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Review

Nutritional comparison of fresh, frozen and canned fruits and vegetables. Part 1. Vitamins C and B and phenolic compounds

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Abstract: The first of a two-part review of the recent and classical literature reveals that loss of nutrients in fresh products during storage and cooking may be more substantial than commonly perceived. Depending on the commodity, freezing and canning processes may preserve nutrient value. The initial thermal treatment of processed products can cause loss of water-soluble and oxygen-labile nutrients such as vitamin C and the B vitamins. However, these nutrients are relatively stable during subsequent canned storage owing to the lack of oxygen. Frozen products lose fewer nutrients initially because of the short heating time in blanching, but they lose more nutrients during storage owing to oxidation. Phenolic compounds are also water-soluble and oxygen-labile, but changes during processing, storage and cooking appear to be highly variable by commodity. Further studies would facilitate the understanding of the changes in these phytochemicals. Changes in moisture content during storage, cooking and processing can misrepresent changes in nutrient content. These findings indicate that exclusive recommendations of fresh produce ignore the nutrient benefits of canned and frozen products. Nutritional comparison would be facilitated if future research would express nutrient data on a dry weight basis to account for changes in moisture.

Keywords: nutrient; fruit; vegetable; canned; frozen; vitamins; phenolic

INTRODUCTION

Fruits and vegetables are colourful, flavourful and nutritious components of our diets and are often most attractive and health-promoting when harvested at their peak maturity. Unfortunately, most people do not have home gardens capable of supplying the recommended 5–13 daily servings year round. Many fruits and vegetables grow only in certain parts of the world, under specific temperature and humidity environments, and at particular times of the year. In addition, fruits and vegetables are typically over 90% water and, once they are harvested, begin to undergo higher rates of respiration, resulting in moisture loss, quality deterioration and potential microbial spoilage. Harvesting itself separates the fruit or vegetable from its source of nutrients, the plant or tree, and it essentially uses itself as a source of calories. Many fresh fruits and vegetables have a shelf life of only days before they are unsafe or undesirable for consumption.

Storage and processing technologies have been utilised for centuries to transform these perishable fruits and vegetables into safe, delicious and stable products. Refrigeration slows down the respiration of fruits and vegetables and allows for longer shelf lives. Freezing, canning and drying all serve to transform perishable fruits and vegetables into products that can be consumed year round and transported safely to consumers all over the world, not only those located near the growing region. As a result of processing, respiration is arrested, thereby stopping the consumption of nutritious components, the loss of moisture and the growth of micro-organisms. The first objective of fruit and vegetable processing is to ensure a safe product, but processors also strive to produce the highest-quality products. Depending on how processing is carried out, it may result in changes in colour, texture, flavour and nutritional quality, the last of which is the subject of the following literature review.

A substantial amount of research literature has been published over the past 75 years reporting the effects of processing, storage and cooking on the nutritional quality of fruits and vegetables. Washing, peeling and blanching steps prior to processing are responsible for some loss of water-soluble nutrients. However, the thermal processing often associated with canning and pre-freezing blanching treatments is especially detrimental to heat-sensitive nutrients such as ascorbic acid (vitamin C) and thiamin.[1] When used prior to canning, blanching serves to expel air in the tissue and improve thermal conductivity and packing into the container. The primary purpose of

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blanching prior to freezing is to inactivate naturally occurring enzymes that may still be active in the frozen product. Blanching is an important preservation step in the canning and freezing processing of many vegetables. Fruits, on the other hand, are usually not blanched prior to freezing owing to their delicate nature and inherent acidity. Nutrients may also be lost through oxidation, especially during heat treatment and storage. Since both unprocessed and processed fruits and vegetables must undergo some transport and storage, degradation of some nutrients prior to consumption is expected. Lower temperatures, even in frozen goods, tend to prolong the shelf life of fruits and vegetables.[2] Additional cooking of the processed product can also destroy nutrients, although the extent of degradation is dependent on cooking method, nutrient and commodity. In Part 1 we discuss vitamins C and B and phenolic compounds. Part 2 will look at vitamin A and carotenoids, vitamin E, minerals and fibre.[3]

Research approaches

The retention of ascorbic acid is often used as an estimate for the overall nutrient retention of food products.[4,5] Ascorbic acid is by far the least stable nutrient during processing; it is highly sensitive to oxidation and leaching into water-soluble media during processing, storage and cooking of fresh, frozen and canned fruits and vegetables.[6,7] Other vitamins, minerals and bioactive components are more stable; high retention of certain components, such as vitamin E, is common during processing, storage and cooking. Retention of nutrients is highly dependent on cultivar, production location, maturity stage, season and processing conditions.[8–14]

Despite the wealth of research published, understanding nutritional differences between fresh, frozen and canned foods is complex. Researchers often examine the effects of processing and storage on a single cultivar by randomly harvesting fruits or vegetables from the same location to limit variability due to production area, harvest time and cultivar. While this enables researchers to directly understand the effects of thermal processing on a specific commodity, it does not accurately represent the choice consumers have at the supermarket. At the other extreme, some researchers simply purchase fresh products from the grocery store and use these as the raw materials for processing studies, without adequate information on cultivar, maturity and production location.

Different cultivars are often used for canned and frozen products than for those products intended for fresh consumption, and nutritional differences exist between cultivars. Furthermore, studies examining the effects of processing on a food may not subsequently study the effects of storage and cooking on the same food. By the time a consumer consumes fresh purchased goods, the canned or frozen equivalent may be nutritionally similar owing to oxidative degradation of the nutrients during handling and storage of the fresh product. Researchers should simulate conditions on the known cultivars harvested from selected locations. Nutritional qualities also vary according to season and growing location, so individual results may not be representative of yearly averages or regional availability.

Some researchers have approached these problems by examining the differences in fresh, frozen and canned fruits and vegetables purchased at a retail market. Although the cultivars are likely not consistent and the products have undergone different storage and processing conditions, these retail market studies offer a representation of the nutritional differences between fresh, frozen and canned products that are available to consumers in that location.

Besides variance in methodologies, changes in nutritional data may be reported on a dry weight (DW) or a wet weight (WW) basis. Moisture content often changes during processing, especially during canning with the addition of aqueous media. Furthermore, changes in moisture content due to weight loss can occur during storage, the extent of which is dependent on conditions such as relative humidity. Measurements of changes in bioactive components on a wet weight basis may thus be misleading. Some researchers avoid this dilemma by comparing results on both bases or by adjusting their wet weight products for content of soluble solids. However, many studies still report results only on a wet weight basis, complicating the interpretation of results.

Nutritional guidelines

Despite possible degradation of nutrients during processing, storage and cooking, fruits and vegetables are rich sources of many vitamins and minerals, as well as fibre. The United States Food and Drug Administration (FDA) defines a ‘good source’ of a nutrient as one serving of food containing 10–19% of the Recommended Dietary Allowance (RDA) or Adequate Intake (AI) for that nutrient. However, nutrient retention data are often reported in units per 100 g rather than per serving. Since serving size for labelling depends on commodity, a single serving may be more or less than 100 g.

