Review

Nutritional comparison of fresh, frozen, and canned fruits and vegetables II. Vitamin A and carotenoids, vitamin E, minerals and fiber

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Abstract: In this second part of our review, we examine the literature for changes in carotenoids, vitamin E, minerals, and fiber due to processing, storage, and cooking of fresh, frozen, and canned fruits and vegetables. While inconsistencies in methodology and reporting methods complicate interpretation of the data, the results show that these nutrients are generally similar in comparable fresh and processed products. The higher levels of carotenoids typically found in canned as compared to fresh products may be attributed to either reporting results on a wet rather than dry weight basis, greater extractability, or differences in cultivars. There are relatively few studies on processing, storage, and cooking effects on vitamin E in fruits and vegetables. Further research is needed to understand nutritional changes in those few fruits and vegetables rich in vitamin E, such as tomatoes. Minerals and fiber are generally stable to processing, storage, and cooking, but may be lost in peeling and other removal steps during processing. Mineral uptake (e.g., calcium) or addition (e.g., sodium) during processing can change the natural mineral composition of a product. Sodium concerns in canned food can be addressed by choosing products with no salt added. Since nutrient content varies considerably by commodity, cultivar, and postharvest treatments, inclusion of a wide variety of fruits and vegetables in the diet is encouraged.

Keywords: carotenoids; vitamin E; sodium; minerals; fiber; canned

INTRODUCTION

In Part I of this review we discussed the changes in vitamin C, B, and phenolic compounds due to processing, storage, and cooking of fresh, frozen, and canned fruits and vegetables.[1] Although processing can often lower the nutritional value of fruits and vegetables, the extent of nutrient degradation is highly variable and may be insignificant when compared with losses during storage and cooking of fresh produce. The water-soluble nutrients examined in part I were especially sensitive to thermal treatments such as blanching and/or cooking. Ascorbic acid is generally used as a marker for nutrient degradation; however, since it is so sensitive, its degradation does not accurately reflect the degradation of more stable nutrients, such as those examined in this second part of the review. In this installment, we examine the lipid-soluble vitamins A and E, as well as other carotenoids (including lycopene), minerals, and fiber.

Vitamin E and A, along with other carotenoids, are lipid soluble, and are less affected than water-soluble nutrients by processing steps such as washing and blanching, as well as cooking at home. Leaching of water-soluble nutrients during these preparation and processing operations is common. Although vitamin E and carotenoids are also susceptible to oxidation, they are not as sensitive as those vitamins covered in part I of this review. Minerals and fiber are more resilient nutrients in general; therefore, changes in their content are usually less notable. Exceptions include sodium or other minerals that may be added during processing, in which case the content will obviously increase.

The nutrients reviewed in this paper, with the exception of sodium, have all been identified recently as lacking in the American diet.[2] Table 1 details the dietary reference intakes for the nutrients covered in both parts of our review. Vitamin A is one of several nutrients particularly lacking in the diets of low-income, breastfeeding women. To increase vitamin A intake, the Women, Infants and Children (WIC) program includes fresh, frozen, or canned carrots as a supplemental food item in food packages provided to breastfeeding women.

The suboptimal consumption of fruits and vegetables is not unique to the United States. The World Health Organization (WHO) places low fruit and vegetable intake sixth on its list of 20 risk factors for mortality worldwide. WHO further estimates that sufficient fruit and vegetable consumption could save up to 2.7 million lives annually (http://www.who.int/dietphysicalactivity/media/en/gsfs_fv.pdf).

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Table 1. Dietary reference intakes for healthy adults (www.iom.edu)

	Vitamin C (RDA)	Thiamin (RDA)	Riboflavin (RDA)	Vitamin B_6 (RDA)	Niacin (RDA)	Folate (RDA)	Vitamin A (RDA)	Vitamin E (RDA)	Calcium (RDA)	Potassium (AI)	Sodium (AI)	Fiber (AI)
RDA/AI (mg d^{-1})	82.5	1.15	1.2	1.3	15	0.40	0.80	15	1000	4.7	1.5	30
EAR (mg d^{-1})	67.5	0.95	1.0	1.2	11.5	0.32	0.56	12	–	–	–	–

Table 2. Economic Research Service consumption data, pounds per capita for 2004 (www.ers.usda.gov/data/foodconsumption/)

Commodity	Fresh	Frozen	Canned
Asparagus	1.0	0.07	0.20
Beans, snap	1.9	1.9	3.7
Carrots	8.9	1.6	1.2
Corn	9.6	9.1	8.2
Green peas	–	1.9	1.2
Mushrooms	2.6	–	1.6
Peaches and nectarines	5.1	0.55	3.6
Pineapple	4.4	–	4.8
Spinach	2.1	0.93[a]	
Tomatoes	19.3	–	70.4

[a] Total for all processing varieties.

Many countries use programs such as the United States' Five-A-Day to encourage the intake of fruits and vegetables. It is important to note that foodstuffs may only bear the Five-A-Day logo if they meet the Food and Drug Administration's requirements for 'healthy' food, which places restrictions on fat, saturated fat, cholesterol, and sodium. In particular, sodium levels must be below 480 mg per serving to bear the Five-A-Day logo. In general, canned fruits and vegetables meet this requirement, which may be contrary to popular belief (http://www.5aday.gov/health_professionals/program_guidelines.html).

