Nutritional Comparison of Frozen and Non-Frozen Fruits and Vegetables: Literature Review

White Paper

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July 28, 2010

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ABSTRACT

Fruits and vegetables have long been a nutritious and healthful part of the human diet because they are low in calories and fat, and are important sources of vitamins, minerals, and fiber. In addition, fruits are also high in phenolic compounds such as anthocyanins and flavanoids, which have been correlated with lower risks of chronic diseases. The challenge of the producer has always been to find ways to preserve food in a high quality state until it reaches the consumer. Freezing foods has been used for centuries as a preservation method, but it was not until the early 20th century that the technology was developed for mass production and distribution of a variety of foods. Loss of nutritional value due to the freezing process has been studied extensively in fruits and vegetables, particularly vitamin C. It is the purpose of this paper to review the existing food processing, nutrition, and dietary literature for the purposes of preparing this white paper that conveys, from the body of literature, a comparative analysis of the nutritional contents of frozen fruits and vegetables to non-frozen produce and products. Traditional search engines were used to generate an extensive body of literature dating back to 1920's. Besides compiling the information available on this subject, this paper also points out gaps still found in the literature that will guide future research trends based on the current interest denoted by the food industry.

INTRODUCTION

The Beginning of a Revolution in Food Preservation

Clarence Birdseye, an American inventor in the early 20th century, was the first to develop a freezing process that preserved both taste and appearance, in addition to keeping the product safe from spoilage. In 1922, he founded Birdseye Seafoods from his observations on how Eskimos in the Arctic preserved fish by quickly freezing them in the environmental conditions and how the fish tasted fresh when thawed and eaten. Birdseye further developed freezing technology until 1929, when the first frozen foods were commercially produced (Archer, 2004).

The concept developed by Birdseye is very simple, where foods are frozen so fast that large ice crystals are unable to form, hence the name of the technology “quick-frozen”. In the process of freezing, large ice crystals are formed that can damage cell walls and destroy the texture and flavor of foods. If these ice structures are unable to form, the frozen food will maintain its maximum flavor, texture, and color after thawing. Birdseye went on to develop a double-belt contact freezer that became a US patent and would revolutionize the frozen food industry. Further development of the frozen food industry happened in the 1940s after the development of blanching processes which led to a boom of the frozen vegetable industry. After the achievement of success in stopping enzymatic degradation, the industry of frozen vegetables gained a strong retail and institutional appeal (Barbosa-Cánovas *et al*., 2005).

Fruits and vegetables are highly perishable foods subject to rapid deterioration by microorganisms, enzymes, or oxidation reactions. According to Delgado and Sun (2000), freezing technology combines the beneficial effects of low temperatures at which microorganisms cannot grow, chemical reactions are reduced, and cellular metabolic reactions are delayed; and is a process considered superior to canning or dehydration when the retention of sensory attributes and nutritional properties are considered (Fennema, 1982). The use of freezing technologies allows the retention of freshness qualities of fruits and vegetables for long periods, extending their availability well beyond the normal season of most horticultural crops (Arthey, 1993).

The process of freezing involves lowering the product temperature generally to -18ºC or below and maintaining those low temperatures during storage (Kramer, 1979; Fennema, 1973). Studies done by Guadagni and Kelly (1958) showed that in frozen strawberries the total and biologically active ascorbic acid remain the same for a year or longer if the food is stored below -18^{o}C; however, conversion to dehydroascorbic acid (partially active) and 2, 3-diketogulonic acid (totally inactive) increases with increasing storage temperatures, and nearly complete conversion occurs in 8 months at -10^{o}C, and less than 2 months at -2^{o}C. These findings were fundamental to establish -18^{o}C as the upper limit for frozen food storage, and for the use of biologically active ascorbic acid as an indicator of deterioration in storage. For this reason, much of the literature on frozen fruits and vegetables include the measurement of ascorbic acid at the different steps of the process. However, even at such low temperatures, certain enzymatic and non-enzymatic changes will continue at slower rates, and which limit the storage life of frozen foods (Kramer, 1979).