When interpreting data, it is important to consider intake guidelines for each nutrient, such as the Dietary Reference Intakes (DRIs) used in the USA and Canada and published by the Food and Nutrition Board of the National Academy of Sciences (Table 1). DRIs refer to intake recommendations for various nutrients and include the aforementioned RDA and AI in addition to Estimated Average Requirement (EAR) and Tolerable Upper Intake Level (UL). EARs are based on the daily requirements of 50% of healthy individuals in a particular group, while RDAs are set slightly higher to meet the needs of most (97–98%) individuals. When there are insufficient data to set an EAR for a particular nutrient, such as potassium, an AI is specified as an approximation. Nutrients that may pose health risks above a certain level,

Table 1. Dietary Reference Intakes (mg day^{-1}) for healthy adults (www.iom.edu)

	Vit. C (RDA)	Thiamin (RDA)	Riboflavin (RDA)	Vit. B_6 (RDA)	Niacin (RDA)	Folate (RDA)	Vit. A (RDA)	Vit. E (RDA)	Calcium (RDA)	Potassium (AI)	Sodium (AI)	Fibre (AI)
RDA or AI	82.5	1.15	1.2	1.3	15	0.40	0.80	15	1000	4.7	1.5	30
EAR	67.5	0.95	1.0	1.2	11.5	0.32	0.56	12	–	–	–	–

RDA, Recommended Dietary Allowance; AI, Adequate Intake; EAR, Estimated Average Requirement.

such as sodium, are assigned a UL. In September 2005 the United States Department of Agriculture (USDA), Agricultural Research Service published a review of 2001–2002 food intake data, finding that most Americans have significantly lower intakes of vitamins A, C and E, as well as magnesium, than the EAR for each nutrient. Additionally, although no EAR is set for vitamin K, fibre, potassium or calcium, these nutrients may also be consumed in less than desirable quantities. These findings may reflect the insufficient consumption of fruits and vegetables by most Americans.

While nutrient intakes vary by location, inadequate fruit and vegetable consumption is a worldwide concern. The World Health Organisation (WHO) estimates that worldwide consumption of fruits and vegetables is only 20–50% of the recommended daily minimum of 400 g per person (Food and Agriculture Organisation of the United Nations: http://www.fao.org/ag/magazine/0606sp2.htm) In fact, low fruit and vegetable intake is sixth on WHO's list of 20 risk factors for mortality worldwide. WHO estimates that sufficient fruit and vegetable consumption could save up to 2.7 million lives annually (WHO: http://www.who.int/dietphysicalactivity/media/en/gsfs_fv.pdf). Reasons for insufficient fruit and vegetable intake vary among different climates, cultures and countries. Postharvest loss due to perishability may be up to 50% in some developing nations. In developed nations where different forms of fruits and vegetables are plentiful, low intake is sometimes attributed to consumers' desire for more convenience foods.

Health agencies in many countries, including the USA, support a Five-A-Day goal to encourage the consumption of fruits and vegetables. Although barriers to consumption vary, the recommendation to increase consumption of fruits and vegetables is a global standard. The Food and Agricultural Organisation (FAO) has collaborated with WHO to lead the Global Fruit and Vegetables Initiative for Health. The first phase of this initiative, 2006–2009, will include support for national action programmes in up to six pilot countries in developing regions such as Southern Africa and Latin America.

Government recommendations and current consumption

In the USA, several different agencies promote the consumption of all forms of fruits and vegetables. The 2005 Dietary Guidelines for Americans, published jointly by the Department of Health and Human Services and the Department of Agriculture, suggest that both males and females increase their overall fruit and vegetable consumption to nine servings (about 4.5 cups) a day for a 2000 calorie diet. This is an increase of 50 to over 100% from current consumption. These guidelines specifically state that all types of fruits and vegetables, including fresh, frozen, canned and dried products, should be consumed to meet dietary recommendations. Similarly, the Centers for Disease Control and Prevention state that 'all fresh, frozen, dried or canned fruits and vegetables count towards the Five-A-Day goal, as long as they don't have added sugars or fats' (http://www.cdc.gov/nccdphp/dnpa/5aday/faq/types.htm). It is important to note that foodstuffs may only bear the Five-A-Day logo if they meet the FDA 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 (http://5aday.gov/about/pr.html).

The Women, Infants and Children (WIC) programme seeks to improve the nutritional status of low-income women and their children, in part by providing food packages designed to address their nutritional deficiencies. Recent proposed changes to WIC packages include the addition of monthly \$8–10 vouchers for the purchase of fresh fruits and vegetables. Canned, dried or frozen fruits and vegetables would be allowable substitutes when fresh forms are unavailable.[15]

Clearly, government guidelines encourage the intake of all fruits and vegetables, whether fresh, frozen, canned or dried, so long as added ingredients such as sugar, fat and salt are not significant. This recommendation is supported by an independent study at the University of Illinois Department of Food Science and Nutrition. Researchers at Illinois compared USDA nutrient data for fresh, frozen and canned fruits and vegetables (Klein BP and Kalitz R, personal communication). They determined that canned fruits and vegetables were nutritionally similar and sometimes superior for some nutrients to their fresh and frozen counterparts.

Although most people do not consume enough total fruits and vegetables, it is interesting to note that in the USA more processed fruits 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 USA are canned, it is

Table 2. Economic Research Service consumption data (lb 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 processed varieties.

Table 3. Ascorbic acid (g kg^{-1} wet weight) in fresh and canned vegetables

Commodity	Fresh	Canned	Loss (%)	Authors	Year
Broccoli	1.12	0.18	84	Murcia *et al.*[5]	2000
Corn	0.042	0.032	0.25	Dewanto *et al.*[18]	2002
Carrots[a]	0.041	0.005	88	Howard *et al.*[10]	1999
Green peas	0.40[b]	0.096[b]	73	Weits *et al.*[23]	1970
Spinach	0.281[b]	0.143[b]	62		
Green beans	0.163[b]	0.048[b]	63		
	0.053	0.050	NS	Jiratanan and Liu[20]	2004
Beets	0.148	0.132	10		

[a] Average of two consecutive years.

[b] Based on USDA nutrient database. Authors did not provide values.

NS, not significant.

Table 4. USDA nutrient data for ascorbic acid (g kg^{-1} wet weight) in fresh and canned products[16]

		Canned	
Commodity	Fresh	Drained solids	Liquids + solids
Green peas	0.40	0.096	0.098
Spinach	0.281	0.143	0.135
Pineapple (juice pack)	0.169	0.094	0.095
Green beans	0.163	0.048	0.034

especially important to note changes that may occur during the processing of tomatoes.[16] The purpose of this study is to review the literature on the nutritional differences between fresh, frozen and canned fruits and vegetables, concentrating on the years 2000–2005. Results from this review will be presented in two parts. Part 1 includes the water-soluble vitamins C and B in addition to phenolic compounds. Part 2 will focus on the lipid-soluble vitamins A and E in addition to other carotenoids, minerals and fibre.[3]

Whenever possible, the effects of storage and cooking on the fresh and processed fruits and vegetables are also compared. Canned foods undergo thermal processing and are thus most comparable to cooked fresh or cooked frozen products. However, canned foods can be served cold or reheated. For consistency with previous studies, reheated canned foods will be referred to as ‘cooked’. Values from the USDA nutrient database, which are usually yearly averages owing to seasonal variability, are also considered.