Although most people do not consume an adequate amount of fruits and vegetables, it is interesting to note that in the United States more processed fruit and vegetables are consumed overall than their fresh counterparts. Table 2 details fruits and vegetables commonly consumed in their processed form. Since nearly 80% of all tomatoes consumed in the United States are canned, it is especially important to note changes that may occur during the processing of tomatoes. Interestingly, industrial processing tomato cultivars may contain, on average, significantly higher levels of α-tocopherol (vitamin E) and carotenoids than fresh tomato cultivars.[3] Nutritional quality is highly dependent on cultivar, and different cultivars are often used for canned and frozen products than for those products intended for fresh consumption.

Currently, government guidelines encourage the intake of all forms of fruits and vegetables, as long as added ingredients such as sugars, salt, and fat are limited. The aim of this research was to determine whether these all-inclusive recommendations are warranted based on the nutritional changes that can occur during processing, storage, and cooking. Whenever possible, the same initial raw material is followed through these postharvest processes. However, very few researchers have critically evaluated the effects of all of these processes. More commonly, researchers merely examine one or two steps in the process (e.g., fresh storage, processing, or processing and storage). Some investigators have opted to analyze what is realistically available to consumers, and thus have purchased fresh, frozen, or canned fruits and vegetables at retail markets (hereafter referred to as 'retail market studies'). Nutritional data will undoubtedly vary by regional availability and transportation, in addition to cultivar, seasonality, and other conditions. The USDA nutrient database along with nutrition fact labels can provide year-round averages for nutritional content but may not represent the variability that is inherent to different cultivars, farming practices, seasonality, etc. It is important for consumers to recognize this diversity, which provides an additional impetus to support a diet including a variety of fruits and vegetables. As with the first part of this review, variability in methodologies used to analyze nutrients complicates conclusions drawn from this review. Furthermore, changes in nutritional content that occur during postharvest procedures can be misleading when these changes are presented on a wet weight basis. Since moisture content can change significantly through processing, storage, and cooking, evaluating changes as expressed on a dry weight basis would be more appropriate.

VITAMIN A AND CAROTENOIDS

Moshfegh *et al*. reported that most Americans do not meet their adequate intake for vitamin A (retinol).[2] The primary source of vitamin A in fruits and vegetables is in the form of its precursor, β-carotene. The dietary reference intakes therefore utilize retinol activity equivalents as a standard, where 12 µg β-carotene is equivalent to 1 µg RAE. Two other carotenoids have notable provitamin A activity – α-carotene and β-cryptoxanthin – for each of which 24 µg is equivalent to 1 µg RAE. While the nutritional importance of carotenoids is based primarily on vitamin A activity, carotenoids have also been extensively studied for their potential protection against numerous cancers. Lycopene, a carotenoid without provitamin A activity, has been found both to have greater antioxidant capacity and stronger inhibition of cancer cell proliferation than other carotenoids.[4–6] Important sources of

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carotenoids include carrots, spinach, tomatoes, and apricots.[7]

Processing

Because they are lipid soluble, carotenoids are not significantly lost to leaching into water-soluble mediums during processing and storage in the can. They are, however, sensitive to oxidation. The extent of degradation is dependent on temperature, light, acidity, and amount of available oxygen. Carotenoids are thus susceptible to loss of provitamin A activity through oxidation during processing.[6] Furthermore, thermal processing can cause the naturally predominant all-*trans* carotenoids to isomerize to *cis* conformations, β-carotene being the most sensitive to isomerization.[3] While most research measures total β-carotene, *trans*-β-carotene has been shown to have the highest biological activity. The three common *cis* isomers that form during processing have at most 50% the activity level of all-*trans* isomers.[8] Lycopene is less sensitive to isomerization, but interestingly lycopene has been shown to be more bioavailable in its *cis* form.[5,9] In fact, several studies have found greater carotenoid bioactivity after consumption of processed tomatoes as compared to fresh tomatoes.[5,10] These results may be attributed to the isomerization that takes place or to the greater extractability of carotenoids after cooking.

Canning

Studies on the effect of canning on provitamin A carotenoids are inconsistent (Tables 3 and 4). Lessin *et al*. found increases (dry weight, DW) in total β-carotene, α-carotene, and β-cryptoxanthin following canning of carrots, collard greens, spinach, and sweet potatoes, but losses in peaches and tomatoes (Table 3).[8] A study published in 1979 found a 4% (DW) increase in total carotene in peaches, but found 8% and 14% (DW) losses in green beans and sweet potatoes, respectively.[14] The authors noted fluctuation of carotene in green beans during the canning process. In the production of tomato paste, Abushita *et al*. found increased dry weight concentrations of total β-carotene in the intermediate hot-break extract, but final levels in tomato paste were lower than in fresh tomatoes.[3] Canning may improve the extraction of carotenoids from their cellular matrix, therefore resulting in higher levels in thermally processed products. However, excess heat may also lead to degradation.

In contrast to the dry matter studies, most studies reporting results on a wet weight basis reported decreases or no change in carotenoid concentration in all commodities studied (Tables 3 and 4). Since the data are from different years and for different commodities, it is difficult to compare these results. Results presented on a wet weight basis may be unreliable because moisture content in the unprocessed and canned product may not be the same. This inconsistency suggests a need for further research, including a standardized method of measurement and reporting, preferably on a dry weight basis.