LITERATURE SEARCH METHODOLOGY

This review of the literature on the nutritional comparison of frozen and non-frozen fruits and vegetables was conducted in two sequential steps: horizontal and vertical. In the horizontal step, a "starting point" in the literature was identified which was a review with the closest objective to the one of the current review. The review used was the one by Rickman et al. (2007) from the University of California-Davis (UC Davis), entitled "Review: Nutritional Comparison of Fresh, Frozen and Canned Fruits and Vegetables", and published in two parts in the Journal of the Science of Food and Agriculture.

Once the "starting point" was identified, the literature was scanned in retrospect and in prospect, according to the diagram in Figure 1. In retrospect, the studies in the reference list in the UC Davis review were scanned and labeled as 1st Generation References. Then the articles appearing in the reference lists of the 1st Generation References were scanned, and consequently labeled as 2nd Generation References, and so forth. Occasionally, the same article appeared in different Generations. These articles were labeled according to their first appearance. A similar technique was used to scan articles in prospect from the "starting point". The articles scanned were referred to as 1st Generation Citations. The studies that cited articles in 1st Generation Citations were labeled as 2nd Generation Citations, and so forth.

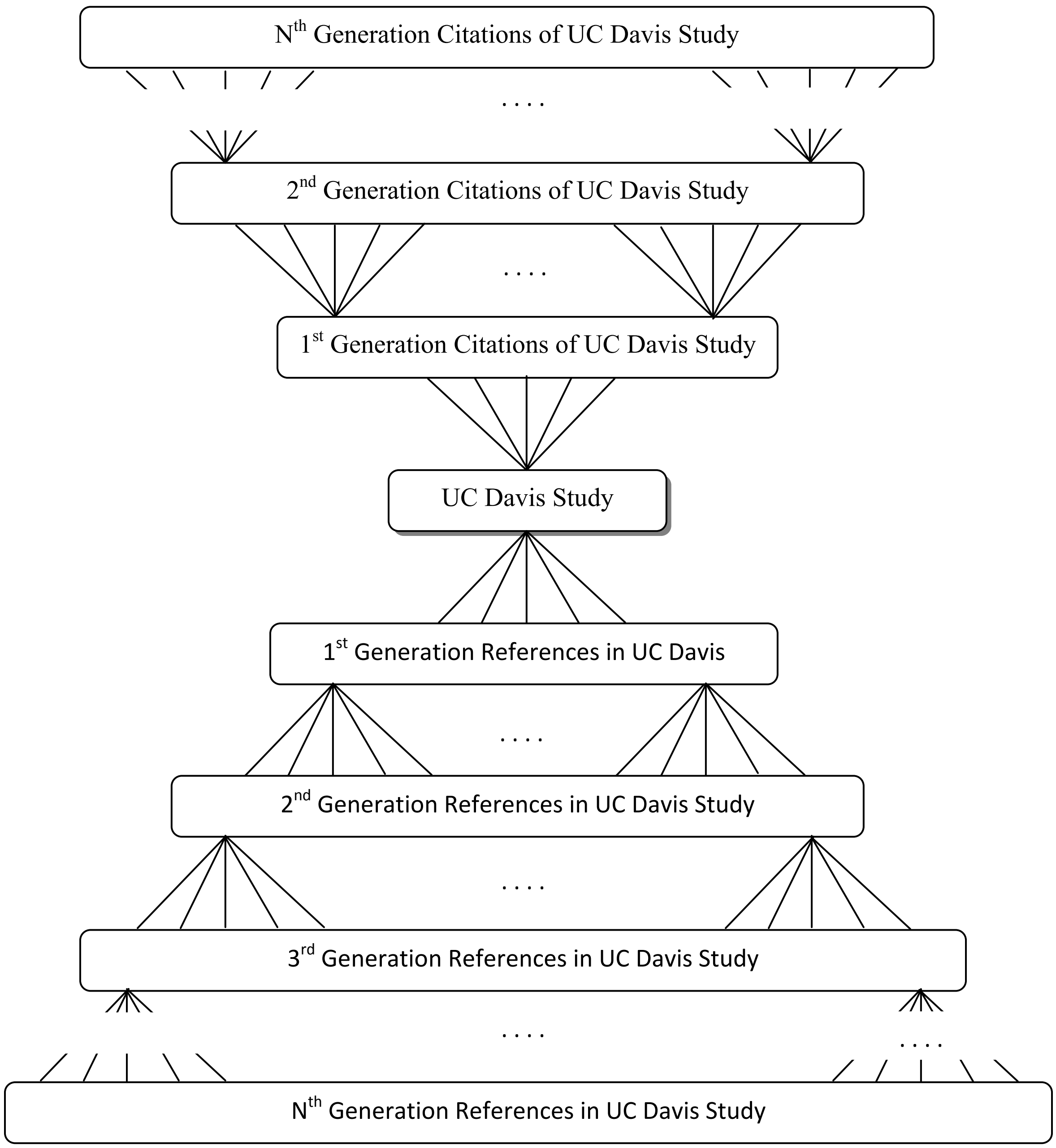

Figure 1: The Horizontal Search Process

The foundation of the vertical search is the source of the publication. The search engines used to find and retrieve articles for this review were the Web of Science (which includes the Science Citation Index), PubMed, Google Scholar, University of Nebraska-Lincoln library resources and interlibrary loans. This process is supposed to endorse the results from the horizontal search, and possibly reveal articles that were not cited but otherwise satisfy the search criteria. The vertical search also covered the articles published between the upper time cutoff for the UC Davis review and the publication year of the UC Davis review.

The search for this review was restricted to the list of the articles that satisfied the following criteria:

1. Only the articles with explicit relevance to the objective were considered: nutritional comparison of frozen and non-frozen fruits and vegetables. Therefore, articles that focused on human health and diet, metabolism of different nutrients, animals, economics, etc., were excluded from the review.

2. Only peer reviewed articles were considered.

3. Only articles published in English were considered to avoid inconsistencies and misinterpretations during translations.

4. Studies with qualitative results were excluded. Even though articles with qualitative results are very insightful, it is hard to combine them with studies with quantitative results and draw comparisons among them.

5. Research published before 1929 was excluded from the review. The modern freezing industry began in 1929 with the development of the double belt-contact freezing, which was adequate for large-scale freezing of fruits and vegetables. Moreover, the blanching step before freezing has been in use since 1929, which justified the exclusion of the literature published before 1929 (Archer, 2004).

REVIEW

Effects of Pre-Freezing Treatments on the Nutritional Value of Fruits and Vegetables and their Phytochemicals

The freezing process includes pre-freezing treatments, freezing, frozen storage, and thawing. Even though freezing is regarded as the simplest and most important preservation process for fruits and vegetables, it is not a perfect process since it is well known that some nutritional value (vitamins and minerals) may be lost during the freezing process. According to Fennema (1982), losses of nutrients during freezing can be the result of physical separation (peeling and trimming prior to freezing, or exudates loss during thawing), leaching (especially during blanching), thermal (during blanching) or chemical degradation (during storage).

According to Thane and Reddy (1997), some fruits and vegetables require peeling before processing, such as peaches, tomatoes and carrots. This process may be achieved with the use of hot water, hot sodium hydroxide solution or mechanical peelers. This process may remove some of the nutrients with the portions that are separated from the peeled products. Also, by exposing the flesh/phloem of the fruit/vegetable to the atmosphere, some carotenoid activity may be lost through oxidation (Thane and Reddy, 1997).