Vitamin C, the B vitamins and phenolic compounds are all, to varying degrees, water-soluble, thermally labile and sensitive to oxidation. All these properties make these nutrients more susceptible to degradation during processing, storage and cooking than the nutrients studied in Part 2.

VITAMIN C (ASCORBIC ACID)

Vitamin C is highly water-soluble and sensitive to heat. These properties make it susceptible to processing technologies as well as cooking in the home. According to the Centers for Disease Control and Prevention, good sources of vitamin C include broccoli, tomatoes, leafy greens, apricots and pineapple (http://www.cdc.gov/nccdphp/dnpa/5ADay/index.htm).

Processing

Canning

Many recent and classical studies have examined the effects of thermal processing on ascorbic acid for various commodities (Table 3). Among the recent products studied were tomatoes, asparagus, corn, broccoli, mushrooms and green beans. All reported a decrease in ascorbic acid during commercial thermal processing conditions.[5,10,11,13,17–23]

On a wet weight basis, loss of ascorbic acid during processing ranged from 8% in beets to 90% in carrots.[10,20] Martin-Belloso and Llanos-Barriobero[13] reported their results on a dry weight basis, finding losses of approximately 25–30% for white asparagus, lentils and tomatoes and 41% for mushrooms. Saccani *et al.*[22] found similar results for tomatoes. They reported ascorbic acid losses ranging from 29 to 33% after normalising tomato samples by bringing concentrations to 5° Brix. Although most studies did not analyse the drained liquid, any ascorbic acid remaining in the liquid would likely be minimal since it is easily oxidised. This is supported by USDA nutrient data, which show little difference in ascorbic acid content when the canning liquid is included in the analysis along with the fruit or vegetable (Table 4).

Freezing

Several studies considered the effects of freezing on the same product that was canned.[5,10,11,21] In general, frozen samples contained higher levels of ascorbic acid than canned samples (Table 5). Favell[24] reported changes in ascorbic acid due to freezing for several vegetables on a dry weight basis. He found negligible losses in carrots but 20 and 30% losses in broccoli and green peas respectively.

These results are consistent with older studies on blanching and freezing, which show the highest

Table 5. Losses of ascorbic acid (% wet weight) due to canning and freezing processes

Commodity	Canning	Blanching and freezing	Authors	Year
Broccoli	84	50–55	Murcia *et al.*[5]	2000
	–	30	Howard *et al.*[10]	1999
Carrots	90	0–35		
Green beans	–	17		
	63	28	Weits *et al.*[23]	1970
Green peas	73	51		
	84	63	Fellers and Stepat[25]	1935
	–	20	Hunter and Fletcher[26]	2002
Spinach	–	50		
	62	61	Weits *et al.*[23]	1970

average losses of vitamin C for spinach and broccoli and relatively lower amounts for legumes. Asparagus is reportedly most resistant to losses during the blanching and freezing process, with retention averaging 90%. Retention of ascorbic acid can vary tremendously in all products, depending on cultivar and processing conditions among other variables. In general, losses due to the entire freezing process can range from 10 to 80%, with averages around 50%.[1] This compares favourably with canning, where average losses are greater than 60%.

Storage

Fresh

In a study on the effects of storage and freezing on fresh vegetables, Favell[24] found that freshly picked vegetables consistently contained the greatest amounts of ascorbic acid in all vegetables studied (Table 6). Ascorbic acid begins to degrade, however, immediately after harvest. Green peas, for example, were found to lose 51.5% WW of ascorbic acid during the first 24–48 h after picking.[25] Furthermore, ascorbic acid degrades steadily during prolonged storage, although refrigeration can slow its degradation rate (Tables 6 and 7). The losses of ascorbic acid that occur between harvest and consumption suggest that processing can have a preserving effect for some vegetables.[10,23,25,26] For instance, levels of ascorbic acid in fresh peas and fresh spinach stored at 4 °C fell below levels in the frozen product after 10 days. Fresh storage at ambient temperatures resulted in greater loss; for example, fresh peas stored at ambient temperatures lost 50% of their ascorbic acid in 1 week, while fresh spinach stored at ambient temperatures lost 100% of its ascorbic acid in less than 4 days.[26]

Table 6. Losses of ascorbic acid (% dry weight) due to fresh and frozen storage[24]

Commodity	Fresh, 20 °C, 7 days	Fresh, 4 °C, 7 days	Frozen, −20 °C, 12 months
Broccoli	56	0	10
Carrots	27	10	–
Green beans	55	77	20
Green peas	60	15	10
Spinach	100	75	30

Frozen

Ascorbic acid also continues to degrade during prolonged storage of frozen products (Tables 6 and 7). Losses after 1 year for fruits and vegetables stored at −18 to −20 °C averaged 20–50% WW for products such as broccoli and spinach. Asparagus and green peas, which are generally more resistant to processing, suffered minimal losses. Hunter and Fletcher[26] did not provide an explanation for the increase observed during storage of frozen green peas, although a change in moisture content may be responsible. Table 6 offers details on specific studies.

Canned

Ascorbic acid losses during storage of canned goods tend to be small (<15%) when compared with storage

Table 7. Losses of ascorbic acid (% wet weight) due to storage of fresh, frozen and canned vegetables

	Fresh			Frozen		Canned			
Commodity	Time (days)	°C	Loss (%)	Time (months)	Loss (%)	Time (months)	Loss (%)	Authors	Year
Broccoli[a]	21	4	13	12	50	–	–	Howard *et al.*[10]	1999
			48						
Carrots[a]	84		5		0	12	NS		
			10		50				
Green beans	16		90		45	–	–		
	–	–	–	6	4	6	8	Weits *et al.*[23]	1970
Green peas	–	–	–				NS		
	21	4	40	1	+20[b]	–	–	Hunter and Fletcher[26]	2002
	7	20	60	–	–	–	–		
Spinach	21	4	75	1	NS	–	–		
	4	20	100	–	–	–	–		
	–	–	–	6	26	6	NS	Weits *et al.*[23]	1970

[a] Results for two consecutive years.

[b] Authors reported an increase.