Few studies have distinguished between β-carotene isomers. Loss of *trans*-β-carotene may sometimes be attributed to gain of *cis*-β-carotene (Table 5). Interestingly, Lessin *et al*. showed no difference in *trans*-β-carotene between fresh and canned spinach, but did show an increase in *cis*-β-carotene in the canned sample.[8] These authors suggest that the observed increase is caused by increased extraction efficiency due to release of protein-bound carotenoids, degradation of oxidative enzymes, and/or loss of soluble solids. Increases in both *trans*- and *cis*-β-carotene were found in canned collard greens, while sweet potatoes lost *trans*- and gained *cis*-β-carotene, for a net overall increase on a dry matter basis. These two studies suggest sensitivity to isomerization may be dependent on commodity, maturity, or tissue type. Further research is needed to support these findings.

Several researchers have studied the impact of thermal processing on lycopene and β-carotene in tomatoes. Only one out of three recent studies found

Table 3. Percent change (DW) in total β-carotene and total provitamin A carotenoids due to canning[8]

Commodity	β-Carotene	α-Carotene	β-Cryptoxanthin	Total provitamin A
Carrots	+7	+33	–	+16
Collard greens	+50	–	–	+50
Peaches	−50	–	−40	−49
Spinach	+19	–	–	+19
Sweet potato	+22	–	–	+22
Tomato	−13	–	–	−13

Table 4. Percent loss (WW) of total α- and β-carotene due to canning

Commodity	Loss (%)	Authors	Year
Corn[a]	NS	Scott and Eldridge[11]	2005
Fiddlehead greens	−26	Bushway *et al*.[12]	1985
Green beans	−17	Weits *et al*.[13]	1970
Green peas	−22		
Spinach	−17		

[a] Also includes β-cryptoxanthin.
NS, not significant.

Table 5. Percent change (DW) in *trans, cis*, and total β-carotene due to canning

Product	*trans*-β-carotene	*cis*-β-carotene	Total β-carotene	Authors	Year
Collard greens	+12	+163	+50	Lessin *et al*.[8]	1997
Peaches	−59	−25	−50		
Spinach	NS	+91	+19		
Sweet potato	−25	+100	+18		
Whole tomatoes	−30	+110	−13		
Tomato paste	−29	+90	NS	Abushita *et al*.[3]	2000

NS, not significant

an increase in *trans*-β-carotene, and then only when results were expressed on a wet weight basis. For lycopene, the results are inconsistent, depending on dry or wet weight expression. Seybold *et al*. recorded changes on both a wet and dry weight basis, finding that the decrease in moisture content during processing 'masked' the loss of the carotenoids (Table 6): expression on a dry weight basis determined the wet weight results to be artificially high. In general, thermal processing caused a decrease in *trans*-β-carotene and *trans*-lycopene when results were expressed on a dry weight basis.[15]

Freezing

Recent research on the effects of freezing on carotenoids has focused on those with provitamin A activity. Tomatoes, the major source of lycopene in the American diet, are not commonly frozen; therefore the need to study the effects of freezing processes on lycopene has not arisen. All studies reviewed reported results on a wet weight basis, and the majority found carotenoid losses from 5% to 48% for freezing. Only one study found an increase in β-carotene in corn (Table 7), which does not contain significant levels of this carotenoid. Furthermore, the authors reported the freezing process might have resulted in a decrease in moisture content of the corn, thereby artificially inflating the carotenoid content on a wet weight basis.[11] In comparison to canned products, frozen products usually contained slightly higher levels of β-carotene than canned on a wet weight basis (Table 8). However, Howard *et al*. found that results depended on the harvest year for broccoli and carrots.[17]

Storage

Few studies were found detailing the degradation of carotenoids during fresh storage. Salunkhe *et al*. states that carotenoid degradation during storage is low

Table 6. Percent changes in lycopene and β-carotene due to tomato processing

Initial product	Final product	*trans*-β-carotene	*trans*-lycopene	Dry/wet weight basis	Authors	Year
Raw tomatoes	Tomato paste	−29	+37	DW	Abushita *et al*.[3]	2000
	Tomato sauce	–	−8		Seybold *et al*.[15]	2004
	Tomato soup	−56	−48			
		+62	+117	WW		
	Cooked puree	–	+165		Dewanto *et al*.[16]	2002
Canned tomatoes	Tomato juice	−35	−30	DW	Seybold *et al*.[15]	2004
		−21	−17	WW		

Table 7. Percent change in carotenoids due to blanching and freezing (WW)

Commodity		*trans*-β-carotene	Total β-carotene	α- and β-carotene	Authors	Year
Broccoli[a]	Year 1	−22	–	–	Howard *et al*.[17]	1999
	Year 2	−48	–	–		
Carrots[a]	Year 1	−10	–	–		
	Year 2	−36	–	–		
Green beans		−5	–	–		
		–	–	−8	Weits *et al*.[13]	1970
Green peas		–	–	−16		
Spinach		–	–	−12		
Corn[b]		–	+6	–	Scott and Eldridge[11]	2005
			+189			
Fiddlehead greens		–	−19	–	Bushway *et al*.[12]	1985

[a] Results for two consecutive harvest years.
[b] Results for two distinct cultivars.

Table 8. β-carotene in fresh, frozen, and canned products ($g\ kg^{-1}$ WW)

Commodity	Fresh	Frozen	Canned	Authors	Year
Carrots[a]	0.0700	0.0450	0.0350	Howard *et al*.[17]	1999
	0.0630	0.0570	0.0760		
Corn[b]	0.000157	0.000167	0.000117	Scott and Eldridge[11]	2005
	0.0000082	0.000024	0.0000068		
Fiddlehead greens	–	0.0165	0.015	Bushway *et al*.[12]	1985

[a] Results for two consecutive harvest years.
[b] Results for two distinct cultivars.