As a pre-freezing process, blanching is used to inactivate enzymes that cause detrimental changes in color, flavor, and nutritive value during frozen storage (Fennema, 1982); however, this treatment can also cause loss of such characteristics (Gutschmidt, 1968). According to Spiess (1984), the loss of water-soluble minerals and vitamins during blanching should also be minimized by keeping blanching time and temperature at an optimum combination. Almost every vegetable needs to be blanched and rapidly cooled prior to freezing, and this process is usually achieved with the use of heat (boiling water, steam or microwave) for a short period of time. Blanching is usually carried out between 75 and 95ºC for 1 to 10 minutes, depending on the size of individual vegetable pieces (Holdsworth, 1983). Steam blanching takes longer than the water method, but helps retain water-soluble nutrients, such as some vitamins and minerals (Barbosa-Cánovas *et al*., 2005; Fennema, 1982). After blanching, the product should be rapidly cooled down to minimize the degradation of heat-labile nutrients (Barbosa-Cánovas *et al*., 2005).

In general, since fruits are more sensitive to heat, only a few types are blanched by heating and the treatment may be achieved by the use of chemical treatments or additives.

Data available in the literature, from 1928 until 1956, concerning the changes in nutrients and other components, such as minerals, sugars, proteins, carotene, thiamine, riboflavin, niacin, ascorbic acid, and chlorophyll, during blanching of vegetables was thoroughly reviewed by Lee (1958). Based on data available at the time, the author mentioned that between water and steam-blanching, the latter one is the more effective of the two for the conservation of soluble nutrients.

With the introduction of microwave cooking, the field of research for the effect of blanching on nutrients and quality of frozen fruits and vegetables was revisited to include this technology, and later on some work with high temperature, short time steam as a blanching process was also evaluated. Some of the studies on vitamin retention after blanching was summarized by Lund (1988) and is expanded here to include available information until 2003.

Table 1: Effect of blanching treatment on the vitamin content of a variety of vegetables and leafy greens as reported by several authors.

Product	Nutrient	Blanching process[a]	Loss (%)	Comments	References
Peas	Ascorbic Acid	W, 3 min/93^{o}C	33	Other temperature-time combinations were done on other vegetables: green beans, lima beans, spinach.	Guerrant *et al*. (1947)
		W, 6 min/93^{o}C	46		
		W, 9 min/93^{o}C	58		
	Riboflavin	W, 3 min/93^{o}C	30		
		W, 6 min/93^{o}C	30		
		W, 9 min/93^{o}C	50		
	Thiamin	W, 3 min/93^{o}C	16		
		W, 6 min/93^{o}C	16		
		W, 9 min/93^{o}C	34		
	Carotene	W, 3 min/93^{o}C	2		
		W, 6 min/93^{o}C	0		
		W, 9 min/93^{o}C	0		
Lima beans	Niacin	W, 2 min/93^{o}C	32		
		W, 4 min/93^{o}C	32		
		W, 6 min/93^{o}C	37		
Sweet peas (Immature)	Ascorbic acid	W, 1 min/85^{o}C	10	Loss values calculate on dry solids base. W, 5 min/96^{o}C: value reported here was the average of 5 runs presented by the authors. W, 5 min/96^{o}C: blanched in a commercial blancher; other conditions done in an experimental blancher.	Heberlein *et al*., (1950)
		W, 4 min/85^{o}C	2		
		W, 8 min/85^{o}C	20		
		W, 1 min/96^{o}C	0		
		W, 3 min/96^{o}C	17		
		W, 5 min/96^{o}C	21		
		W, 6 min/96^{o}C	25		
	Thiamine	W, 1 min/85^{o}C	1		
		W, 4 min/85^{o}C	1		
		W, 8 min/85^{o}C	12		
		W, 1 min/96^{o}C	0		
		W, 3 min/96^{o}C	5		
		W, 5 min/96^{o}C	8		
		W, 6 min/96^{o}C	0		

