Variation in β -Carotene and Total Carotenoid Content in Fruits of *Capsicum*

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Additional index words. peppers, pigments, human nutrition, vegetable breeding, chiles, *Capsicum annuum*, *Capsicum chinense*, *Capsicum baccatum*, *Capsicum frutescens*, *Capsicum chacoense*, *Capsicum eximium*

Abstract. The β -carotene and total carotenoid content of either fresh or dried tissue of fruits of a total of 57 cultivars of six *Capsicum* species were analyzed using high performance liquid chromatography (HPLC). β -Carotene levels in ripe fruit varied from 0 to 166 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight, and carotenoid levels were from 1 to 896 $\mu\text{g}\cdot\text{g}^{-1}$ in ripe fruit in 1996. The range of values for β -carotene was similar in 1997, but that for total carotenoids was wider (4 to 1173 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight). Fresh fruit of the cultivars Greenleaf Tabasco, Pulla, Guajillo, NuMex Conquistador, Ring-O-Fire, and Thai Dragon contained greater amounts of β -carotene per 100 g fresh weight than the recommended dietary allowance (RDA) for vitamin A for the average adult. For dried *Capsicum* entries, New Mexican, aji, pasilla, and ancho types had the highest levels of β -carotene. In 1996, β -carotene levels among the dried *Capsicum* germplasm ranged from 2 to 739 $\mu\text{g}\cdot\text{g}^{-1}$ dry weight, and carotenoid levels from 111 to 6226 $\mu\text{g}\cdot\text{g}^{-1}$. Values were higher in 1997, ranging from 24 to 1198 $\mu\text{g}\cdot\text{g}^{-1}$ dry weight for β -carotene and from 187 to 10,121 $\mu\text{g}\cdot\text{g}^{-1}$ for total carotenoids. A pasilla type (*C. annuum* L.) had the highest total carotenoid content among the dried entries in both years.

Chiles (*Capsicum* sp.) are one of the oldest cultivated plants of the Americas, have been part of the human diet for thousands of years (Bosland, 1994), and are rich in vitamins A and C (Bureau and Bushway, 1986; Howard et al., 1994; Mejia et al., 1988; Simonne et al., 1997). Worldwide, vitamin A deficiency is the most common form of malnutrition after protein deficiency (World Bank, 1993). In parts of Asia, Africa, and Latin America, vitamin A deficiency occurs in millions of children (Sommer, 1989), and chiles could be an important source of provitamin A for the people of those regions. Chile production and consumption is increasing globally. Worldwide production is 11 million tons, with more than 48% produced in Asia, and per capita consumption is estimated at 10 g per day (Food and Agriculture Organization, 1995). In northern Mexico, consumption is ≈ 40 g per day (Valencia et al., 1983).

The yellow, orange, and red colors of *Capsicum* fruit originate from carotenoid pigments produced during ripening. Red chile and pa-

prika carotenoids are used by the food industry as natural red colorants, but also have immense nutritional value as provitamin A and antioxidants. Evidence for antitumor activity of carotenoids has renewed interest in foods containing these compounds. The antioxidant properties of carotenoids appear to protect against heart disease (Kritchevsky, 1999) and cancer of the lungs, stomach, cervix, and throat (Byers and Perry, 1992; Machlin, 1995). Reports on the carotenoid content of chiles are primarily for bell, paprika, and jalapeño types (Bureau and Bushway, 1986; Howard et al., 1994; Levy et al., 1995; Mejia et al., 1988; Simonne et al., 1997). More than 30 carotenoids have been isolated from chiles (Gregory et al., 1987). The red capsanthin, capsorubin, and cryptocapsin pigments are valued mostly as natural colorants, whereas β -carotene, α -carotene, γ -carotene and β -cryptoxanthin have provitamin A activity, with β -carotene having the highest activity.

Improvement of chiles (New Mexican type, *C. annuum* L.) for carotenoid and nutrient content is the goal of several breeding programs. To assist in identifying sources of high levels of carotenoids, 57 *Capsicum* cultivars from six species and 25 different fruit types were evaluated for variation in β -carotene and total carotenoid content. β -Carotene is the precursor for the predominant orange and red pigments in chiles, and genotypes with high concentrations of β -carotene proved to be richest in total carotenoid content. Therefore, β -carotene may be a selection criterion for developing highly colored chiles (Levy et al., 1995).