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Table 9. Percent changes (DW) in carotenoids during storage

Commodity	Carotenoids	Storage time (months)	Frozen	Storage time (months)	Canned	Authors	Year
Carrots	Total β-carotene	1.5	+101.69	–	–	Guerra-Vargas *et al.*[19]	2001
Green jalapeno peppers		0.83	+34.55				
Green beans	Total carotene	–	–	18	−24	Elkins[14]	1979
Peaches					−9		
Sweet potatoes					−12		

Table 10. Percent changes (WW) in carotenoids due to storage

Commodity	Carotenoids	Storage time (months)	Frozen	Storage time (months)	Canned	Authors	Year
Broccoli[a]	*trans*-β-carotene	12	0	–	–	Howard *et al.*[17]	1999
			−15.7				
Green beans			−30				
Carrots			0	12	NS		
Fiddlehead greens	Total β-carotene	10	NS	10	NS	Bushway *et al.*[12]	1985
Tomatoes		–	–	12	−5 to −50	Saldana *et al.*[20]	1979
Green beans	Total carotene	6	−3	6	+2	Weits *et al.*[13]	1970
Green peas			−6		+6		
Spinach			NS		+5		
Fiddlehead greens	α-Carotene	10	+86	10	+93	Bushway *et al.*[12]	1985

[a] Results for two consecutive harvest years.
NS, not significant

for intact living tissues, and that in fact postharvest carotene production can occur in some products.[6] Howard *et al*. studied changes in β-carotene on a wet weight basis of broccoli, carrots, and green beans during refrigerated storage for two consecutive harvest years. They reported a 10% increase in β-carotene in both years for carrots refrigerated for 14 days. However, they found an average loss of 10% of β-carotene in green beans refrigerated for 16 days. These authors found no pattern in the changes of β-carotene in broccoli during refrigerated storage.[17] Simonetti *et al*. found significant decreases of β-carotene after 3 weeks storage of peas (46% WW, 56% DW) and spinach (10% WW, 23% DW).[18]

Gains in carotenoid concentration on a wet and dry weight basis have been observed in storage of frozen vegetables (Tables 9 and 10).[14,19] On a wet weight basis, small to significant losses were reported during frozen storage of broccoli, green beans, and green peas. Elkins found losses of total carotenoids on a dry weight basis during storage of canned green beans, peaches, and sweet potatoes.[14] On a wet weight basis, the majority of recent studies found no change or increases in carotenoids during storage of canned vegetables.

Cooking

Several authors have reported increases in β-carotene during cooking of fresh and frozen vegetables on a wet weight basis (Table 11). In addition, Lessin *et al*. found a 26% increase (DW) in total β-carotene after cooking fresh broccoli. These authors also distinguished between isomers, finding an increase in both *cis*- and *trans*-β-carotene.[8] Howard *et al.* found conflicting results for cooking canned carrots depending on the year of harvest.[17]

Cooked frozen and cooked canned products generally contained similar amounts of β-carotene regardless of storage time (Table 12). In addition, most cooked fresh vegetables contained similar amounts of β-carotene to their cooked processed counterparts (Table 13). Howard *et al*., however, found significantly higher amounts of β-carotene in cooked fresh carrots for two consecutive harvest years.[17] The cooked canned carrots were still good sources of vitamin A. These results are consistent with USDA data (Table 14).

Retail market products and USDA database

Few studies have compared carotenoid levels in market-purchased fresh, frozen, and canned fruits and vegetables. Wills *et al*. reported that cooked fresh

Table 11. Percent changes (WW) in β-carotene due to cooking

Commodity		Fresh	Frozen	Canned	Authors	Year
Carrots[a]	Year 1	−2	+21	−13	Howard *et al.*[17]	1999
	Year 2	+5	+21	+18		
Broccoli[a]	Year 1	+21	+2	–		
	Year 2	+21	+20	–		
Green beans		−15	−6	–		
Spinach		+48	+69	–	Simonetti *et al.*[18]	1991
Peas		+30	−8	–		

[a] Results for two consecutive harvest years.

Table 12. Mean carotene concentration after storage and cooking (g kg^{-1} WW)

Commodity	Carotenoids measured	Fresh Storage (days)	Cooked from fresh	Frozen Storage (months)	Cooked from frozen	Canned Storage (months)	Cooked from canned	Authors	Year
Broccoli[a]	Trans β-carotene	21	0.0085	12	0.0065	–	–	Howard *et al.*[9]	1999
			0.0095		0.0088				
Carrots[a]		84	0.0746		0.0510	12	0.0352		
			0.0890		0.0610		0.0640		
Green beans		16	0.00093		0.0036	–	–		
	Total carotene	0	0.0030	6	0.0028	6	0.0027	Weits *et al.*[21]	1970
Spinach			0.0311		0.0343		0.0334		
Green peas			0.0050		0.0037		0.0036		
	β-carotene		0.0031	0	0.0037	–	–	Simonetti *et al.*[39]	1991
			0.0789		0.0625				
Collard greens		–	–		0.052	0	0.0523	Smith and Kramer[28]	1972

[a] Results for two consecutive harvest years.

