Mean for acceptable foods more than two times median.

Table 5
Number of means and acceptable references for carotenoid content of fruits and vegetables

Aggregate/ carotenoid[a]	No. of means used	Acceptable references
Apple, raw		
β-car	2	29
α-car	2	29
lut	2	29
lyc	2	29
Apricot, canned, drained		
β-car	3	24, 29, 45
α-car	1	29
lut	2	24, 29
lyc	1	24
β-cryp	1	24
Apricot, dried		
β-car	2	24, 54
lut	1	24
lyc	1	24
β-cryp	1	24
Apricot, raw		
β-car	2	24, 25
α-car	2	24
lut	1	24
lyc	1	24
β-cryp	1	24
Asparagus, raw		
β-car	2	25, 26
α-car	2	25, 26
Avocado, raw		
β-car	1	29
lut	1	29
Banana, raw		
β-car	3	29, A[b]
α-car	3	29, A
lut	3	29, A
lyc	2	A
Basil, not dried		
β-car	5	46
Beet greens		
β-car	5	25, 26, 45, 55
α-car	3	25, 26, 55
Beet, canned		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Bitter melon, raw		
β-car	1	46
Blueberries		
α-car	1	25
Bottle gourd, raw		
β-car	1	46
Broccoli, cooked		
β-car	7	45, 56, A
lut	6	56, A
Broccoli, raw		
β-car	6	25, 26, 29, 45, 55, 57
α-car	4	25, 26, 29, 55
lut	2	29, 57
lyc	1	29
Brussels sprouts		
β-car	9	29, 45, 55, 57, A
α-car	2	29, 55
lut	5	29, 57, A
lyc	1	29
Cabbage, chinese, bok choy, raw		
β-car		
2	29, 46	α-car
1	29	lut
1	29	lyc
1	29	
Cabbage, chinese, wild		
β-car	4	46
Cabbage, red, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Cabbage, white		
β-car	7	29, 46, 57, 58, A
α-car	2	29, A
lut	3	29, 57, A
lyc	2	29, A
Cantaloupe, raw		
β-car	6	24, 25, 55, A
α-car	2	25, 55
lut	1	24
lyc	1	24
β-cryp	1	24
Carrot, cooked, canned, frozen		
β-car	12	34, 45, 56, 59, A
α-car	12	34, 45, 56, 59, A
lyc	1	34
Carrot, raw		
β-car	14	25, 26, 29, 35, 45, 46, 55, 59, 60, 61, A
α-car	12	25, 26, 29, 35, 45, 55, 59, 61, A
lut	2	29, 35
lyc	1	29
Carrot, A+ variety, raw		
β-car	1	34
α-car	1	34
lyc	1	34
Carrot, A+ variety, cooked		
β-car	1	34
α-car	1	34
lyc	1	34
Cashew apple, raw		
β-car	2	62
α-car	2	62
Cashew apple juice		
β-car	1	62
β-cryp	1	62
Cassava leaf		
β-car	2	63, 64
Cauliflower		
β-car	4	29, 46, A
α-car	3	29, A
lut	3	29, A
lyc	3	29, A
Celeriac, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Celery		
β-car	4	29, 46, A
α-car	2	29, A
lut	2	29, A
lyc	2	29, A
Chicory, leaf, raw		
β-car	1	58
Coriander, not dried		
β-car	3	46, 58
Corn, yellow		
β-car	3	29, 46, 65
α-car	1	29
lut	7	29, A
lyc	1	29
Cranberries, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Cress leaf, raw		
β-car	1	55
Cucumber pickle		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Cucumber, raw		
β-car	3	29, 46, A
α-car	3	29, A
lut	2	29, A
lyc	2	29, A
Currants, raw		
β-car	2	29
α-car	2	29
lut	2	29
lyc	2	29
Dill, not dried		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Eggplant		
β-car	5	46
Endive		
β-car	2	45, 58
Fennel leaves		
β-car	1	46
Grapefruit, pink, raw		
β-car	2	24, 26
α-car	1	26
lut	1	24
lyc	1	24
β-cryp	1	24
Grapefruit, white, raw		
β-car	3	25, 26, 29
α-car	3	25, 26, 29
lut	1	29
lyc	1	29
Grapes, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Green beans		
β-car	7	25, 29, 55, A
α-car	3	25, 29, 55
lut	5	29, A
lyc	1	29
Greens, collard		
β-car	3	45, A
Greens, fiddlehead		
β-car	4	47, 59
α-car	4	47, 59
Greens, mustard		
β-car	4	46, A
lut	2	A
Guava juice		
β-car	1	48
lyc	1	48
Guava, raw		
β-car	2	66
lyc	2	66
Jackfruit, raw		
β-car	1	46
Jellies, jams, preserves		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Kale		
β-car	11	45, 57, 58, 67, 68, A
lut	4	57, A
Kale, chinese		
β-car	2	46
Kiwi fruit, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Leek, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Lemon, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Lettuce, iceberg		
β-car	2	25, A
α-car	1	25
Lettuce, leaf		
β-car	2	29, 58
α-car	1	29
lut	1	29
lyc	1	29
Lettuce, romaine		
β-car	3	A
Lima beans, cooked		
α-car	1	A
Loofah fruit, raw		
β-car	1	46
Mango, raw		
β-car	11	36, 46, 49, A, B[c]
α-car	2	A, B
lut	1	B
lyc	1	B
β-cryp	1	B
Mint, not dried		
β-car	1	46
Mushroom		
β-car	2	29
α-car	2	29
lut	2	29
lyc	2	29