Sweet peas (Nearly mature)	Ascorbic acid	W, 1 min/85°C	12		
		W, 6 min/85°C	18		
		W, 1 min/96°C	15		
		W, 3 min/96°C	10		
		W, 4 min/96°C	14		
		W, 5 min/96°C	14		
		W, 8 min/96°C	23		
	Thiamine	W, 1 min/85°C	3		
		W, 6 min/85°C	5		
		W, 1 min/96°C	5		
		W, 3 min/96°C	12		
		W, 4 min/96°C	12		
		W, 5 min/96°C	6		
		W, 8 min/96°C	14		
Peas	Vitamin C	S	12.3		Holmquist *et al*. (1954)
		W	25.8		
Brussels sprouts	Vitamin C	W, 9 min/88°C	24		Dietrich and Neumann (1965)
		S, 11 min/88°C	16		
		W, 6 min/93°C	16		
		S, 7 min/93°C	16		
		W, 5 min/100°C	19		
		W, 6 min/100°C	20		
Brussels sprouts	Vitamin C	W, 6 min/100°C	43		Dietrich *et* al., (1970)
		M, 1 min + W, 4 min/100°C	29		
		M, 3 min + W, 2 min/100°C	35		
Lima beans	Vitamin B_6	W, 10 min/100°C	21		Raab *et al*. (1973)
		S, 10 min/100°C	14		
Green beans	Vitamin C	S, 2.5 min	8 mg/100g	No initial content reported.	Bomben *et al*. (1973)
		IQB	11 mg/100g		
Lima beans	Vitamin C	S, 3.0 min	16 mg/100g		
		IQB	24 mg/100g		

Brussels sprouts	Vitamin C	S	47 mg/100g		
		IQB	46 mg/100g		
Peas	Vitamin C	S	21 mg/100g		
		IQB	18 mg/100g		
Asparagus	Ascorbic acid	W, 3.5 or 4.5 min/88°C	35.7 mg/100g	No initial content reported.	Drake *et al*. (1981)
		S, 3.5 or 4.5 min/88°C	35.3 mg/100g		
		M, 3 or 4 min/1500 W	18.9 mg/100g		
Green beans	Ascorbic acid	W, 2 min/88°C	22.5 mg/100g		
		S, 2 min/88°C	23.3 mg/100g		
		M, 4 min/1500 W	13.1 mg/100g		
Green peas	Ascorbic acid	W, 2 min/88°C	15.6 mg/100g		
		S, 2 min/88°C	11.0 mg/100g		
		M, 3 min/1500 W	9.3 mg/100g		
Sweet corn	Ascorbic acid	W, 2 min/88°C	15.8 mg/100g		
		S, 2 min/88°C	13.6 mg/100g		
		M, 3 min/1500 W	12.9 mg/100g		
Mustard greens	Ascorbic acid	W, 2 min/boiling	55	Overall loss for blanching in water 39%, steam 35%, and microwave 38%.	Lane *et al*. (1985)
		S, 2.5 min	58		
		M, 6 min/700 W	55		
Green beans	Ascorbic acid	W, 3 min/boiling	26		
		S, 4 min	26		
		M, 4 min/700 W	23		
Purple hull peas	Ascorbic acid	W, 2 min/boiling	29		
		S, 4 min	11		
		M, 6 min/700 W	28		
Squash	Ascorbic acid	W, 3 min/boiling	46		
		S, 2 min	45		
		M, 6 min/700 W	46		