NS, not significant.

losses in fresh and frozen products (Table 7). At least two studies have shown that no statistically significant losses of ascorbic acid occur during storage of canned green beans at room temperature, and one study showed a slight loss of 6% after 18 months of storage of canned green beans.[9,27,28] These results are consistent with classical studies suggesting strong retention (>85%) of ascorbic acid in canned goods stored at ambient temperature for up to 1 year.[2]

Cooking

Depending on the cooking method used, losses of ascorbic acid during home cooking range from 15 to 55%.[29] Additional ascorbic acid losses due to cooking canned products are minimal, since little if any added water is needed and the heating time is generally less than the cooking time needed for fresh or frozen products.[4,25] Unheated canned products are thus usually compared with cooked fresh and/or cooked frozen foods. Cooked frozen products have often been shown to be equal or superior to cooked fresh products in their ascorbic acid levels. This is likely due to the losses of vitamin C during storage of the fresh produce (Table 8).[4,24,26,30]

Howard *et al.*[10] compared uncooked and microwave-cooked fresh refrigerated, frozen and canned carrots.[10] Interestingly, the cooked versions did not always contain lower amounts of ascorbic acid. Microwave cooking may increase the content of ascorbic acid in a food, although no overall pattern was observed. Since results were expressed on a wet weight basis, the apparent increase may be attributed to loss of soluble solids: the authors suggest that the rate of diffusion of ascorbic acid out of the cell may be slower than that of other solids such as sugars. This poses an avenue for future research. Of the products compared, cooked canned carrots contained the lowest amounts of vitamin C, although the results may be nutritionally insignificant, since carrots are not good sources of the vitamin (Table 8).

Retail market products and USDA database

Hunter and Fletcher[26] compared ascorbic acid levels in fresh, frozen and canned peas and spinach purchased at a retail market (Table 9).[26] Both vegetables contained the lowest levels of ascorbic acid in the canned form, even after cooking fresh and frozen products. Interestingly, fresh was not always best. Cooked frozen peas and frozen leaf spinach (*versus* frozen chopped) contained amounts of ascorbic acid greater than or equal to those in the cooked fresh products. These results are inconsistent with USDA data for processed spinach, which report the highest levels of ascorbic acid in the canned form. For green peas, USDA data report the highest levels of ascorbic

Table 8. Total losses of ascorbic acid (% wet weight (WW)) due to processing, storage and cooking

		Fresh		Frozen		Canned			
Commodity	Initial concentration (g kg^{-1} WW)	Storage time (days), refrigerated	Loss (%)	Storage time (months)	Loss (%)	Storage time (months)	Loss (%)	Authors	Year
Broccoli[a]	1.23	0–21	5	0–12	35	–	–	Howard *et al.*[10]	1999
	1.80		38		62				
Carrots[a]	0.043	0–7	42	0–12	12	0–12	81		
	0.039		+50[b]		56		95		
Green beans	0.152	0–21	37	0–12	20	–	–		
	0.163[c]	0	23	6	48	6	68	Weits *et al.*[23]	1970
Green peas	0.40[c]	0	28	6	66	6	77		
	0.354	1–2	61	0	70	0	85	Fellers and Stepat[25]	1935
Spinach	0.281[c]	0	64	6	81	6	67	Weits *et al.*[23]	1970

[a] Authors reported total losses as an average of values collected throughout the total storage time. The two values for each vegetable represent results from consecutive years.

[b] Authors reported an increase.

[c] Based on USDA nutrient database.[16] Authors did not provide values.

Table 9. Average ascorbic acid levels (g kg^{-1} wet weight) found in market-purchased products

	Fresh		Frozen		Canned			
Commodity	Uncooked	Cooked	Uncooked	Cooked	Uncooked	Cooked	Authors	Year
Green beans	0.057	–	0.020	–	0.212	–	Tinklin and Harrison[32]	1959
	0.21	0.13	0.11	0.03	0.04	0.03	Wills *et al.*[33]	1984
Green peas	0.32	0.14	0.21	0.11	0.13	0.06		
	0.183	–	0.194	–	0.0471	–	Hunter and Fletcher[26]	2002
Spinach	0.289	–	0.35	–	0.029	–		
Tomatoes	0.10	0.071	–	–	0.107	–	Franke *et al.*[6]	2004
	0.080	–	–	–	0.080	–	Nagarajan and Hotchkiss[31]	1999

Table 10. USDA nutrient data for ascorbic acid (g kg^{-1} wet weight) in selected fruits and vegetables[16]

	Fresh		Frozen		Canned	
Commodity	Uncooked	Cooked	Uncooked	Cooked	Drained solids	Liquids + solids
Green beans	0.163	0.097	0.129	0.041	0.048	0.034
Green peas	0.400	0.142	0.180	0.099	0.096	0.098
Spinach	0.281	0.098	0.243	0.022	0.143	0.135
Peaches	0.066	–	0.942[a]	–	0.028	0.028
Pineapple (juice pack)	0.169	–	0.080	–	0.094	0.095
Tomatoes	0.127	0.228	–	–	–	0.090

[a] Ascorbic acid may be added during processing to prevent enzymatic browning.

acid in cooked fresh peas, with similar levels in cooked frozen and canned products (Table 10).

In two other retail market studies, purchased fresh and canned tomatoes were compared.[6,31] The results for tomatoes are quite different from those found for peas and spinach. In both studies, canned tomatoes were found to have similar or higher levels of ascorbic acid than the fresh product (Table 9). Only one of these studies cooked the fresh tomatoes, and it was found that boiling resulted in losses of nearly 30% WW.[6] On the other hand, USDA data show higher levels of ascorbic acid in cooked fresh tomatoes than in unprocessed tomatoes on a wet weight basis (Table 10). The discrepancy could be due to variation in cultivars or cooking techniques.

To further examine the differences in retail market products, we turned to older studies. In one study conducted for three consecutive years, 1956–1958, researchers compared fresh, frozen and canned green beans purchased from a market at various times. The beans were cooked 'with minimum liquid and for as short a time as feasible to conserve the nutritive value and the general acceptability of the products'. These researchers found that cooked fresh green beans contained, on average, significantly higher levels of ascorbic acid than cooked canned or frozen beans (Table 9). In comparing cooked canned and frozen samples, however, the study found variance due to grade of bean (A, B or C) and brand of product. On average, cooked canned green beans contained comparable amounts of ascorbic acid to cooked frozen beans.[32] A 1984 Australian study found similar results for market-purchased green beans, with cooked fresh beans having the greatest amount of ascorbic acid, while cooked frozen and canned beans contained the same amount (Table 9).[33]

Conclusions

Research supports the common perception that fresh is often best for optimal vitamin C content, as long as the fresh product undergoes minimal storage at either room or refrigerated temperatures. While the canning process causes significant initial loss of ascorbic acid, further losses due to storage and cooking are minimal. In contrast, the blanching and freezing process is not as destructive to ascorbic acid, but continued storage and subsequent cooking of frozen products result in significant degradation of the vitamin. Studies of produce on the retail market and USDA nutrient data reveal that cooked canned and frozen products can contain similar or higher levels of ascorbic acid as cooked fresh products, depending on commodity. Moreover, canned foods such as tomatoes and pineapples can make significant contributions to the RDA for vitamin C. More studies with greater sample sizes are needed to compare ascorbic acid levels in foods available to the consumer.