Continued on next page

Table 5
Number of means and acceptable references for carotenoid content of fruits and vegetables (cont)

Aggregate/ carotenoid[a]	No. of means used	Acceptable references
Mushroom, chanterelle, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Nectarine, raw		
β-car	1	26
α-car	2	25, 26
Okra, raw		
β-car	3	25, 46, 64
α-car	1	25
Olive, green		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
β-cryp	1	29
Onion, yellow, raw		
β-car	3	29, 46
α-car	1	29
lut	1	29
lyc	1	29
Orange juice		
β-car	14	29, 37, 38, 69, 70, A
α-car	14	29, 37, 38, 69, 70, A
lut	13	29, 37, 38, 69, A
lyc	3	29, A
β-cryp	7	37, 70
Orange, raw		
β-car	4	25, 29, A
α-car	4	25, 29, A
lut	2	29, A
lyc	1	A
Papaya, raw		
β-car	2	46, 64
α-car	1	A
lyc	1	A
β-cryp	1	A
Parsley, not dried		
β-car	2	29, 58
α-car	1	29
lut	1	29
lyc	1	29
Peach, canned, drained		
β-car	3	24, 29, A
α-car	2	29, A
lut	3	24, 29, A
lyc	2	24, A
β-cryp	1	24
Peach, dried		
β-car	1	24
lut	1	24
lyc	1	24
β-cryp	1	24
Peach, raw		
β-car	4	24, 29, 42, A
α-car	3	25, 29, A
lut	3	24, 29, 42
lyc	1	24
β-cryp	2	24, 42
Pear, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Peas, green		
β-car	10	25, 26, 29, 55, 63, 64, A
α-car	3	25, 29, 55
lut	5	29, A
lyc	1	29
Pepper, green, raw		
β-car	4	25, 26, 29, 55
α-car	4	25, 26, 29, 55
lut	1	29
lyc	1	29
Pepper, red		
β-car	3	29, 45
α-car	2	45
Pepper, yellow, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Pigeon peas		
β-car	1	63
Pineapple, canned, drained		
β-car	1	29
α-car	1	29
lut	1	29
Plum, raw		
β-car	1	29
lut	1	29
lyc	1	29
Potato salad		
β-car	1	71
α-car	1	71
lyc	1	71
Potato, white, cooked		
β-car	1	A
α-car	1	A
lut	1	A
lyc	1	A
Potato, white, raw		
β-car	3	29, 59
α-car	2	29
lut	2	29
lyc	2	29
Prune, dried		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Pumpkin		
β-car	9	29, 34, 45, 64, A
α-car	8	29, 34, 45, A
lut	2	29, A
lyc	3	29, 45
Radish, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Raisins		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Raspberries, raw		
β-car	1	29
α-car	2	25, 29
lut	1	29
lyc	1	29
Rhubarb, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Roquette, raw		
β-car	1	58
Rose hip puree, canned		
β-car	1	71
α-car	1	71
lyc	1	71
Rutabaga, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Scallion, raw		
β-car	2	55, A
α-car	1	55
lut	1	A
Spinach, cooked		
β-car	10	45, A
lut	6	A
Spinach, raw		
β-car	6	25, 26, 29, 45, 57, 68
α-car	3	25, 26, 29
lut	2	29, 57
lyc	1	29
Squash, summer		
β-car	2	25, A
α-car	1	25
lut	2	A
Squash, winter, cooked		
β-car	9	31, 72, A
α-car	6	31, 72, A
lut	4	72, A
β-cryp	1	72
Squash, winter, raw		
β-car	7	26, 45, 46, 55, 67, 72
α-car	4	26, 45, 46, 72
lut	1	72
β-cryp	1	72
Strawberries		
β-car	1	29
α-car	2	25, 29
lut	1	29
lyc	1	29
Sweet potato, cooked		
β-car	13	34, 45, 50, A
α-car	2	34
lyc	2	34
Sweet potato, raw		
β-car	5	25, 26, 34, 45, 50
α-car	2	26, 29
lyc	1	34
Swiss chard, raw		
β-car	2	25, 55
α-car	2	25, 55
Tangerine, tangelo juice		
β-car	3	37, 43, 70
α-car	3	37, 43, 70
lut	2	37, 43
β-cryp	3	37, 43, 70
Tangerine, raw		
β-car	1	29
α-car	1	29
lut	1	29
Tomato catsup, Finnish		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Tomato juice, canned		
β-car	1	A
lyc	4	56, A
Tomato paste, canned		
β-car	1	A
lyc	3	A
Tomato sauce, canned		
β-car	1	A
lyc	2	A
Tomato, raw		
β-car	6	29, 46, 55, 67, 73, A
lut	1	29
lyc	5	29, 73, A
Turnip, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	1	29
Watermelon, raw		
β-car	1	29
α-car	1	29
lut	1	29
lyc	4	29, A
Yard-long beans, raw		
β-car	1	46