Table 13. Average carotenoid contents found in retail products compared with USDA nutrient data (g kg^{-1} WW)[22,23]

	β-Carotene			α-Carotene			Cryptoxanthin		
Product	Cooked from fresh	Cooked from frozen	Canned	Cooked from fresh	Cooked from frozen	Canned	Cooked fresh	Cooked from frozen	Canned
Green beans[a]	0.0039	0.0029	0.0030	0.0007	0.0006	0.0005	0.0007	0.0007	0.0005
USDA[b]	0.0042	0.0033	0.0026	0	0	0	0	0	0
Green peas[a]	0.0038	0.0050	0.0035	0	0	0.0001	0.0007	0.0007	0.0005
USDA[b]	0.0047	0.0125	0.0032	0.0002	0.0002	0	0	0	0

[a] Canned values for cooked product
[b] Canned values for uncooked product

Table 14. USDA nutrient data for β-carotene in select vegetables (g kg^{-1} WW)[23]

	Fresh		Frozen		Canned	
	Uncooked	Cooked	Uncooked	Cooked	Drained solids	Liquids and solids
Apricots[a]	0.01094	–	–	–	0.01746	0.00735
Carrots	0.08285	0.08219	0.0530	0.08199	0.05331	0.05859
Spinach	0.05626	0.06288	0.07035	0.07237	0.05881	–
Sweet potatoes[a]	0.08509	0.11509	0.0622	0.12498	0.05501	0.04518

[a] Product was canned in heavy syrup.

green beans contained higher levels of β-carotene than cooked frozen and cooked canned green beans purchased from a market. They also found that cooked frozen green peas contained higher levels of β-carotene than cooked fresh and cooked canned. Other provitamin A carotenoids were also lowest in canned vegetables, as compared to their fresh and frozen counterparts.[22] It is important to note that those vegetables that initially contained high levels of β-carotene were still good sources of vitamin A in their canned and frozen forms. These results are consistent with USDA nutrient data, although the USDA nutrient database does not provide information on cooked canned products (Tables 13 and 14).

Nagarajan and Hotchkiss purchased a variety of fresh tomatoes and canned tomato products and analyzed them for average lycopene content (Table 15). They reported their data on a wet weight basis and adjusted for soluble solids. Processed tomatoes generally contained higher levels of lycopene than fresh on both a wet and dry weight basis.[24] This is consistent with USDA data, although the study overall

Table 15. Average lycopene in tomato products[24] compared with USDA nutrient data (g kg^{-1})

		Lycopene		
Product	Soluble solids (%)	Wet weight basis	Adjusted for soluble solids	USDA values
Fresh tomatoes	3.8	0.065	0.065	0.026
Canned whole tomatoes	5.5	0.11	0.077	0.027
Canned diced tomatoes	5.5	0.16	0.11	–
Tomato sauce	9.0	0.10	0.045	0.152
Tomato purée	9.5	0.23	0.09	0.218
Tomato paste	24	0.25	0.04	0.288
Tomato juice	5.5	0.10	0.07	0.09

found significantly higher levels of lycopene than the reported USDA values for tomatoes. Diced tomatoes had the highest lycopene values on an adjusted basis, most likely because thermal treatments were less severe compared to other products.

Conclusions

Inconsistent reporting of carotenoids on a dry *versus* wet weight basis and lack of comprehensive studies render interpretation of the effects of processing on carotenoids rather difficult. In comparison with the water-soluble vitamins, the provitamin A carotenoids and lycopene appear to be relatively stable to processing, storage, and cooking, despite some oxidation and isomerization. The apparent increases observed in some studies may be due to changes in moisture content during processing, or they may be attributed to release of carotenoids from cellular matrices during thermal degradation. The need for a standard reporting method seems especially imperative for future interpretation of carotenoid studies.

VITAMIN E

Few studies have examined the effects of canning on vitamin E, probably since the commonly canned foods (fruits and vegetables) are generally not significant sources of the vitamin. Exceptions include sweet potatoes, spinach, and tomato products, the last of which has been the most studied.[3,11,15,25] In the case of tomatoes, several studies point to high levels of vitamin E in the processed product.[3,15,25] One of these studies found tomato cultivars used for processing had on average 166% (wet weight, WW) higher levels of α-tocopherol than those intended for fresh consumption. In processing to tomato paste, however, 20.3% of α-tocopherol was lost. It is interesting to note that the intermediate hot-break extract contained higher levels of α-tocopherol than the raw material.[3] This is consistent with other findings, in which processed tomatoes contained higher levels of α-tocopherol than the unprocessed product. In one such study, heating initially led to an increase in α-tocopherol, although continued heating led to degradation. The researchers suggest α-tocopherol is released during thermal processing; however, once the maximum amount is released from the cells, α-tocopherol content will decline due to thermal degradation. Further research is needed to understand the structure of α-tocopherol in tomatoes and the effects of processing.[3]

The USDA data currently support the suggestion that canned products generally contain significant levels of vitamin E (WW) compared with fresh and frozen counterparts. Of the vegetables compared, only asparagus was found to contain significantly lower amounts of vitamin E in the canned version compared with the fresh product (Table 16).