B VITAMINS

The B vitamin family includes thiamin (B_1), riboflavin (B_2), niacin (B3), biotin, pantothenic acid, B_6, folate and B_{12}. Their water solubility renders them prone to leaching during cooking and processing. Additionally, many of the B vitamins, especially thiamin, are sensitive to degradation during processing. Next to vitamin C, thiamin is the least stable of the vitamins to thermal processing, so its losses are the most studied of the B vitamins.[29,34] However, fruits and vegetables are generally not good sources of thiamin, so its retention may not be representative of the overall nutrient retention of a food.[29] Riboflavin is unstable to light, so processing and storage conditions play a role in its retention. Since biotin and pantothenic acid are widespread in food, changes in these B vitamins during processing are generally not of nutritional concern. B_{12} is found mostly in animal products, so its sensitivity is not reported here.

Moshfegh *et al.*[35] reported that most Americans consume adequate intakes of riboflavin and niacin. Thiamin and folate intakes are lower than desirable among female populations, while inadequate intake of vitamin B_6 was identified as a potential problem for older females. Many fruits and vegetables, especially leafy greens, can contribute B vitamins to the diet.

Processing

Much of the original research on the effects of processing on the B vitamins was completed between 1960 and 1990. Few researchers in recent years have focused their studies on B vitamin losses as a result of canning, freezing and subsequent storage. With continual advances in technology, it may be important to update these data.

Canning

Thiamin (B_1). Several studies have shown significant decreases in thiamin content during thermal processing, although the extent of degradation depends on the commodity.[9,13,27] Losses may range from 25% DW in asparagus to 66% DW in spinach.[13,36] At least two recent reports suggest no significant thiamin losses (WW) after canning tomatoes, although one study reported a loss of 53% DW.[13,22,36] This difference may be due to the expression of nutrient content on a dry rather than a wet basis, but the deviation suggests the need for additional research.

Riboflavin (B_2). Retention of riboflavin during the canning process is much higher than that of thiamin. Research suggests retention of 68% in mushrooms and lentils to 95% or higher in asparagus, sweet potatoes and peaches (DW).[9,13] Again, there are discrepancies among tomato studies due to different dry *versus* wet weight reporting practices. One study of tomatoes reported a 61% DW retention rate for riboflavin, while another found no significant decreases during canning (WW).[13,22]

Vitamin B_6. Retention of B_6 during the canning process ranges from 54% DW in mushrooms to 80% DW in cherries and lentils.[13,27] Schroeder[37] found 57–77% WW less vitamin B_6 in canned vegetables than in their fresh counterparts. Saccani *et al.*[22] brought all tomato samples to 5° Brix before analysis to account for the change in moisture content. They found significant increases of 14–38% in B_6 after canning tomatoes, depending on the type of can (lacquered or plain) and the temperature used for sterilisation.

Niacin (B_3). Most data suggest that niacin is stable to processing.[36] Retention rates of 93% or higher were found after canning and subsequent storage of green peas, green beans, peaches and sweet potatoes on both wet and dry weight bases.[9,33] In fiddlehead greens, however, nearly 50% WW of the original niacin concentration was lost after canning.[38]

Folate. Only one recent study examined folate retention after canning. Jiratanan and Liu[20] found a 30% WW loss of folate as a result of canning beets but did not find a reduction in folate after canning green beans. They attributed the results to the reducing environment in green beans created by packing and processing in water, whereas the beets were packed without a filling medium. The authors suggested that the reducing environment created by the addition of water might allow for the recycling of folate or slow its degradation.

Freezing

The use of blanching as a pre-freezing treatment is responsible for the loss of water-soluble B vitamins. Losses of 9–60% thiamin and up to 20% riboflavin have been reported for vegetables such as green peas and beans.[39] Hebrero *et al.*[40] reported a 30% DW loss of thiamin in spinach due to blanching before freezing. Bushway *et al.*[38] found 30, 38 and 35% WW lower levels of thiamin, riboflavin and niacin respectively after blanching and freezing fiddlehead greens.

A few recent studies have compared B vitamins in frozen and canned legumes. On a wet weight basis, frozen legumes contained significantly higher levels of thiamin than their canned counterparts.[21,33] USDA nutrient data, which report data on a wet weight basis, support this finding (Table 11). Lisiewska *et al.*,[21] however, found that the differences were insignificant when dry matter content was considered.

Storage

Fresh

Spinach has been found to lose 13 and 46% DW of its original thiamin content during storage for 1 and 3 weeks respectively at 4–6 °C. Green peas retained much more thiamin, losing only 23% DW after 3 weeks of storage at 4 °C. Riboflavin also degrades during storage. After 3 weeks at 4 °C, losses of 39 and 24% DW were determined for spinach and peas respectively.[41] Storage temperature can have a significant effect; even greater losses were found in spinach stored at room temperature.[40]

Frozen and canned

The few studies on changes in B vitamins during canned and frozen storage suggest that there is some degradation of these vitamins during storage for most products.[9,38] During long-term storage (6–18 months) at room temperature, significant losses (DW) of thiamin were observed in canned tomatoes and peaches, but only small losses (DW) were found in canned green beans.[9,22,27] Canned tomatoes also lost significant amounts of riboflavin, vitamin B_6 and niacin during 8 months of storage.[22] Canned cherries and green beans lost vitamin B_6 during 4 and 6 months of storage respectively.[27] For canned and frozen fiddlehead greens, no significant changes in thiamin, riboflavin and niacin were found during 10 months of storage.[38] Hebrero *et al.*[40] found a 25.4% DW increase in thiamin after 40 days in frozen spinach. The authors suggest that further research is needed to satisfactorily explain the increase.

Cooking

Cooking vegetables can result in thiamin losses ranging from 11 to 66% WW, depending on the commodity and cooking process.[42] Retention of other B vitamins is generally high, although losses due to leaching can be significant, depending on cooking conditions. In one study on green peas and green beans, cooked fresh products consistently contained more thiamin and riboflavin than both cooked frozen and canned samples on a wet weight basis. Thiamin, riboflavin and niacin contents were the same in cooked frozen and canned green beans. In the case of green peas, thiamin and niacin were significantly lower in the cooked canned sample than in the cooked frozen sample.[33] Since the results were reported on a wet weight basis, dilution of the vitamins may account for some of the differences. Another study showed that cooked fresh and frozen green peas contained similar amounts of thiamin and riboflavin on a wet weight basis.[41] The frozen product, however, did not undergo any storage. Since these vitamins may undergo continued degradation during storage, these results may be nutritionally insignificant. Other studies suggest that cooked frozen and canned legumes contain similar amounts of thiamin, although both contain less than cooked fresh legumes.[21,33]

USDA nutrient database

USDA nutrient data on selected fruits and vegetables can be found in Table 11. Canned green beans, green peas and spinach generally contain the least amount of B vitamins when compared with their fresh and frozen counterparts. Canned peaches are similar to frozen peaches in B vitamin content, although both contain lower amounts than fresh peaches. Canned tomatoes generally contain higher levels of B vitamins than fresh tomatoes.