[a]β-car = β-carotene; α-car = α-carotene; lut = lutein + zeaxanthin; lyc = lycopene; β-cryp = β-cryptoxanthin.
[b]A = Unpublished data provided by Judy C. Harris, Arthur D. Little, Inc, Cambridge, Mass, under NCI Contract NO1-CN-55442, 1988.
[c]B = Unpublished data provided by Frederick Khachik, Nutrient Composition Laboratory, Beltsville Human Nutrition Research Center, Agriculture Research Service, Beltsville, Md, 1990.

Table 6
Imputed values for carotenoids in fruits and vegetables

Aggregate	α-Car	β-Cryp	Lyc	Lut
	µg/100g			
Apple, raw	. . .	0[a]	. . .	. . .
Apricot, dried	0[a]	. . .	. . .	. . .
Asparagus, raw	. . .	0[a]	0[a]	640[b]
Avocado, raw	0[a]	0[a]	0[a]	. . .
Banana, raw	. . .	0[a]	. . .	. . .
Beet greens	. . .	0[a]	0[a]	7,700[b]
Beet, canned	. . .	0[a]	. . .	. . .
Blueberries[e]	. . .	0[a]	0[a]	37[d]
Broccoli, cooked	1[d]	0[a]	0[a]	. . .
Broccoli, raw	. . .	0[a]	. . .	. . .
Brussels sprouts	. . .	0[a]	. . .	. . .
Cabbage, chinese, bok choy, raw	. . .	0[a]	. . .	. . .
Cabbage, red, raw	. . .	0[a]	. . .	. . .
Cabbage, white	. . .	0[a]	. . .	. . .
Carrot, cooked/canned/frozen	. . .	0[a]	. . .	260[d]
Carrot, raw	. . .	0[a]	. . .	. . .
Cauliflower	. . .	0[a]	. . .	. . .
Celery	. . .	0[a]	. . .	. . .
Chicory leaf, raw	0[a]	0[a]	0[a]	10,300[b]
Corn, yellow	. . .	0[a]	. . .	. . .
Cranberries, raw	. . .	0[a]	. . .	. . .
Cress leaf, raw	0[a]	0[a]	0[a]	12,500[b]
Cucumber pickle	. . .	0[a]	. . .	. . .
Cucumber, raw	. . .	0[a]	. . .	. . .
Currants, raw	. . .	0[a]	. . .	. . .
Eggplant	0[a]	0[a]	0[a]	0[a]
Endive	0[a]	0[a]	0[a]	4,000[b]
Grapefruit, white, raw	. . .	0[a]	. . .	. . .
Grapes, raw	. . .	0[a]	. . .	. . .
Green beans	. . .	0[a]	. . .	. . .
Greens, collard	0[a]	0[a]	0[a]	16,300[b]
Greens, mustard	0[a]	0[a]	0[a]	. . .
Guava juice	23[b]	0[a]	. . .	0[a]
Guava, raw	70[c]	0[a]	. . .	0[a]
Jellies, jams, preserves	. . .	0[a]	. . .	. . .
Kale	0[a]	0[a]	0[a]	. . .
Kiwi fruit, raw	. . .	0[a]	. . .	. . .
Leek, raw	. . .	0[a]	. . .	. . .
Lemon, raw	. . .	0[a]	. . .	. . .
Lettuce, iceberg	. . .	0[a]	0[a]	1,400[b]
Lettuce, leaf	. . .	0[a]	. . .	. . .
Lettuce, romaine	0[a]	0[a]	0[a]	5,700[b]
Lima beans, cooked[e]	. . .	0[a]	0[a]	0[a]
Mushroom	. . .	0[a]	. . .	. . .
Nectarine, raw	. . .	43[b]	0[a]	15[b]
Okra, raw	. . .	0[a]	0[a]	6,800[b]
Onion, yellow, raw	. . .	0[a]	. . .	. . .
Orange, raw	. . .	149[b]	. . .	. . .
Parsley, not dried	. . .	0[a]	. . .	. . .