Green beans	Ascorbic acid	W, 3 min/boiling S, 3 min M, 3 min/700 W	13.2 0 9.6	Other combinations of microwave time and conditions were evaluated.	Brewer *et al.* (1994)
Broccoli	Ascorbic acid	W, 4 min/boiling S, 4 min M, 4 min/700 W	19.5 18.1 15.4		Brewer *et al.* (1995)
Peas	Vitamin C β-carotene Folic acid	W and S, 2 min/95°C W and S, 2 min/95°C W and S, 2 min/95°C	0.0 - 26.7 +33.3 - 33.3 4.3 - 35.0	Ranges included different varieties for peas and different cuts (cubes or slices) for carrots. Some nutrients were increased by blanching and freezing (denoted by "+" with the range value)	Puupponen-Pimiä *et al*. (2003)
Carrots	Vitamin C β-carotene α-carotene	W and S, 3 min/97°C W and S, 3 min/97°C W and S, 3 min/97°C	19.0 - 27.9 +5.6 - +80.3 +11.3 - +60.0		
Cauliflower	Vitamin C Folic acid	W and S, 3 min/96°C W and S, 3 min/96°C	16.1 40.2		
Cabbage	Vitamin C Folic acid	W and S, 3 min/96°C W and S, 3 min/96°C	30.2 61.5		
Potato	Vitamin C	W and S, 3 min/96°C	26.1 - 26.7		
Corn (White Shoepeg)	β-carotene	S, 3 min/87.8-93.3°C	+189.0		Scott and Eldridge (2005)
Corn (White Shoepeg)	β-carotene	S, 3 min/87.8-93.3°C	+6.3		

[a]Process to blanch adequately, generally determined by peroxidase inactivation, or otherwise specified by temperature and time conditions.

W, water; S, steam; IQB, individual quick blanch; M, microwave.

Source: Modified and expanded from Lund (1988).

From the data on Table 1, the studies done by Heberlein *et al*., (1950), showed that for immature sweet peas the best retention was observed in the one minute treatment. However, the longer the time the sweet peas were maintained at that temperature, the retention of ascorbic acid was lower in the final product. For nearly mature sweet peas, the authors pointed out that the retention of ascorbic acid was the same for all the treatments applied from a practical standpoint. The data obtained for the effect of blanching on thiamine showed that for most of the treatments, the loss after blanching was less than 10% of the thiamine in the raw peas. Heberlein *et al*. (1950) also pointed out that because thiamine does not undergo any oxidative changes during blanching, it enables the observation of the leaching effect of blanching on this vitamin. Studies done by Lisiewska and Kmiecik (1991) also showed a loss of 4-10% in the thiamin content and 7-18% in the riboflavin content of broad beans during blanching. In these studies, blanching was done at 96-98ºC for 2.5-4.0 min, depending upon the degree of seed ripeness, to fully inactivate targeted enzymes.

In the results provided by Lane *et al*. (1985), Table 1, except for the steam treatment for purple hull peas, there was no difference among the blanching processes tested. The biggest loss in ascorbic acid occurred in mustard greens, which had the largest inherent surface area per unit weight, and according to the authors, higher losses of ascorbic acid seem to depend on greater surface-to-mass ratio of the vegetable, rather than on blanching parameters, which also indicate that losses occur primarily by leaching rather than degradation (Fennema, 1982). When the overall retention of ascorbic acid by the three blanching processes employed by Lane *et al*. (1985) was compared, no difference was observed with retentions varying from 61-65% for ascorbic acid. The authors attributed the losses to aqueous extraction during the blanching process, regardless of the amount of water present during the treatment.

When the results obtained by Drake *et al*. (1981) and Lane *et al*. (1985), Table 1, are compared, the greater ascorbic acid content after water and steam blanching showed by Drake *et al*. (1981) probably was a result from the shorter blanch time (2 min) and lower water temperature (88^{o}C) as compared to Lane's *et al*. (1985) data (100^{o}C for 3 min); however, because the initial values of ascorbic acid were not reported by Drake *et al.* (1981) the actual retention of the compound cannot be evaluated and direct comparisons between the two sets of data could be misleading.