Table 16. USDA data for α-tocopherol in select vegetables (g kg^{-1} WW)

	Fresh		Frozen		
Commodity	Uncooked	Cooked	Uncooked	Cooked	Canned
Spinach	0.0203	0.0208	0.0290	0.0354	0.0194
Asparagus	0.0113	0.0150	–	0.0120	0.0031
Tomatoes	0.0054	0.0056	–	–	0.0071
Sweet potatoes	0.0026	0.0071	–	0.0077	0.01

MINERALS

Influence of processing on calcium, sodium, and potassium

Minerals are heat stable under normal processing conditions. Food products, however, can gain or lose minerals based on the various processing conditions they are exposed to, such as the addition of salt or leaching of minerals during blanching. Sodium is often added to canned vegetables, primarily for flavor enhancement. Since 86% of Americans consume sodium at levels above the Tolerable Upper Intake of 2.3 mg per day, sodium in canned food is of nutritional interest.[2] On the other hand, canned vegetables also may have higher levels of calcium and other minerals, due to uptake from hard water used in processing. While the water can significantly increase calcium levels, the extent of change is highly dependent on the processing plant location and resources. A more predictable increase in calcium can be attributed to the addition of this mineral to vegetables, especially tomatoes, to minimize softening during processing.[26]

Some mineral content may be lost during blanching, but retention is generally high (78–91%).[4] The increases in sodium, potassium, and calcium, due to addition during processing or hard water utilization, far exceed any losses due to leaching. Loss of minerals can also be observed when certain mineral-rich vegetable parts are discarded; for instance, removal of mushroom stems decreased potassium levels in canned mushrooms.[27]

Canning and freezing

Since mineral content is highly dependent on commercial processing techniques and local water content, a wide variety of results have been reported. Martin-Belloso and Llanos-Barriobero found significantly higher levels of sodium in canned products than the values reported in USDA data tables (Table 17).[27] Processors involved in this study followed recommendations of the Spanish National Technical Center of Canned Vegetables, which may differ from those techniques used in the United States. While little change in potassium was found in asparagus and tomatoes, mushrooms lost significant amounts largely due to removal of the bottoms of the stems. The increase in potassium in lentils came from soaking in a potassium metabisulfite solution. Calcium uptake from hard water was observed in all vegetables, though mushrooms, packed with the hardest water, experienced the greatest increase.

Saldana *et al*. found significantly different calcium levels in canned tomatoes due to variance in processing plant practices. The addition of a salt–calcium–acidulant tablet raised calcium levels up to 0.37 g kg^{-1} WW in canned tomatoes, whereas concentrations of only 0.07 g kg^{-1} WW were found in canned tomatoes not utilizing this practice.[20] The USDA database reports an average of 0.31 g calcium kg^{-1} WW.

Makhlouf *et al*. studied beans, sweet corn, and peas for three years. They found significant nutritional variance due to harvest location, year, and processing plant. The average mineral content for fresh, frozen, and canned vegetables can be found in Table 18. Canned vegetables, as expected, contained significantly higher levels of sodium than their fresh and frozen counterparts. Potassium was highest in frozen vegetables, with the exception of corn. Canned corn contained slightly higher levels of potassium than fresh or frozen corn. Calcium levels varied, but in general canned vegetables contained similar or greater amounts of calcium compared with fresh.[28] USDA data, on the other hand, report lower levels of calcium in canned beans and peas compared with the fresh and frozen products.

Storage

Minerals are generally unaffected during storage, except for iron and copper in canned foods.[14,29] Iron can increase in foods canned in tin-plated steel cans; copper can decrease due to reaction with tin. Sodium, potassium, and calcium are thus not expected to change significantly during storage. This is consistent with reported results.[14,12]

Table 17. Selected mineral content in canned vegetables (g kg^{-1} WW) and percent change from fresh (%DW)[27] compared with USDA values for canned vegetables

		Sodium		Potassium		Calcium	
Commodity		g kg^{-1} WW	%DW	g kg^{-1} WW	%DW	g kg^{-1} WW	%DW
Asparagus[a]	Study	6.20	+597	1.20	+2	0.118	+15
	USDA	2.87	–	1.72	–	0.16	–
Whole peeled tomatoes	Study	1.50	+336	2.20	−5	0.13	+83
	USDA	1.28	–	1.88	–	0.31	–
Mushrooms	Study	6.00	+324	0.83	−35	0.19	+225
	USDA	4.25	–	1.29	–	0.11	–
Lentils	Study	5.80	+930	1.50	+42	0.17	+120

[a] Values for study are for white asparagus; USDA values do not specify color.

Table 18. Average selected mineral content of fresh, frozen, and canned vegetables[28] compared with USDA values (g kg^{-1} WW)

		Sodium			Potassium			Calcium		
Commodity		Fresh	Frozen	Canned	Fresh	Frozen	Canned	Fresh	Frozen	Canned
Corn (vacuum pack)	Study	0.032	0.010	2.288	1.73	2.475	2.515	0.009	0.025	0.017
	USDA	0.15	0.03	2.72	2.70	2.10	1.86	0.02	0.04	0.05
Beans	Study (yellow and green)	0.011	0.008	2.143	1.942	2.634	1.328	0.255	–	0.236
	USDA (green)	0.06	0.03	2.62	2.09	1.86	1.09	0.37	0.42	0.26
Green peas	Study	0.047	0.427	2.150	1.913	2.582	1.632	0.141	0.146	0.163
	USDA	0.04	0.04	2.52	2.00	1.92	1.73	0.43	0.50	0.20

Table 19. Selected mineral content in green beans (12 months), peaches (18 months), and sweet potatoes (18 months) after canning and storage,[14] compared with USDA data

		Sodium		Potassium		Calcium	
Commodity		g kg^{-1} WW	% change from fresh[a]	g kg^{-1} WW	% change from fresh*	g kg^{-1} WW	% change from fresh*
Green beans	Study	2.73	+1606	1.18	−38	0.227	−54
	USDA	2.62	–	1.09	–	0.26	–
Peaches (heavy syrup)	Study	0.069	+47	1.04	−41	0.040	−40
	USDA	0.06	–	0.94	–	0.03	–
Sweet potatoes (vacuum packed)	Study	0.55	+586	3.06	+34	0.228	−30
	USDA	0.53	–	3.12	–	0.22	–

[a] Adjusted for moisture content.