Peach, dried	0[a]	. . .	. . .	
Pear, raw	. . .	0[a]	. . .	. . .
Peas, green	. . .	0[a]	. . .	. . .
Pepper, green, raw	. . .	0[a]	. . .	. . .
Pepper, red	. . .	0[a]	0[a]	6,800[b]
Pineapple, canned, drained	. . .	0[a]	0[a]	. . .
Plum, raw	0[a]	0[a]	. . .	. . .
Potato salad	. . .	0[a]	. . .	0[a]
Potato, white, cooked	. . .	0[a]	. . .	. . .
Potato, white, raw	. . .	0[a]	. . .	. . .
Prune, dried	. . .	0[a]	. . .	. . .
Pumpkin	. . .	0[a]	. . .	. . .
Radish, raw	. . .	0[a]	. . .	. . .
Raisins	. . .	0[a]	. . .	. . .
Raspberries, raw	. . .	0[a]	. . .	. . .
Rhubarb, raw	. . .	0[a]	. . .	. . .
Rutabaga	. . .	0[a]	. . .	. . .
Scallion, raw	. . .	0[a]	0[a]	. . .
Spinach, cooked	0[a]	0[a]	0[a]	. . .
Spinach, raw	. . .	0[a]	. . .	. . .
Squash, summer	. . .	0[a]	0[a]	. . .
Squash, winter, cooked	. . .	. . .	0[a]	. . .
Sweet potato, cooked	. . .	0[a]	. . .	0[a]
Sweet potato, raw	. . .	0[a]	. . .	0[a]
Swiss chard, raw	. . .	0[a]	0[a]	11,000[b]
Tangerine, raw	. . .	106[b]	0[a]	. . .
Tomato catsup, Finnish	. . .	0[a]	. . .	. . .
Tomato juice, canned	. . .	0[a]	. . .	330[b]
Tomato paste, canned	. . .	0[a]	. . .	190[b]
Tomato sauce, canned	. . .	0[a]	. . .	42[b]
Tomato, raw	. . .	0[a]	. . .	. . .
Turnip, raw	. . .	0[a]	. . .	. . .
Watermelon raw	. . .	0[a]	. . .	. . .

[a-d]Superscripts correspond to imputation method as described in Figure 3.
[e]For β-carotene, blueberries have an imputed value of 14 µg/100 g using method e in Figure 3 and lima beans have an imputed value of 0 µg/100 g using method a in Figure 3.
Key: α-Car = α-carotene; β-Cryp = β-cryptoxanthin; Lyc = lycopene; Lut = lutein + zeaxanthin.

in foods. These factors include varietal differences (34-41), variable growth and harvesting conditions (40-44), and different postharvest handling and processing (28,41,45-51).

The β-carotene content of cantaloupe illustrates the variable nature of food carotenoid content. Reported values of β-carotene range from 1,640 µg/100 g for cantaloupe purchased in Maine (25) to 25,500 µg/100 g for cantaloupe purchased in Maryland (24). Analytic differences may be partially responsible for this difference but are not likely to be the only cause for this range of values as both studies met established criteria for acceptability of analytic methods. Because of the variable carotenoid content of foods, feeding studies with controlled carotenoid intakes must continue to rely on analysis of foods.