This information is useful not only for breeding highly colored paprika and chiles for

the food industry, but also provides nutritional data for the range of fruit types within the *Capsicum* genus. Most vitamin A values reported in food composition tables are overestimated, because they are based on methodology in which β -carotene was not separated from other provitamin A pigments with lower activity (Haytowitz and Matthews, 1984). β -Carotene concentrations now can be accurately determined with HPLC (Bushway and Wilson, 1982).

Materials and Methods

β -Carotene and total carotenoid content were evaluated in different *Capsicum* fruit types and species using fresh fruit from 25 cultivars and dried fruit from 40 cultivars selected to represent a range of fruit types and uses (fresh or processed). Plots were established from transplants on a sandy loam soil at the Fabian Garcia Agricultural Science Center in Las Cruces, N.M., in 1996 and 1997. The beds were on 1-m centers and furrow-irrigated. Fertilizer (112 kg·ha⁻¹ P and 168 kg·ha⁻¹ N) was applied preplant as diammonium phosphate and in the irrigation water as urea and ammonium nitrate. Either fully ripened, succulent fruit or ripened, partially dry fruit were harvested for analysis. The number of fruit harvested per plant varied according to fruit type, and ranged from three for the larger bell, cubanelle, and pimiento types, to 150 for the smaller piquin and tepin types. Fruit were harvested separately from four plants and destemmed in the field. Fruit were deseeded for analysis of fresh fruit, except for the small-fruited tabasco, guajillo, Asian hot, serrano, and datil pod types, but not of dry fruit. Moisture content at harvest was determined from a subsample of each entry using an IR-100 moisture balance (Denver Instruments Co., Arvada, Colo.). Fruit harvested from individual plants were kept separate in the laboratory, and one sample from each accession was extracted and analyzed at the same time. There were four samples per accession.

Carotenoid extraction from fresh fruit samples was according to the methodology of Bureau and Bushway (1986). Chile samples were chopped into small pieces, and a 10-g subsample was immediately combined with 1 g MgCO₃, 5 g Na₂SO₄, and 125 mL tetrahydrofuran (THF) stabilized with 0.01% butylated hydroxytoluene (BHT). Each sample was homogenized with a Tekmar tissumizer (Cincinnati) for 5 min on medium speed. Samples were vacuum filtered (Whatman #42), and the residue was re-extracted with an additional 125 mL THF. A 20-mL portion of the sample was concentrated under nitrogen gas and stored at -20°C until HPLC analysis. Samples were resuspended in 0.4 mL THF and vortexed. Acetonitrile and methanol were added in equal amounts to a final volume of 4 mL.

Prior to extraction of dry samples, whole fruit were dried in a 55 $^{\circ}\text{C}$ oven and ground in a Wiley mill to pass through a 1-mm sieve. Carotenoids were extracted from dried samples by placing 0.2 g of powder in 50 mL stabilized THF. After 16 h in the dark, a 10-mL aliquot

Received for publication 31 Mar. 2000. Accepted for publication 2 Oct. 2000. This research was supported by the Chile Improvement Project of the New Mexico State Univ. Agricultural Experiment Station. We thank Kathleen Dixon, Kelly Callahan, and Li Fang for excellent technical assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

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was concentrated under nitrogen gas and stored at -20°C . Samples were resuspended in 0.2 mL THF, and acetonitrile and methanol were added in equal amounts for a final volume of 4 mL.

All samples were filtered through a nylon Magna 0.22- μm filter into HPLC vials for injection. Analysis followed a modified carotenoid separation method of Ittah et al. (1993) and Levy et al. (1995) for nonsaponified pigments. A Hewlett-Packard 1090 series liquid chromatograph (Hewlett-Packard, Wilmington, Del.) fitted with a Hewlett-Packard 1040 series II photodiode array detection system was used. A gradient elution was used with an ODS Hypersil C-18 narrow-bore column (5 μm , 100×2.1 mm; Hewlett-Packard), starting with 39:53:8 acetonitrile:2-propanol:water and ending with 60:40 acetonitrile:2-propanol after 20 min. A 5-min post-run period with solvents reset to initial conditions was included. A 20- μL sample was injected at a solvent flow rate of 0.5 mL $\cdot\text{min}^{-1}$. Column temperature was 40°C . The range on the photodiode array detector was set at 380–550 nm, with maximum detection at 454 nm.