Table 11. USDA data for B vitamins (g kg^{-1} wet weight) in selected fruits and vegetables[16]

Commodity		Thiamin	Riboflavin	Niacin	B_6	Folate
Green beans	Cooked from fresh	0.00074	0.00097	0.00614	0.00056	0.00033
	Cooked from frozen	0.00035	0.00090	0.00383	0.00060	0.00023
	Canned	0.00015	0.00056	0.00201	0.00037	0.00032
Green peas	Cooked from fresh	0.00259	0.00149	0.0202	0.00216	0.00063
	Cooked from frozen	0.00283	0.00100	0.0148	0.00113	0.00059
	Canned	0.00121	0.00078	0.00732	0.00064	0.00044
Tomatoes	Cooked from fresh	0.00036	0.00022	0.00532	0.00079	0.00013
	Canned	0.00045	0.00047	0.00735	0.00090	0.00008
Peaches	Cooked from fresh	0.00024	0.00031	0.00806	0.00025	0.00004
	Cooked from frozen	0.00013	0.00035	0.00653	0.00018	0.00003
	Canned[a]	0.00012	0.00026	0.00614	0.00019	0.00003
Spinach	Cooked from fresh	0.00095	0.00236	0.00490	0.00242	0.00146
	Cooked from frozen	0.00078	0.00176	0.00439	0.00136	0.00121
	Canned	0.00018	0.00106	0.00271	0.00080	0.00058

[a] Canned in heavy syrup; drained.

Conclusions

Although there are inconsistencies with methodology and data reporting, most data suggest that the B vitamins are sensitive to thermal processing, storage and cooking. However, more studies should be completed to determine the differences in fresh, frozen and canned products available to the consumer at retail markets. Most importantly, dry weight results should be reported to avoid apparent differences due to changes in moisture content during processing and storage.

PHENOLIC COMPOUNDS

Epidemiological studies show positive correlations between a diet high in phenolic-rich fruits and vegetables and reduced risk of chronic diseases such as cancer and cardiovascular disease. In general, phenolic compounds are thus considered a positive quality of fruits and vegetables.[43] However, phenolic compounds are not considered vital nutrients for humans, and their potential benefit to human health is still under discussion. Their nutritional benefits are often attributed to their substantial antioxidant activity. Some researchers have suggested that phenolic compounds are responsible for stalling or stopping the 'initial trigger' of chronic disease by serving as sacrificial antioxidants to damaging oxidants in the body.[43,44] Since there are hundreds of phenolic compounds found in fruits and vegetables, many authors report composite total phenolic (TP) values.

Processing

The phenolic composition of fruits and vegetables is dependent on commodity, cultivar, maturity stage and postharvest conditions. Since phenolic compounds are antioxidants, they are subject to oxidation during storage and processing of foods.[44] The blanching process often used prior to canning and freezing inactivates enzymes that cause the oxidation of phenolics.[45] However, chemical degradation can still occur during storage, depending on available oxygen and exposure to light.

Phenolic compounds are also water-soluble, rendering them susceptible to leaching. Furthermore, phenolic compounds and other phytochemicals are found in significant amounts in the peels of fruits, so some content is lost during the peeling step of processing. Removal of peach peel resulted in 13–48% loss of total phenolics, depending on the maturity stage of the fruit.[46] Separation of other plant tissues, such as removal of mushroom stems, may also influence the final phenolic composition of a food.

Canning

Several researchers have reported significant declines in TP content due to thermal processing. The evidence suggests, however, that the decline is largely due to leaching into the brine or syrup rather than oxidation.[47,48] Furthermore, vegetables vacuum packed and/or canned without a liquid topping juice (beets, tomatoes and corn) were found to have very slight changes in their TP content (Table 12). In fact, beets experienced a further increase (+17% WW from control) after additional heating for a total of 45 min.[20] Interestingly, Bing cherries also experienced an overall increase in TPs due to thermal processing when the canning syrup was included in the analysis. However, 50% WW of the TPs were transferred from the fruit to the syrup.[47]

The largest loss of TPs due to canning was found in mushrooms (Table 12), which underwent several washing and immersion steps in addition to thermal processing.[49] The stems of the mushrooms were also removed, but the authors did not quantify the TPs that may have been lost in this step. This may be important, since other authors have suggested stem removal as a significant reason for nutrient loss in mushrooms.[13] Two brines were used in canning to determine the effects of adding ascorbic acid to the canning medium. As expected, mushrooms canned with ascorbic acid had a retention rate 20% WW higher than those canned without ascorbic acid, suggesting that oxidation is also a significant cause of loss of TPs in mushrooms.

When analysing specific phenolic compounds, similar results were found. Total flavonoids decreased by 60% WW in green beans packed in water but increased by 30–50% WW in beets in which no topping juice was used.[20] No significant change was found in total flavonoids after canning tomatoes.[8] Anthocyanins were found to increase slightly in Bing cherries after canning with syrup, but nearly 50% WW of the anthocyanins were transferred to the syrup.[47] Although procyanidin values for fresh clingstone peaches were not reported, Hong *et al.*[48] compared frozen peaches with canned peaches and reported that the apparent losses observed during thermal processing may be attributed to migration of procyanidins into the canning syrup.

Freezing

In general, freezing causes minimal destruction of phenolic compounds in fruits, with retention levels dependent on cultivar.[49–51] Increases in the phenolic content of some fruit varieties have also been reported (Table 13). After freezing raspberries, González *et al.*[50] found a 12% WW loss in one early harvest cultivar but a 12% WW gain in another. The authors also found increases (up to 40% WW) in total anthocyanins for early harvest cultivars but decreases (−17% WW) for late harvest varieties. The late harvest raspberries, however, still contained significantly higher levels of total anthocyanins after freezing. The same study found 8 and 15% WW losses of TPs and total anthocyanins respectively after freezing wild blackberries. In another study on raspberries, no significant difference in total anthocyanins and TPs was found after freezing.[51]

Table 12. Total phenolics (g gallic acid equivalents kg^{-1} wet weight (WW)) in fresh and canned products

Commodity	Fresh product	Canned product (drained)	Total canned product (fruit or vegetable + canning liquid)	Change due to canning (% WW)	Authors	Year
Beets	1.20	1.30	No liquid used	+5	Jiratanan and Liu[20]	2004
Green beans	0.78	0.53	Not reported	−32		
Bing cherries	1.94	1.13[a]	233	−40[b]	Chaovanalikit and Wrolstad[47]	2004
		1.17[a]	259			
Clingstone peaches	0.397	0.314	Not reported	−21	Asami *et al.*[46]	2002
Corn	0.72	0.68	No liquid used	−5	Dewanto *et al.*[18]	2002
Tomatoes	0.142	–	0.149	NS		
Mushrooms	1.80	0.162	Not reported	−91	Vivar-Quintana *et al.*[49]	1999
		0.603[c]		−67[c]		

[a] Results for canned product correspond to different batches.
[b] Does not include syrup.
[c] Ascorbic acid was added to canning brine.
NS, not significant.