Differences noted in Tables 3 and 4 between the carotenoid content of raw and cooked forms of the same food are more likely attributable to factors other than cooking or processing differences. For example, as Table 3 shows, the median of seven acceptable studies of the β-carotene content of cooked broccoli is 1,300 µg/100 g with a confidence code of "A" whereas the median value of six studies of raw broccoli is 700 µg/100 g with a confidence code of "A." Broccoli is unlikely to actually gain this much β-carotene with cooking. Results for cooked and raw broccoli were often generated by different scientists or laboratories with samples procured in different geographic locations and seasons and, thus, do not represent a controlled study of the effects of cooking. As data with more detailed descriptions of foods become available, aggregations can be modified to provide more information about the carotenoid content of specific varieties of foods or the influence of growing, storage, and processing conditions.

Table 6 provides a listing of imputed carotenoid values for foods where no analytic data were reported. Because missing values are probably the largest cause of errors in nutrient calculation (52), we decided to impute values rather than leave them as missing. For example, no analytic values were available for the lutein content of collard greens. But because other similar green leafy vegetables, such as mustard greens, kale, and spinach, contain substantial amounts of lutein (Table 3), replacing missing lutein values with a zero would lead to underestimation of the lutein intake of an individual who consumes collard greens. Values were imputed in an attempt to provide consistent values for users.

The evaluation of carotenoid content of fruits and vegetables represents an initial step in the development of reliable data on carotenoid content of foods. The evaluation system permitted consistent, objective, and efficient rating of data from numerous references. Quantitative data on the carotenoid content of common foods will be useful for the estimation of dietary carotenoid intake and for the evaluation of the possible effects of carotenoid intake on disease incidence.

IMPLICATIONS

A primary objective for critically evaluating food composition data is the identification of food items for future laboratory analysis. Foods believed to contain notable amounts of a carotenoid, but that had a confidence code of "C" or had no reliable data, are a priority for additional analyses. Information about those foods can be used as the basis for development of a sampling strategy to obtain statistically representative food samples for carotenoid analysis as has been done for selenium (53). Because data on the effects of cooking or processing on individual carotenoids in foods are limited, this is another area for investigation. Foods with highly divergent values for carotenoids are also a priority for further investigation. The evaluation system allows for continual, objective, and consistent updating of the database.

Data-quality indicators, a part of the evaluation system, allow users to make informed decisions about appropriate uses for the data. The inclusion of references for acceptable data also helps the user make decisions about data applications.

This is the third system that has been developed for the evaluation of analytic data for nutrient content of foods (20-22). Although the evaluated components differ, the similarities of the evaluation systems demonstrate the feasibility of multinutrient evaluation systems. This approach could be useful in development of multinutrient food composition tables. In addition, reviewers of manuscripts can use the evaluation categories and the nutrient-specific criteria as guidelines for manuscript quality.

Values for specific carotenoids in foods are necessary to estimate dietary intakes of individual carotenoids in the population. The dietary intake distribution of carotenoids can then be used to examine the relationship between individual and total carotenoid intake and disease incidence. Because lower carotenoid intake has been implicated as a risk factor in certain types of cancer, especially lung cancer, this database could be used to permit greater specificity in examining the relationship between dietary exposure and cancer risk. ■

Partial support by the National Cancer Institute through reimbursable agreement YO1-CN-30609 is acknowledged.

The authors thank Carol S. Davis for creating the tables and figures, Doug Bigwood for computer programming, Frederick Khachik for insightful discussions, and Larry Douglass and Will Potts for statistical advice.

References

1. Byers T, Vena J, Mettlin C, Swanson M, Graham S. Dietary vitamin A and lung cancer risk: an analysis by histologic subtypes. *Am J Epidemiol.* 1984; 120:769-776.

2. Hinds MW, Kolonel LN, Hankin JH, Lee J. Dietary vitamin A, carotene, vitamin C and risk of lung cancer in Hawaii. *Am J Epidemiol.* 1984; 119:227-237.

3. Kvale G, Bjelke E, Gart JJ. Dietary habits and lung cancer risk. *Int J Cancer.* 1983; 31:397-405.

4. Le Marchand L, Yoshizawa CN, Kolonel LN, Hankin JH, Goodman MT. Vegetable consumption and lung cancer risk: a population-based case-control study in Hawaii. *J Natl Cancer Inst.* 1989; 81:1158-1164.

5. Pisani P, Berrino F, Macaluso M, Pastorino U, Crosignani P, Baldasseroi A. Carrots, green vegetables and lung cancer: a case-control study. *Int J Epidemiol.* 1986; 15:463-468.