The carotenoids were identified by their absorption spectra captured by the photodiode array detector, and HPLC retention times in comparison with authentic standards. Also, samples were spiked with standards to verify the identity of sample peaks with similar retention times. Capsanthin was obtained from Hoffman-La Roche (Basel, Switzerland) and β -carotene was obtained from Sigma Chemical Co. (St. Louis). Total carotenoids were quantified as capsanthin equivalents, and β -carotene by using an authentic standard. All standards were handled under low light on ice.

Standard solutions of β -carotene were prepared in 20 mL THF, and capsanthin standards in methanol:acetonitrile (1:1). Aliquots were diluted in methanol:acetonitrile (1:1) to provide standard concentrations ranging from 2 to 10 $\mu\text{g}\cdot\text{L}^{-1}$. The detection limit was 0.1 $\mu\text{g}\cdot\text{L}^{-1}$.

Data were analyzed using the generalized linear models procedure of SAS (SAS Institute, Cary, N.C.) for a randomized complete-block design, with samples blocked based on time of laboratory extraction and analysis.

Results and Discussion

Wide variation was observed among *Capsicum* entries for β -carotene ($P \leq 0.0001$) and total carotenoids ($P \leq 0.0001$) content of fresh and dry fruit for both years (Tables 1 and 2). Variation between years was nonsignificant for β -carotene ($P = 0.40$) or total carotenoids ($P = 0.37$) content in fresh fruit, but was significant for content of both in dry fruit ($P \leq 0.0001$ and 0.001 for β -carotene and total carotenoids, respectively). In most cases, lower levels of β -carotene and total carotenoids were observed in 1996 than in 1997. The significant effect of years on dry, but not fresh, fruit pigment content can perhaps be explained by climatic differences. The weather at the time preceding and during fresh fruit ripening was similar in both years, with average daily temperatures of 26 to 27°C in July and August. However, in September, when fruit were beginning to dehydrate on the plants and accumulate pigments, the average daily temperatures were 22 and 25°C in 1996 and 1997, respectively. In 1996, the cool September weather slowed ripening and was followed by an early freeze on 22 Oct. (-2.2°C) and 23 Oct.

(-1.7°C), allowing less time for pigment accumulation and crop dry-down before the freeze. In 1997, a light frost occurred on 27 Oct. (-0.6°C), but the first hard freeze did not occur until 30 Nov. (-2.2°C). Fruit allowed to dry on the plant accumulate more pigments (Kanner et al., 1977; Palevitch et al., 1975), and fruit harvested after a freeze generally have less color in the dried product (Isidoro et al., 1990).

The interaction between years and cultivars was significant for all analyses ($P \leq 0.0001$). This may have resulted from the large number of entries and the difference in magnitude between years. However, the performance of certain cultivars was inconsistent from 1996 to 1997 relative to that of the majority of entries. For example, dry fruit of 'Aji Brown' and 'Kalocsa', and fresh fruit of 'Greenleaf Tabasco', 'Habanero Red', 'Sante Fe Grande', and 'Biscayne' contained more carotenoids in 1996 than in 1997, whereas most of the remaining cultivars had higher carotenoid levels in 1997. Only one cultivar ('NuMex Conquistador') that was analyzed both as fresh and as dry fruit consistently had high carotenoid levels in all analyses for both years.

β -Carotene and total carotenoid contents were lowest in fresh fruit that were yellow or orange at harvest (Table 1). This agrees with reports for bell peppers, in which β -carotene was highest in brown and red fruit and lowest in orange- and yellow-fruited cultivars (Simonne et al., 1997). For red, ripe fruit in 1996, β -carotene levels ranged from 12 to 166 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight, and carotenoid levels from 232 to 896 $\mu\text{g}\cdot\text{g}^{-1}$. The range of values for β -carotene was similar in 1997, but a wider range in total carotenoids for red fruit was

Table 1. β -Carotene, total carotenoid, and moisture content of fresh *Capsicum* fruit.