Table 13. Total phenolics (g gallic acid equivalents kg^{-1} wet weight) in selected fresh and frozen fruits

Commodity	Fresh	Frozen	% change	Authors	Year
Raspberries	0.576	0.565	NS	Mullen *et al.*[51]	2002
	1.134–1.782	0.996–1.885	−12to +12[a]	González *et al.*[50]	2003
Blackberries	9.7771	9.036	−8		
Peaches (peeled)	0.326	0.423	+30	Asami *et al.*[46]	2003

[a] Results varied by cultivar.
NS, not significant.

Asami *et al.*[46] found a significant (30% WW) increase in the TPs of clingstone peaches after freezing.

Puupponen-Pimiä *et al.*[52] studied the effects of blanching and freezing on phenolic compounds of peas, carrots, cauliflower, cabbage and potatoes. The authors reported an average loss of 20–30% DW of TPs in most vegetables, although no change was observed in most carrot samples and a 26% DW increase was observed in cabbage.

Storage

Fresh

Mullen *et al.*[51] simulated the storage of fresh raspberries to predict levels in fruits available at retail market (3 days of storage) and at home (additional 24 h). The levels of TPs increased slightly but significantly during the 3 days of storage and the additional 24 h period. The authors suggest that continued secondary metabolic activity in the stored fruits is responsible for the increases observed in TPs. No significant change was found in total anthocyanin content.

Asami *et al.*[46] reported no significant loss of TPs during cold storage of peeled and unpeeled peaches. Interestingly, they found significant gains (69 and 36% WW respectively for peeled and unpeeled fruits) during 24 h of storage at 30 °C. Levels began to drop off after 24 h, although at 48 h the peeled and unpeeled fruits still contained 50 and 28% WW more TPs respectively than fresh fruits. The authors attributed these gains to the possibility of increased activity of enzymes involved in phenolic synthesis, due to elevated temperatures and tissue stress induced by peeling.

Vegetables may not experience the same beneficial increase reported during fresh storage of fruits. Vallejo *et al.*[53] stored freshly harvested broccoli for 7 days to simulate maximum time spent in transport and distribution and for a further 3 days to simulate time spent in a retail market. After the 10 days, large amounts of phenolic compounds were lost. The authors reported losses of 44–51, 59–62 and 73–74% WW for sinapic acid derivatives, total flavonoids and caffeoyl-quinic acid derivatives.

Frozen

Changes in TPs during frozen storage seem to depend heavily on commodity. No statistically significant change was observed in TPs of frozen peaches during 3 months of storage on a wet weight basis.[46] Puupponen-Pimiä *et al.*,[52] however, found some losses of TPs on a dry weight basis during 12 months of frozen storage of broccoli, carrots, cauliflower, peas and potatoes (Table 14). Significant decreases in TPs and total anthocyanins were also found during frozen storage of Bing cherries (Table 15). Losses of 50 and 87% WW of TPs and total anthocyanins respectively were recorded after 6 months of storage at −20 °C. Cherries stored for 6 months at −70 °C, however, retained 88% of total anthocyanins and 100% of TPs.[47]

Changes in TPs are also dependent on cultivar. González *et al.*[50] studied four raspberry cultivars and found different results for each, ranging from no change to an increase of 12% and decreases of 21 and 28%, during 12 months of frozen storage. Since retention of phenolic compounds seems to be quite erratic during frozen storage, further research

Table 14. Changes in total phenolics (g gallic acid equivalents kg^{-1} dry weight) during freezing and 12 months of frozen storage of vegetables[52]

Commodity	Fresh	Initial frozen	% change due to freezing	Final frozen	% change during frozen storage
Broccoli	–	3.20	NA	3.10	−3
Cabbage	1.90	2.40	+26	1.90	−21
Carrots	1.10–1.30	0.80–1.30	0 to −33	0.80–1.20	−17 to +20
Cauliflower	5.60	4.90	−13	4.50	−8
Peas	0.80–1.20	0.60–0.90	−13 to −25	0.60–0.90	0 to −14
Potatoes	0.50–0.60	0.30–0.60	−16 to −40	0.40–0.50	−20 to +67

NA, not applicable.

Table 15. Total phenolics (g gallic acid equivalents kg^{-1} wet weight) in fresh, frozen and canned fruits after storage

Commodity	Original content	Storage time (days)	Fresh stored (4 °C)	Storage temp. (°C)	Storage time (months)	Frozen stored	Storage temp. (°C)	Storage time (months)	Canned, drained	Canned, including syrup	Authors	Year
Bing cherries	1.94	–	–	−23	3	1.45	2	5	1.27	2.35	Chaovanalikit and Wrolstad[47]	2004
					6	0.96						
				−70	3	2.10	22	5	1.21	2.31		
					6	2.00						
Peeled peaches	0.398	7	38.5	−12	3	0.50	Ambient	3	0.221	–	Asami *et al.*[46]	2003
		14	37.8					6	0.247	–		
Unpeeled peaches	0.468	7	43.9	−12	3	0.526	–	–	–	–		
		14	44.3									

should be completed to specify other variables, such as packaging, that may influence retention rates.

Canned

Peaches canned in enamel-coated cans lost 30–43% WW of TPs after 3 months of storage at room temperature (Table 15).[46] The authors did not assay the syrup in this study, but in a subsequent study they reported that the procyanidins lost during canning had actually migrated to the syrup.[48] Chaovanalikit and Wrolstad[47] found similar results for cherries canned in enamel-coated cans (Table 15). Significant losses of anthocyanins were found in canned cherries and their syrup stored for 5 months at room temperature. Slight but insignificant decreases in TPs, however, were found after 5 months of storage at both chilled and room temperatures. The level of TPs in the cherries and syrup was still higher than that in fresh cherries, however, owing to the apparent increases during thermal processing.

Some authors have suggested that the degradation of phenolic compounds during canned storage may be dependent on the type of can used. Tin-plated cans can sacrifice tin to compete for available oxygen, thus sparing some of the phenolic compounds.[46] Research is needed to determine if this is a viable method for increasing retention rates of phenolic compounds during canned storage.

Cooking

Changes in TPs of vegetables during cooking depend on commodity, cooking method and cooking time. Dewanto *et al.*[8] found that the gains of TPs and flavonoids during thermal processing of tomatoes were not significant on a wet weight basis.[8] Gahler *et al.*,[19] however, found up to a 44% gain of TPs during the baking of tomatoes and up to a 64% increase in TPs during the cooking of tomato sauce on a wet weight basis. Franke *et al.*[6] found that retail-purchased fresh tomatoes lost 30–60% WW quercetin upon boiling.