6. Samet JM, Skipper BJ, Humble CG, Pathik DR. Lung cancer risk and vitamin A consumption in New Mexico. *Am Rev Respir Dis.* 1985; 131:198-202.

7. Shekelle RB, Liu S, Raynor WJ Jr, Lepper M, Maliza C, Rossof AM. Dietary vitamin A and risk of cancer in the Western Electric study. *Lancet.* 1981; 2:1185-1189.

8. Ziegler RG. A review of epidemiologic evidence that carotenoids reduce the risk of cancer. *J Nutr.* 1989; 119:116-122.

9. Ziegler RG, Mason TJ, Stemhagen A, Hoover R, Schoenberg JB, Gridley G, Virgo PW, Fraumeni JR Jr. Carotenoid intake, vegetables, and the risk of lung cancer among white men in New Jersey. *Am J Epidemiol.* 1986; 123:1080-1093.

10. Mackerras D, Buffler PA, Randall DE, Nichaman MZ, Pickle LW, Mason TJ. Carotene intake and the risk of laryngeal cancer in coastal Texas. *Am J Epidemiol.* 1988; 128:980-988.

11. Micozzi MS, Beecher GR, Taylor PR, Khachik F. Carotenoid analyses of selected raw and cooked foods associated with a lower risk for cancer. *J Natl Cancer Inst.* 1990; 82:282-285.

12. Haytowitz DB, Matthews RH. *Composition of Foods: Vegetables and Vegetable Products—Raw, Processed, Prepared.* Washington, DC: US Dept of Agriculture; 1984. Handbook No. 8-11.

13. Souci SW, Fachmann W, Kraut H. *Food Composition and Nutrition Tables 1986/87.* Stuttgart, Germany: Wissenschaftliche Verlagsgesellschaft; 1986.

14. Rodriguez-Amaya DB. Critical review of provitamin A determination in plant foods. *J Micronutr Anal.* 1989; 5:191-225.

15. Beecher GR, Khachik F. Evaluation of vitamin A and carotenoid data in food composition tables. *J Natl Cancer Inst.* 1981; 73:1397-1404.

16. Simpson KL, Chichester CO. Metabolism and nutritional significance of carotenoids. *Ann Rev Nutr.* 1981; 1:351-374.

17. Heinonen M. Food groups as the source of retinoids, carotenoids, and vitamin A in Finland. *Int J Vitam Nutr Res.* 1991; 61:3-9.

18. Ollilainen V, Heinonen M, Linkola E, Varo P, Koivistoinen P. Carotenoids and retinoids in Finnish foods: meat and meat products. *J Food Comp Anal.* 1988; 1:178-188.

19. Ollilainen V, Heinonen M, Linkola E, Varo P, Koivistoinen P. Retinoids and carotenoids in Finnish foods: fish and fish products. *J Food Comp Anal.* 1989; 2:93-103.

20. Holden JM, Schubert A, Wolf WR, Beecher GR. A system for evaluating the quality of published nutrient data: selenium, a test case. *Food Nutr Bull.* 1987; 9(suppl):177-193.

21. Schubert A, Holden JM, Wolf WR. Selenium content of a core group of foods based on a critical evaluation of published analytical data. *J Am Diet Assoc.* 1987; 87:285-296,299.

22. Lurie DG, Holden JM, Schubert A, Wolf WR, Miller-Ihli NJ. The copper content of foods based on a critical evaluation of published analytical data. *J Food Comp Anal.* 1989; 2:298-316.

23. Bigwood DW, Heller SR, Wolf WR, Schubert A, Holden JM. SELEX: an expert system for evaluating published data on selenium in foods. *Anal Chim Acta.* 1987; 200:411-419.

24. Khachik F, Beecher GR, Lusby WR. Separation, identification and quantification of the major carotenoids in extracts of apricots, peaches,