Species	Cultivar	Type	1996			1997			Color
			β -carotene ($\mu\text{g}\cdot\text{g}^{-1}$ FW)	Carotenoids ($\mu\text{g}\cdot\text{g}^{-1}$ FW)	Moisture ^z (%)	β -carotene ($\mu\text{g}\cdot\text{g}^{-1}$ FW)	Carotenoids ($\mu\text{g}\cdot\text{g}^{-1}$ FW)	Moisture ^z (%)	
<i>C. annum</i>	Pulla	Guajillo ^y	99 $\pm$ 25 ^x	849 $\pm$ 32	81.3	136 $\pm$ 7	1173 $\pm$ 49	79.5	Red
	Guajillo	Guajillo	64 $\pm$ 7	849 $\pm$ 32	84.8	107 $\pm$ 11	1157 $\pm$ 97	86.1	Red
	Ring-O-Fire	Cayenne	56 $\pm$ 2	896 $\pm$ 52	81.6	82 $\pm$ 14	980 $\pm$ 121	84.1	Red
	NuMex Conquistador	New Mexican	54 $\pm$ 9	474 $\pm$ 65	88.9	126 $\pm$ 13	893 $\pm$ 63	86.3	Red
	Thai Dragon	Asian hot	51 $\pm$ 9	805 $\pm$ 112	80.1	65 $\pm$ 4	763 $\pm$ 42	79.9	Red
	Cherry Large Hot	Cherry	43 $\pm$ 7	571 $\pm$ 64	95.6	37 $\pm$ 4	522 $\pm$ 26	89.8	Red
	Large Red Thick	Cayenne	34 $\pm$ 3	505 $\pm$ 45	85.9	---	---	---	Red
	Mesilla	Cayenne	---	---	---	34 $\pm$ 5	379 $\pm$ 27	87.8	Red
	Sante Fe Grande	Wax	26 $\pm$ 2	344 $\pm$ 24	89.0	13 $\pm$ 2	143 $\pm$ 28	90.2	Red
	NuMex Joe E. Parker	New Mexican	25 $\pm$ 5	353 $\pm$ 42	87.5	35 $\pm$ 4	348 $\pm$ 36	87.7	Red
	Biscayne	Cubanelle	20 $\pm$ 5	235 $\pm$ 53	92.3	9 $\pm$ 1	94 $\pm$ 12	93.9	Red
	Chocolate Beauty	Bell	20 $\pm$ 2	325 $\pm$ 16	92.0	6 $\pm$ 1	107 $\pm$ 25	92.5	Brown
	Pimiento	Pimiento	19 $\pm$ 3	254 $\pm$ 36	91.0	20 $\pm$ 5	276 $\pm$ 26	91.0	Red
	Tangerine	Squash	17 $\pm$ 3	151 $\pm$ 17	91.6	19 $\pm$ 3	162 $\pm$ 21	91.6	Orange
	Serrano	Serrano	16 $\pm$ 6	266 $\pm$ 30	88.0	20 $\pm$ 2	433 $\pm$ 76	83.5	Red
	Mitla	Jalapeño	12 $\pm$ 2	234 $\pm$ 17	89.7	32 $\pm$ 2	438 $\pm$ 37	88.7	Red
	California Wonder	Bell	12 $\pm$ 1	232 $\pm$ 20	91.2	11 $\pm$ 2	183 $\pm$ 19	92.0	Red
	Gold Finch	Bell	3 $\pm$ 1	34 $\pm$ 19	95.9	---	---	---	Orange
	NuMex Sunrise	New Mexican	---	---	---	5 $\pm$ 1	57 $\pm$ 19	94.3	Yellow
	NuMex Sunset	New Mexican	1 $\pm$ 0.4	29 $\pm$ 3	87.8	1 $\pm$ 0.1	67 $\pm$ 30	75.2	Orange
	Sante Fe Grande	Wax	0.1 $\pm$ 0.1	1 $\pm$ 0.2	92.6	ND	4 $\pm$ 3	93.8	Yellow
<i>C. chinense</i>	Habanero Red	Habanero	40 $\pm$ 8	446 $\pm$ 41	92.3	30 $\pm$ 7	348 $\pm$ 25	87.6	Red
	Datil	Datil	---	---	---	44 $\pm$ 0.9	276 $\pm$ 8	87.3	Orange
	Habanero Orange	Habanero	ND	13 $\pm$ 1	89.1	---	---	---	Orange
<i>C. frutescens</i>	Greenleaf Tabasco	Tabasco	166 $\pm$ 16	849 $\pm$ 87	83.4	71 $\pm$ 6	562 $\pm$ 107	84.2	Red

^xAt harvest. FW = fresh weight.