Turkmen *et al.*[54] studied the effects of cooking (boiling, steaming and microwaving) on TPs in the dry matter of fresh purchased pepper, squash, green beans, leeks, peas, broccoli and spinach. Some losses of up to 40% DW were found after cooking squash, peas and leeks, although pepper, green beans and spinach experienced increases in TPs during all cooking methods. Broccoli increased in TP content by 16% DW after steaming or microwaving but lost a slight (6% DW) amount of TPs from boiling.

These results differ from those of Zhang and Hamauzu,[55] who found that broccoli lost up to 70% WW of its TPs after boiling or microwaving. This difference could be due to the change in moisture content of the broccoli during cooking, since Zhang and Hamauzu reported their results on a wet weight basis.

Clearly, more research is needed to determine the effects of cooking on total phenolics as well as individual phenolic compounds. Research is especially needed to determine any further changes in the phenolic make-up of frozen and canned products during cooking.

Retail market products

Since phenolic compounds can undergo oxidation during storage and transport to the retail market, it is important to measure the phenolic composition of market-available food products. As mentioned previously, several authors have simulated these conditions as fresh, frozen and/or canned storage of single cultivars. Several other researchers opted to purchase fresh tomatoes and canned tomato products to quantify what is available to the consumer. Nagarajan and Hotchkiss[31] found significantly higher levels of TPs in canned tomato products compared with fresh tomatoes on a wet weight basis. When they adjusted their results for the same amount of total soluble solids, however, they found similar levels in most products. Tomato paste and juice were exceptions, with canned tomato paste containing about 40% less TPs and canned tomato juice containing about 67% more TPs than fresh tomatoes.

Franke *et al.*[6] measured individual flavonoids and total flavonoids in canned, fresh and boiled fresh tomatoes. Total flavonoids were highest in fresh tomatoes purchased at a market; boiled and canned tomatoes contained similar amounts of flavonoids. On average, canned tomatoes contained 44% WW less quercetin than fresh tomatoes.[6] Finally, Podsedek *et al.*[56] measured the polyphenol content in bottled tomato juices and canned tomatoes but not in fresh tomatoes. They found that the content in their purchased products was similar to the values reported for fresh tomatoes by other authors.

The phenolic composition of other fruits and vegetables and their processed products available to the consumer should be studied in the future. Since different cultivars are used for fresh, frozen and canned products, the phenolic make-up of retail goods is likely to vary significantly within individual commodities.

Conclusions

Changes in phenolic compounds during processing, storage and cooking appear to be quite variable and may depend highly on commodity. Future studies may clarify some of the reported discrepancies. Thermal treatment via cooking, blanching or canning appears to increase the extractability of phenolic compounds. However, since phenolic compounds are both water-soluble and sensitive to oxidation, degradation of TPs is possible during fresh and frozen storage. Decreases in stored canned foods may be due to migration of TPs from the fruit or vegetable to the canning medium; however, further research is necessary. Currently, the USDA does not include TP values in the nutrient database. Since the reported data are rather erratic, future evaluation of TP contents of retail market foods may be germane. A standardised method of analysis and reporting (wet or dry weight) is also essential for comparing study results.

IMPLICATIONS

Losses of nutrients during fresh storage may be more substantial than consumers realise. Depending on the commodity, freezing and canning processes may preserve nutrient value. While the initial thermal treatment of canned products can result in loss, nutrients are relatively stable during subsequent storage owing to the lack of oxygen. Frozen products lose fewer nutrients initially because of the short heating time in blanching, but they lose more nutrients during storage owing to oxidation. In addition to quality degradation, fresh fruits and vegetables usually lose nutrients more rapidly than canned or frozen products. Other variables such as storage and cooking conditions will also influence the final nutrient content of a food. Consumers should consider such variability when utilising nutrient guidelines such as the USDA nutrient database.

Updates to nutritional recommendations for humans of all ages are ongoing. Exclusive recommendations of fresh produce ignore the nutritional value of canned and frozen products and may conceal the sensitivity of fresh products to nutrient loss. Since nutrient retention is highly variable, a diet filled with diverse fruits and vegetables is ideal. The results presented here suggest that canned, frozen and fresh fruits and vegetables should all continue to be included in dietary guidelines. The Global Fruit and Vegetables Initiative for Health should consider the benefits of including all forms of fruits and vegetables in their recommendations. There are, however, limitations to the present work. Some of the nutrient losses reported during processing, storage and/or cooking may be statistically significant but not significant in terms of human nutrition. For instance, carrots lose significant amounts of vitamin C during canning, but they are not good sources of this nutrient to begin with. Similarly, other products such as pineapple contain high enough levels of vitamin C that they remain good sources of the nutrient despite degradation during thermal processing. Our research also did not examine the effects of other ingredients, such as added sugar, that may affect the overall nutritional value of processed fruits and vegetables. This may be particularly important for canned fruits, which are often filled with syrup. While draining the syrup may minimise sugar intake, it may also result in nutrient loss: our research suggests some nutrients may migrate into the syrup or canning liquid. Vacuum-packed fruits and vegetables appeared to experience less degradation of phenolic compounds; however, further research is also necessary to determine the significance of these results.

Nutrition labels do not impart the significant degradation of nutrients that may occur during storage and cooking of fresh and frozen fruits and vegetables. Since minimal degradation occurs during storage of canned goods owing to the lack of oxygen, nutritional labels are valuable sources of information for these products. Nutritionists thus must interpret our results carefully. Fresh cut vegetables were not examined in this study owing to the lack of research. However, we might assume that these products would experience more rapid degradation of oxygen-sensitive nutrients during storage compared with their intact fresh counterparts owing to the increased exposure to oxygen.

GENERAL CONCLUSIONS

While canned foods are often regarded as less nutritious than fresh or frozen products, research reveals that this is not always true. The effects of processing, storage and cooking are highly variable by commodity. In general, while canning often lowers the content of these water-soluble and thermally labile nutrients, storage and cooking of fresh and frozen vegetables can also significantly lower the nutritional content. Unfortunately, very few studies followed the same product from harvest through processing, storage and cooking. Since nutrient and phytochemical content is highly dependent on commodity, cultivar and growing practices, more studies following the same food throughout the consumer chain would be beneficial. Analysis of fresh, frozen and canned fruits and vegetables available in retail markets would also be more appropriate for understanding the nutritional content of fruits and vegetables available to the consumer. Additionally, these retail market studies would be a useful supplement to the USDA nutrient database.

Understanding nutrient data is quite complex. Variance in methodologies and practices makes interpretation of data difficult. Changes in moisture content during storage, cooking and processing often misrepresent changes in nutrient content. Future research should focus on nutrient data expression on a dry weight basis to account for such changes. Furthermore, many current reports in the literature refer to nutrient retentions for processing, storage and cooking that were compiled more than 25 years ago. It is necessary to update these data, standardising process and reporting methods.

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