cantaloupe, and pink grapefruit by liquid chromatography. *J Agric Food Chem.* 1989; 37:1465-1473.
25. Bureau JL, Bushway RJ. HPLC determination of carotenoids in fruits and vegetables in the United States. *J Food Sci.* 1986; 51:128-130.
26. Bushway RJ. Determination of α- and β-carotene in some raw fruits and vegetables by high-performance liquid chromatography. *J Agric Food Chem.* 1986; 34:409-412.
27. Heinonen M, Ollilainen V, Linkola E, Varo P, Koivistoinen P. Carotenoids and retinoids in Finnish foods: cereal and bakery products. *Cereal Chem.* 1989; 66:270-272.
28. Khachik F, Beecher GR, Goli MB, Lusby WR. Separation, identification, and quantification of carotenoids in fruits, vegetables and human plasma by high performance liquid chromatography. *Pure Appl Chem.* 1991; 63:71-80.
29. Heinonen MI, Ollilainen V, Linkola EK, Varo PT, Koivistoinen PE. Carotenoids in Finnish foods: vegetables, fruits, and berries. *J Agric Food Chem.* 1989; 37:655-659.
30. Sokal RR, Rohlf FJ. *Biometry.* 2nd ed. New York, NY: WH Freeman and Co; 1981.
31. Ollilainen V, Heinonen M, Linkola E, Varo P, Koivistoinen P. Carotenoids and retinoids in Finnish foods: dairy products and eggs. *J Dairy Sci.* 1989; 72:2257-2265.
32. Heinonen M, Ollilainen V, Linkola E, Varo P, Koivistoinen P. Carotenoids and retinoids in Finnish foods: dietary fats. *J Food Comp Anal.* 1988; 1:334-340.
33. Porter DV, Earl RO, eds. *Nutrition Labeling: Issues and Directions for the 1990s.* Washington, DC: National Academy of Sciences; 1990.
34. Khachik F, Beecher GR. Application of C-45-β-carotene as an internal standard for the quantification of carotenoids in yellow/orange vegetables by liquid chromatography. *J Agric Food Chem.* 1987; 35:732-738.
35. Heinonen MI. Carotenoids and provitamin A activity of carrot *(Daucus carota L.)* cultivars. *J Agric Food Chem.* 1990; 38:609-612.
36. Godoy HT, Rodriguez-Amaya DB. Carotenoid composition of commercial mangoes from Brazil. *Lebensm Wiss Technol.* 1989; 22:100-103.
37. Stewart I. Provitamin A and carotenoid content of citrus juices. *J Agric Food Chem.* 1977; 25:1132-1137.
38. Gross J, Gabai M, Lifshitz A. A comparative study of the carotenoid pigments in juice of Shamouti, Valencia and Washington oranges, three varieties of *Citrus sinensis. Phytochemistry.* 1972; 11:303-308.
39. Arima HK, Rodriguez-Amaya DB. Carotenoid composition and vitamin A value of commercial Brazilian squashes and pumpkins. *J Micronutr Anal.* 1988; 4:177-191.
40. Mercadante AZ, Rodriguez-Amaya DB. Carotenoid composition of a leafy vegetable in relation to some agricultural variables. *J Agric Food Chem.* 1991; 39:1094-1097.
41. Gross J. *Pigments in Vegetables.* New York, NY: Van Nostrand Reinhold; 1991.
42. Gross J. Carotenoid changes in the mesocarp of the redhaven peach during ripening. *Z Pflanzenphysiol.* 1979; 94:461-468.
43. Gross J. Carotenoid changes in the juice of the ripening Dancy tangerine *(Citrus reticulata). Lebensm Wiss Technol.* 1982; 15:36-38.
44. Gross J. *Pigments in Fruits.* London, England: Academic Press; 1987.
45. Sweeney JP, Marsh AC. Effect of processing on provitamin A in vegetables. *J Am Diet Assoc.* 1971; 59:238-243.
46. Speek AJ, Speek-Saichua S, Schreurs WHP. Total carotenoid and β-carotene contents of Thai vegetables and the effect of processing. *Food Chem.* 1988; 27:245-257.
47. Bushway AA, Serreze DV, McGann DF, True RH, Work TM, Bushway RJ. Effect of processing method and storage time on the nutrient composition of fiddlehead greens. *J Food Sci.* 1985; 50:1491-1492.
48. Padula M, Rodriguez-Amaya DB. Changes in individual carotenoids and vitamin C on processing and storage of guava juice. *Acta Alim.* 1987; 16:209-216.
49. Godoy HT, Rodriguez-Amaya DB. Changes in individual carotenoids on processing and storage of mango *(Mangifera indica)* slices and puree. *Int J Food Sci Technol.* 1987; 22:451-460.
50. Chandler LA, Schwartz SJ. Isomerization and losses of trans-β-carotene in sweet potatoes as affected by processing treatments. *J Agric Food Chem.* 1988; 36:129-133.