^yFruit were deseeded, except for small-fruited tabasco, guajillo, Asian hot, datil, and serrano types.

^zData are means for four replications $\pm$ SE. ND = not detectable.

Table 2. β -Carotene, total carotenoid, and moisture content of dried *Capsicum* fruit.

Species	Cultivar	Type	1996			1997			Color
			β -carotene ($\mu\text{g}\cdot\text{g}^{-1}$ DW)	Carotenoids ($\mu\text{g}\cdot\text{g}^{-1}$ DW)	Moisture ^z (%)	β -carotene ($\mu\text{g}\cdot\text{g}^{-1}$ DW)	Carotenoids ($\mu\text{g}\cdot\text{g}^{-1}$ DW)	Moisture ^z (%)	
<i>C. annuum</i>	Bajio	Pasilla	539 $\pm$ 63 ^y	6226 $\pm$ 766	78.7	1198 $\pm$ 123	10,121 $\pm$ 1036	83.3	Brown
	NuMex Conquistador	New Mexican	669 $\pm$ 74	4682 $\pm$ 392	83.1	1141 $\pm$ 129	5597 $\pm$ 1312	82.1	Red
	NuMex RNaky	New Mexican	633 $\pm$ 57	5011 $\pm$ 558	80.5	---	---	---	Red
	NuMex Sweet	New Mexican	606 $\pm$ 49	5227 $\pm$ 583	80.3	927 $\pm$ 127	6781 $\pm$ 1047	86.9	Red
	Ancho 101	Ancho	510 $\pm$ 29	4093 $\pm$ 668	83.0	785 $\pm$ 70	5830 $\pm$ 846	82.3	Red
	Biber Sivilir	Turkish	448 $\pm$ 20	3935 $\pm$ 298	81.5	---	---	---	Red
	Sandia	New Mexican	444 $\pm$ 70	4178 $\pm$ 568	74.8	559 $\pm$ 41	4359 $\pm$ 157	86.3	Red
	Merah	Asian hot	428 $\pm$ 43	5130 $\pm$ 762	70.3	736 $\pm$ 66	5853 $\pm$ 437	84.9	Red
	Carliston	Wax	390 $\pm$ 32	3881 $\pm$ 608	87.7	336 $\pm$ 46	3488 $\pm$ 576	55.0	Red
	Pulla	Guajillo	369 $\pm$ 52	2998 $\pm$ 317	65.8	940 $\pm$ 225	6344 $\pm$ 1376	71.7	Red
	Guajillo	Guajillo	343 $\pm$ 54	3721 $\pm$ 547	66.2	538 $\pm$ 124	4082 $\pm$ 575	85.7	Red
	Kalocsa	Wax	328 $\pm$ 18	4659 $\pm$ 297	81.6	360 $\pm$ 21	3000 $\pm$ 105	56.7	Red
	Ring-O-Fire	Cayenne	318 $\pm$ 9	3507 $\pm$ 100	66.8	446 $\pm$ 26	3990 $\pm$ 212	80.0	Red
	Ancho Mulato	Ancho	317 $\pm$ 41	3070 $\pm$ 326	80.8	674 $\pm$ 108	4944 $\pm$ 802	85.4	Brown
	Tejaswini	Indian	268 $\pm$ 15	3140 $\pm$ 297	57.5	448 $\pm$ 87	3388 $\pm$ 555	56.7	Red
	Large Thick Red	Cayenne	217 $\pm$ 22	2642 $\pm$ 363	84.4	249 $\pm$ 29	3053 $\pm$ 471	88.2	Red
	Thai Dragon	Asian hot	217 $\pm$ 24	2300 $\pm$ 334	75.6	304 $\pm$ 29	2976 $\pm$ 187	79.0	Red
	De Arbol	De arbol	197 $\pm$ 28	2254 $\pm$ 170	54.2	---	---	---	Red
	Santaka	Asian hot	179 $\pm$ 26	2240 $\pm$ 244	56.3	225 $\pm$ 12	2398 $\pm$ 145	52.1	Red
	NuMex Mirasol	Mirasol	173 $\pm$ 21	2256 $\pm$ 226	71.2	353 $\pm$ 66	2948 $\pm$ 478	72.4	Red
	Thai	Asian hot	157 $\pm$ 26	1924 $\pm$ 244	57.1	---	---	---	Red
	Tepin	Tepin	88 $\pm$ 14	748 $\pm$ 131	55.2	169 $\pm$ 28	872 $\pm$ 114	55.0	Red
	Tarahumara	Tepin	78 $\pm$ 31	845 $\pm$ 227	50.2	---	---	---	Red
	NuMex Bailey Piquin	Piquin	71 $\pm$ 4	780 $\pm$ 43	61.2	95 $\pm$ 4	963 $\pm$ 80	52.5	Red
	NuMex Sunburst	De arbol	2 $\pm$ 2	111 $\pm$ 12	70.1	24 $\pm$ 8	187 $\pm$ 25	72.0	Orange
	Thai Hot	Asian hot	---	---	---	615 $\pm$ 116	3933 $\pm$ 571	79.9	Red
	Bulgaria	Wax	---	---	---	440 $\pm$ 39	3324 $\pm$ 407	77.0	Red
	Super Cayenne	Cayenne	---	---	---	435 $\pm$ 39	3891 $\pm$ 405	77.8	Red
	Flash	Asian hot	---	---	---	423 $\pm$ 43	3662 $\pm$ 486	70.3	Red
	Turkey	Turkish	---	---	---	320 $\pm$ 54	3073 $\pm$ 567	75.7	Red
	Spanish Paprika	Spanish	---	---	---	317 $\pm$ 113	2729 $\pm$ 968	88.9	Red
<i>C. baccatum</i>	Aji Escabeche	Aji	565 $\pm$ 94	1986 $\pm$ 433	83.7	586 $\pm$ 140	1708 $\pm$ 383	76.7	Orange
	Aji Amarillo Mirasol	Aji	455 $\pm$ 22	1476 $\pm$ 61	84.5	---	---	---	Red
	Aji Amarillo	Aji	34 $\pm$ 4	248 $\pm$ 31	83.3	---	---	---	Yellow
	Aji Colorado	Aji	---	---	---	341 $\pm$ 24	2611 $\pm$ 259	72.4	Red
<i>C. chacoense</i>	Wild type	Tepin	---	---	---	137 $\pm$ 19	633 $\pm$ 137	52.3	Red
<i>C. chinense</i>	Aji Brown	Aji	739 $\pm$ 85	5432 $\pm$ 866	84.3	285 $\pm$ 55	1991 $\pm$ 304	70.6	Brown
<i>C. eximium</i>	Wild type	Tepin	---	---	---	97 $\pm$ 11	649 $\pm$ 119	58.6	Red
<i>C. frutescens</i>	Tabasco	Tabasco	351 $\pm$ 47	1484 $\pm$ 306	66.4	409 $\pm$ 35	1639 $\pm$ 134	75.6	Red
	Greenleaf Tabasco	Tabasco	245 $\pm$ 42	1334 $\pm$ 273	79.1	437 $\pm$ 19	1999 $\pm$ 77	75.6	Red