The set of data reported by Brewer *et al.* (1995) showed no treatment differences existed in average ascorbic acid retention (15.4 – 19.5%) after the applied treatments (Table 1). Murcia *et al*. (2000) also studied the effect of blanching on broccoli (florets and stems). They applied a water blanching at 92-96^{o}C for 60-150 s and reported a loss in ascorbic acid varying from 50-51% in the florets and 54-55% in the stems, depending upon the treatment. When data from Brewer *et al.* (1995) in broccoli is compared to other vegetables such as mustard greens, green beans, purple hull peas, and squash studied by Lane *et al*. (1985) (Table 1); broccoli retained more ascorbic acid, even when the blanching was done for longer periods of time (4 min in boiling water as opposed to 2 or 3 min for the other vegetables). When Brewer *et al.* (1994) studied the effect of steam, water, and microwave blanching on the retention of ascorbic acid in green beans the best results were obtained with steam and it was no different than the initial amount of ascorbic acid quantified in the unblanched samples (Table 1). Wu *et al*. (1992) reported a reduction of about 14% on the dried weight basis (DWB), or 17%, on wet weight basis (WWB), of ascorbic acid in green beans during blanching for 3 min in boiling water; while broccoli was reported to lose about 21% (DWB) or 40% (WWB).

The results reported by Puupponen-Pimiä *et al*. (2003) were for vegetables that were water and steam blanched, followed by quickly freezing at -40^{o}C (Table 1). The authors considered that the freezing step did not affect the nutritional value of the vegetables and all the differences observed between the raw and frozen product were attributed to the blanching step. More discussion on the effects of the freezing step will follow. Therefore, according to the authors, significant losses of vitamins were observed in many of the treatments applied. Vitamin C losses were strongly plant and species dependent, with the highest losses around 30%. As much as a half of folic acid was lost during blanching as a result of its solubility and reactivity. De Souza and Eitenmiller (1986) also studied the effect of blanching on the folate content of spinach and broccoli. After treatment, they reported losses of 83% and 42% for water and steam blanching for spinach and 60% and 9% for water and steam blanching of broccoli. For some vegetables, like carrots and some species of peas, Puupponen-Pimiä *et al*. (2003) reported the increase in concentration of carotenoids right after blanching and freezing. Van den Berg *et al*. (2000) have discussed both the negative (loss due to oxidation) and positive (increased bioavailability) impact of food processing on carotenoids, which may explain the higher carotenoid content in blanched vegetables reported by Puupponen-Pimiä *et al*. (2003).

Scott and Eldridge (2005) reported significant increases in the level of β-carotene in corn, especially on the White Shoepeg variety, after blanching and freezing, as showed in Table 1. The authors compared the β-carotene contents of fresh and frozen corn on a fresh weight basis, and attributed the increases observed to a possible dehydration of the kernels as the result from water weight losses during steam blanching and freezing.

In general, the data presented in Table 1 shows that for water blanching, the loss of water-soluble vitamins increases with contact time, and fat-soluble vitamins are relatively unaffected. Steam blanching, in general, resulted in greater retention of water-soluble vitamins. The IQB process seems to be better than steam for blanching; however retention data were not available for this process, which makes a broader comparison between this method and nutrient retention obtained with other studies using steam blanching difficult.

Drake and Carmichael (1986) compared the effect of water blanching with a high temperature, short time (HTST) steam blanching on the amount of ascorbic acid in different vegetables after treatment. After blanching, the vegetables were frozen and stored for 90 days at -23^{o}C. They found that snap peas treated with water (82^{o}C 3 min) and steam (45 psi 35-55 sec) did not show differences in their ascorbic acid content, except for the treatment at 45 psi for 35 sec, which resulted in less destruction of ascorbic acid. Sweet peas were treated with water at 88^{o}C for 2 min and steam at 15-20 psi for 35-45 sec, and none of the treatments differed in the amount of ascorbic acid after blanching. For lima beans the treatments applied were water at 88^{o}C for 2 min and steam at 20-40 psi for 20-60 sec, and the amount of ascorbic acid decreased as the time of the HTST increased. Lima beans blanched at 20 psi for 60 sec showed 23% less ascorbic acid than the water-blanched product. When carrots were evaluated, the treatments were water at 88^{o}C for 2 min and steam at 45-60 psi for 30-60 sec, and the results showed that ascorbic acids were significantly greater for the HTST-blanched carrots at 45 psi for 40 sec or 60 psi for 30 sec, when compared to the water-blanched carrots.