51. Beecher GR, Khachik F. Analysis of micronutrients in foods. In: Moon TE, Micozzi MS, eds. *Nutrition and Cancer Prevention: Investigating the Role of Micronutrients.* New York, NY: Marcel Dekker, Inc; 1989:103-158.
52. Buzzard IM, Price KS, Warren RA. Considerations for selecting nutrient-calculation software: evaluation of the nutrient database. *Am J Clin Nutr.* 1991; 54:7-9.
53. Holden JM, Gebhardt S, Davis CS, Lurie DM. A nationwide study of the selenium contents and variability in white bread. *J Food Comp Anal.* 1991; 4:183-195.
54. Hsieh YP, Karel M. Rapid extraction and determination of alpha- and beta-carotene in foods. *J Chromatogr.* 1983; 259:515-518.
55. Bushway RJ, Yang A, Yamani AM. Comparison of alpha- and beta-carotene content of supermarket versus roadside stand produce. *J Food Qual.* 1987; 9:437-443.
56. Brown ED, Micozzi MS, Craft NE, Bieri JG, Beecher G, Edwards BK, Rose A, Taylor PR, Smith JC Jr. Plasma carotenoids in normal men after a single ingestion of vegetables or purified β-carotene. *Am J Clin Nutr.* 1989; 49:1258-1265.
57. Khachik F, Beecher GR, Whittaker NF. Separation, identification, and quantification of the major carotenoid and chlorophyll constituents in extracts of several green vegetables by liquid chromatography. *J Agric Food Chem.* 1986; 34:603-616.
58. Ramos DMR, Rodriguez-Amaya DB. Determination of the vitamin A value of common Brazilian leafy vegetables. *J Micronutr Anal.* 1987; 3:147-155.
59. Bushway RJ, Wilson AM. Determination of α- and β-carotene in fruit and vegetables by high performance liquid chromatography. *Can Inst Food Sci Technol.* 1982; 15:165-169.
60. Ogunlesi AT, Lee CY. Effect of thermal processing on the stereoisomerization of major carotenoids and vitamin A value of carrots. *Food Chem.* 1979; 4:311-318.
61. Simon PW, Wolff XY. Carotenes in typical and dark orange carrots. *J Agric Food Chem.* 1987; 35:1017-1022.
62. Cecchi HM, Rodriguez-Amaya DB. Carotenoid composition and vitamin A value of fresh and pasteurized cashew-apple *(Anacardium occidentale L.)* juice. *J Food Sci. 1981; 46:147-149.*
63. Speek AJ, Temalilwa CR, Schrijver J. Determination of β-carotene content and vitamin A activity of vegetables by high-performance liquid chromatography and spectrophotometry. *Food Chem.* 1986; 19:65-74.
64. Pepping F, Vencken CMJ, West CE. Retinol and carotene content of foods consumed in East Africa by high performance liquid chromatography. *J Sci Food Agric.* 1988; 45:359-371.
65. Lee CY, McCoon PE, LeBowitz JH. Vitamin A value of sweet corn. *J Agric Food Chem.* 1981; 29:1294-1295.
66. Padula M, Rodriguez-Amaya DB. Characteristics of the carotenoids and assessment of the vitamin A value of Brazilian guavas. *Food Chem.* 1986; 20:11-19.
67. Rodriguez-Amaya DB, Kimura M, Godoy HT, Arima HK. Assessment of provitamin A determination by open column chromatography/visible absorption spectrophotometry. *J Chromatogr Sci.* 1988; 26:624-629.
68. Mercadante AZ, Rodriguez-Amaya DB. Comparison of normal-phase and reversed-phase gravity-flow column methods for provitamin A determination. *Chromatographia.* 1989; 28:249-252.
69. Gross J, Gabai M, Lifshitz A. Carotenoids in juice of Shamouti orange. *J Food Sci.* 1971; 36:466-473.
70. Stewart I. High performance liquid chromatographic determination of provitamin A in orange juice. *J Assoc Off Anal Chem.* 1977; 60:132-136.
71. Heinonen M, Ollilainen V, Linkola E, Varo P, Koivistoinen P. Carotenoids and retinoids in Finnish foods: ready-to-eat foods. *J Food Comp Anal.* 1988; 1:221-230.
72. Khachik F, Beecher GR. Separation and identification of carotenoids and carotenol fatty acid esters in some squash products by liquid chromatography. 1. Quantification of carotenoids and related esters by HPLC. *J Agric Food Chem.* 1988; 36:929-937.
73. Zakaria M, Simpson KL, Brown P. Use of reversed phase HPLC analysis for the determination of provitamin A carotenes in tomatoes. *J Chromatogr.* 1979; 176:109-117.