^zAt harvest. All fruit were destemmed, but not deseeded, dried, and ground before analysis. DW = dry weight.^yData are means for four replications $\pm$ SE.

observed in 1997 (94 to 1173 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight) (Table 1). Variation in pigment levels have been attributed to differences in cultivars, maturity, growing practices, climates, postharvest handling, and analytical methods (Mozafar, 1994).

Between 4.8 and 6.0 mg of β -carotene would supply 100% of the RDA for vitamin A in adult females and males, respectively (National Research Council, 1989). Fresh fruit (100 g) of the cultivars Greenleaf Tabasco, Pulla, Guajillo, NuMex Conquistador, Ring-O-Fire, and Thai Dragon contained greater amounts of β -carotene than the RDA for vitamin A for the average adult (Table 1), assuming that the β -carotene was fully absorbed and converted to vitamin A in the body. Carrots (*Daucus carota* L.), sweet potatoes (*Ipomoea batatas* L.), leafy green vegetables, and pumpkins (*Cucurbita maxima* Duch. ex Lam.) are other vegetables with high provitamin A activity (Bureau and Bushway, 1986). β -Carotene concentrations in sweet potatoes, carrots, beet (*Beta vulgaris* L.) greens and spinach (*Spinacia oleracea* L.) were 86, 76, 50, and 43 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight, respectively (Bureau and

Bushway, 1986). Red fruit of guajillo, tabasco, New Mexican, cayenne, and Asian hot entries tended to have concentrations of β -carotene (Table 1) equivalent to or higher than those of the four vegetables with highest values reported by Bureau and Bushway (1986). However, consumption of 100 g of these pungent chiles may be difficult for many people. One exception is 'NuMex Conquistador', which is a nonpungent cultivar.