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Elkins reported nutrient content in canned green beans, peaches, and sweet potatoes after 12–18 months storage. The percent changes reported are based on comparison with fresh, unprocessed products.[14] The sodium, potassium, and calcium contents determined in this study are compared with USDA data in Table 19. In general, mineral content of products under investigation was found to be quite similar to the USDA reported data.

Cooking

Minerals can be lost during cooking by leaching into the cooking liquid (Table 20). While this is a negative consequence for potassium and calcium, sodium loss is not nutritionally detrimental for most Americans. In fact, consumers can exploit the leaching of sodium to reduce sodium content in canned food. According to a 1975 study, rinsing canned food before reheating can reduce sodium content by 23–45% (Table 21). The study did not detail losses of other micronutrients that may be lost during rinsing.[30]

Table 20. Mineral losses due to cooking fresh green beans and peas (% WW)[22]

	Sodium	Potassium	Calcium
Green beans	0	−60	−29
Green peas	−50	−44	−42

Table 21. Average sodium losses due to rinsing canned vegetables before reheating[30]

	Number of brands studied	Loss (% WW)
Beets	4	40
Corn	6	34
Green beans	5	23
Green peas	6	45

Retail market products and USDA database

Since most minerals are stable during storage, products purchased at retail market may not be very different from those fresh-picked. However, since cultivar, growing region, climate, processing location, and other variables can influence mineral content in food, it is important to quantify and compare mineral content in products available at retail markets. Wills *et al*. assayed nutritional components in cooked market-purchased green beans and green peas. Since salt was not added during home cooking but was in the canning brine, canned vegetables contained significantly higher levels of sodium than fresh and frozen products (Table 22). Potassium levels were relatively similar in all three versions of both vegetables. Calcium levels were similar in all three versions of green beans, but cooked fresh green peas contained significantly lower amounts of calcium than cooked frozen and cooked canned. Calcium uptake during the blanching step of processing may be responsible for the higher levels observed in cooked frozen and cooked canned green peas.[22]

The amount of salt added to fresh or frozen vegetables during cooking or at the table significantly affects sodium levels in consumed foods. According to the USDA nutritional database, fresh and frozen vegetables cooked with salt have sodium levels similar to those of canned foods (Table 23). Products canned without salt added have similar or lower sodium levels than fresh and frozen products cooked without salt.

Conclusions

The natural mineral content of vegetables is usually retained for intact vegetables under commercial processing conditions, although some minimal loss to leaching may occur. Mineral content may increase in canned foods due to uptake from hard water or the addition of brines. Depending on the mineral and the commodity, this may be viewed as either a positive or negative quality. While most minerals are stable during storage, home cooking may cause more significant

Table 22. Selected mineral content (g kg^{-1} WW) in retail purchased green beans and peas[22]

	Sodium			Potassium			Calcium		
	Cooked from fresh	Cooked from frozen	Cooked from canned	Cooked from fresh	Cooked from frozen	Cooked from canned	Cooked from fresh	Cooked from frozen	Cooked from canned
Green beans	0.03	0.02	3.30	0.80	0.76	0.83	0.30	0.33	0.32
Green peas	0.01	0.03	2.30	1.40	1.20	1.20	0.18	0.27	0.27

Table 23. USDA nutrient data for sodium in select vegetables (g kg^{-1} WW)

	No salt added			With salt		
	Cooked from fresh	Cooked from frozen	Canned	Cooked from fresh	Cooked from frozen	Canned
Corn	0.17	0.01	0.03	2.53	2.45	2.72
Green beans	0.01	0.09	0.02	2.39	2.45	2.62
Green peas	0.03	0.05	0.02	2.39	2.41	2.52

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losses of mineral content through leaching. In general, cooked fresh, cooked frozen, and canned products contain similar levels of potassium and calcium. The sodium content of canned vegetables is also similar to cooked fresh and frozen products when salt is added to the latter products prior to consumption. Vegetables canned without added sodium contain similar levels of sodium to fresh and frozen products cooked without salt.

FIBER

Fiber is a general term for plant cell wall components that are poorly digested by humans, such as cellulose and lignin.[31] Until the 1990s, most research on the proximate composition of foods determined the amount of crude fiber, which is the plant cell residue after extraction by acid and alkaline hydrolysis. Crude fiber, however, may only represent 10–50% of the total dietary fiber available in food. Although the recovery rates of crude fiber methods are low, crude fiber is still reported by some researchers. Newer analytical methods assay dietary fiber, which includes both water-soluble and water-insoluble fractions of plant components that are indigestible by the small intestine.[32]

The average dietary fiber intake in the United States is currently around half of the suggested daily intake of 25 g per day.[32] Since fruit and vegetables are good sources of fiber, it is important to analyze any effects processing may have on this component. Fiber can be lost during processing, during separation steps such as peeling, filtration, or stem removal. Some studies have also suggested that heat processing can change the solubility and other physicochemical properties of fiber.[33] However, most studies analyzing crude and dietary fiber reported no significant changes in crude or dietary fiber after canning and freezing.