β -Carotene concentrations in fresh, green fruit of bell, serrano, jalapeño, and New Mexican type chiles have ranged from 2 to 5, 5 to 8, 3 to 5, and 2 to 5 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight, respectively (Bureau and Bushway, 1986; Howard et al., 1994; Mejia et al., 1988; Simonne et al., 1997). In our study, β -carotene content of red bell peppers ('California Wonder') averaged 11 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight, and red, ripe fruit of serrano, jalapeño ('Mitla'), and New Mexican type chiles ('NuMex Joe E. Parker') contained 18, 22, and 30 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight, respectively, when averaged over 2 years. Howard et al. (1994) reported β -carotene concentrations in red, ripe fruit of bell, serrano, jalapeño, and New Mexican type cultivars as high as 14, 13,

26, and 28 $\mu\text{g}\cdot\text{g}^{-1}$ fresh weight, respectively. Therefore, the provitamin A value of ripe fruit can be 3 to 15 times as high as that of green fruit, depending on fruit type, cultivar, and growing conditions.

For dried *Capsicum* entries, New Mexican, aji, pasilla, ancho, and guajillo types had the highest levels of β -carotene (Table 2). About 10 g of these dried fruit would meet or exceed the RDA for vitamin A based on β -carotene alone. In 1996, β -carotene levels among the *Capsicum* cultivars surveyed ranged from 2 to 739 $\mu\text{g}\cdot\text{g}^{-1}$ dry weight, and carotenoid levels from 111 to 6226 $\mu\text{g}\cdot\text{g}^{-1}$ (Table 2). Values were higher in 1997, and ranged from 24 to 1198 $\mu\text{g}\cdot\text{g}^{-1}$ dry weight for β -carotene and from 187 to 10,121 $\mu\text{g}\cdot\text{g}^{-1}$ for total carotenoids (Table 2).

The total carotenoid levels of dried fruit are relevant for breeding high pigment paprika and chiles (*C. annuum*, New Mexican type) for the food industry. Carotenoids are added either as dehydrated, ground fruit or carotenoid extracts (oleoresin) to a range of food products, cosmetics, and pharmaceuticals as natural colorants. New Mexico State Univ.

paprika cultivars ('NuMex Conquistador' and 'NuMex Sweet') were among the six dried entries with the highest β -carotene and total carotenoid content in both years. Thus, genes for high pigment content exist within the germplasm used in the breeding program. However, a pasilla type ('Bajio', *C. annuum*) had the highest total carotenoid content among the dried entries in both years. Also, reports by Levy et al. (1995) of a breeding line with total carotenoids of 16,600 $\mu\text{g}\cdot\text{g}^{-1}$ dry weight shows that further improvements for carotenoid content are possible. Fruits of other *C. annuum* lines contained from 3250 to 10,710 μg total carotenoids, and from 254 to 840 μg β -carotene/g dry weight (Levy et al., 1995), which were similar to our results. We have hybridized 'Bajio' pasilla with 'NuMex Conquistador' and advanced breeding lines in hopes of further enhancing total carotenoids in New Mexican-type chiles.

Consumers should be educated about the benefits of including fresh and dried red *Capsicum* fruit in the diet. Chile fruit are nutritionally balanced with respect to the antioxidant vitamins A, C, and E. Red chiles contain at least three to four times more vitamin A, C, and E than do green fruit (Osuna-Garcia et al., 1998). Also, if the high levels of total carotenoids are considered, the contribution of red chiles to overall human health may be substantial. The antioxidant properties of carotenoids such as capsanthin and capsorubin have not been fully studied, but may be important in preventing cancer and cardiovascular disease (Machlin, 1995).

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