Processing: canning and freezing

In the studies reviewed, the canning process resulted in a significant loss of fiber only in those vegetables that underwent some physical separation. Martin-Belloso and Llanos-Barriobero determined the crude fiber content in mushrooms, tomatoes, asparagus, and lentils before and after canning. They reported a 27% (DW) loss in both asparagus and tomatoes after canning. In both circumstances the loss was attributed to removal of the outer layer. Mushrooms and lentils, which were left intact aside from the removal of mushroom stems, both retained their fiber after processing.[27]

Makhlouf *et al*. studied processing effects on corn, peas, and green and yellow beans. Soluble, insoluble, and total fiber did not change significantly after canning or freezing.[28] Bushway *et al*. studied the effects of canning and freezing on fiddlehead greens. On a wet weight basis, they found slight crude fiber losses of 7% and 8%, respectively. Both apparent decreases were attributed to an increase in moisture content.[12]

Storage

Zurera *et al*. reported no significant changes in dietary fiber on a dry weight basis during refrigerated (27 days) and frozen (10 months) storage of white asparagus.[34] Marlett also reported insignificant changes in the fiber content of Red Delicious apples after 12 months of commercial storage, but reported an increase in the insoluble fiber content of yellow onions.[35] Bushway *et al*. reported crude fiber losses of around 25% (WW) in both canned and frozen fiddlehead greens after 10 months storage. The authors suggest the loss may be attributed to thermally induced hydrolysis of complex carbohydrates within the cell wall.[12] Saldana *et al*. reported no significant changes in crude fiber content after 1-year storage of canned beets and tomatoes.[20]

Cooking

Apparent changes in fiber content during cooking have been attributed to changes in moisture content. Wills *et al*. reported slight (2–7% WW) losses in dietary fiber after cooking fresh green peas and beans, due to the increase in moisture content.[22] Nyman and Svanberg observed an increase (DW) in fiber after cooking blanched/frozen carrots. They attribute the increase to a significant loss of dry matter into the boiling water. Interestingly, the authors also reported that the addition of salt catalyzed the degradation of dietary fiber, with carrots losing about 15% (DW) of their total dietary fiber after cooking in a 100 mmol L^{-1} sodium chloride solution.[36] Further research is necessary to support this result.

Retail market products and USDA database

Wills *et al*. purchased fresh, frozen, and canned green peas and green beans from a retail market. They found 25–35% higher dietary fiber levels (WW) in the cooked frozen and cooked canned vegetables than in cooked fresh products.[22] Differences in cultivar may be responsible for this result. The USDA Nutrient Database also reports higher levels of fiber in canned and cooked frozen green peas than the same serving size (1 cup) of cooked fresh peas. Processed green beans, however, had lower levels of dietary fiber when compared with the same serving size of the cooked fresh vegetable.

Marlett and Vollendorff purchased fresh and canned peaches from a retail market. They found the highest amounts of fiber in unpeeled fresh peaches, but peeled fresh peaches contained similar amounts of total dietary fiber to canned peaches.[37] According to the USDA nutrient database, raw, frozen, and canned (juice pack) peaches all contained similar levels of total dietary fiber, around 0.015g kg^{-1} of fruit.

Conclusions

Changes in fiber during processing, storage, and cooking appear to be minimal for intact fruits

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and vegetables. Products with peels or outer layers removed, however, contained lower amounts of fiber than their unprocessed counterparts. The stability of fiber during storage depends on commodity. In general, fresh, frozen, and canned fruits and vegetables contained similar amounts of fiber. However, recent data on the effects of processing on dietary fiber are limited. Since most Americans consume less than the recommended intake of fiber, further research may be appropriate.

IMPLICATIONS AND GENERAL CONCLUSIONS

Although there are inconsistencies in results and reporting methods, it appears that the nutrients reviewed in part II of this publication are similar in concentration in comparable fresh and processed products. Although fresh-picked produce stored for a short time under optimal conditions and consumed raw will most likely provide maximal nutrition, the availability of such produce is limited by region and seasonality. Furthermore, in some cases, processed products have been associated with greater extractability and bioavailability of lipid-soluble nutrients such as β-carotene and lycopene. Processed products may also contain greater nutritional value due to the fact that some processing cultivars are more nutritious than fresh cultivars, as in the case of tomatoes.

Recently, the obesity epidemic in developed nations has some authorities considering exclusive recommendation of consumption of fresh fruits and vegetables. While we do not deny the benefits of consuming fresh fruits and vegetables, we believe that the scientific evidence shows that frozen and canned fruits and vegetables should not be excluded from recommendations. These processed forms offer added convenience to the consumer and offer diversity to the diet, while generally sacrificing little in nutrition. In many developing nations, the postharvest losses of perishable fruits and vegetables may be exceedingly high, and processing provides a means of stabilizing these commodities.

Concerns regarding added ingredients in frozen and canned fruits and vegetables are warranted; however, this topic was not fully reviewed in this study. We did examine sodium, which may be added to canned vegetables and is often over-consumed in the American diet. We found that draining brine and/or rinsing vegetables and legumes may reduce sodium content but may also cause a loss of other desirable water-soluble nutrients. The significance of nutrients lost in the brine and during rinsing requires further research, as our review found only a limited number of publications on this topic. Canned vegetables or legumes with no salt added have similar levels of sodium to fresh or frozen products. The addition of packing liquid may also have an effect on nutrient stability. Interestingly, vacuum-packed fruits and vegetables appeared to experience less nutrient degradation; however, further research is necessary to determine the significance of these results. In general, current research on nutritional changes due to processing, storage, and cooking is lacking. Further studies may be especially appropriate in light of the recent introduction of new cultivars and processing methods.

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