The effect of blanching conditions on the amount of fiber, minerals and phenolic compounds was also studied by Puupponen-Pimiä *et al*. (2003). The data reported by these authors were for vegetables that were water and steam blanched, followed by quickly freezing at -40^{o}C. For this study, the authors considered that any differences observed in the final product regarding the nutrients and compounds evaluated were a result of the blanching step. From the retention data in Table 2 and according to Puupponen-Pimiä *et al*. (2003), dietary fiber components were rather stable during blanching, and they were either not affected or increased. The authors suggested that the observed increase in fiber was a result of the washing out of soluble components and small molecules leading to the concentration of fiber components in the processed material. Another explanation would be the mechanical disruption of cells during processing that might have resulted in better extraction of fiber components. Pentosans and pectins behaved much in the same way as dietary fiber.

Among minerals, potassium contents were often decreased during blanching, especially in spinach. The authors indicate that the behavior of minerals during blanching is related to their solubility. Potassium, the most abundant mineral in vegetables, is extremely mobile and is easily lost by leaching during blanching because of its high solubility in water. Calcium and magnesium are generally bound to the plant tissue are not readily lost by leaching, and sometimes can even be taken up by vegetables during blanching from the processing water in areas with hard water. In general, the amount of total phenolics decreased during blanching by 20-30%.

Ninfali and Bacchiocca (2003) studied the effect blanching and freezing on the amount of polyphenols and antioxidant capacity of vegetables. The authors reported that the amount of phenols and oxygen radical absorbance capacity (ORAC) values in frozen beet greens were about 30 and 12%, respectively, of those observed in the fresh vegetable. The loss was related to the need of a drastic processing conditions imposed by the texture of the vegetable, and it was suggested that the use of younger beet greens could allow the blanching time to be reduced, thus saving the antioxidant capacity. Frozen broccoli, however, did not show differences in the ORAC value when compared with the fresh vegetable, indicating that the blanching method was mild enough to preserve the antioxidant capacity of the product.

Table 2: Effect of blanching and freezing on the retention (%) of fiber, phenolics compounds and minerals in different vegetables.

Sample	Soluble fiber	Insoluble fiber	Total dietary fiber	Pentosans	Pectins	Total Phenolics	Ca	Mg	K	P	Na	Cu	Mn	Fe	Zn
Peas[a]	149	106	107	108	84	79	114	97	80	94	130	83	102	102	93
Carrots[b]	115	125	120	134	130	92	119	110	98	106	88	92	146	101	96
Cauliflower	113	109	110	98	100	87	100	89	84	87	87	115	75	94	70
Cabbage	154	118	125	125	143	126	-	-	-	-	-	-	-	-	-
Spinach	88	112	108	133	123	-	109	73	64	87	60	100	76	105	112
Potato	83	111	97	116	190	71	75	91	84	90	ND	92	95	97	176

[a]Data included different species of peas; [b]Data included different cuts (cubes and slices) -, not determined; ND, below detection limit.

Source: Puupponen-Pimiä *et al*. (2003).

Effects of the Freezing Step on the Nutritional Value of Fruits and Vegetables and their Phytochemicals

According to Selman (1992), the process of freezing itself does not alter the nutritive value of the product being frozen. It is during the preparative steps prior to freezing, particularly blanching as discussed earlier in this paper, and during subsequent frozen storage that losses of more labile vitamins occur. Fennema (1982) lists a series of more than 10 papers that indicate that the freezing step generally has no significant effect on the vitamin contents of vegetables and fruits. Research done by Drake *et al.* (1981) on freezing using a Lewis individual quick freezing (IQF) tunnel and blast freezer also did not show differences in the ascorbic acid content of vegetables (asparagus, green beans, green peas, and sweet corn). Lisiewska and Kmiecik (1991) also reported no effect of freezing on the contents of thiamin and riboflavin of broad bean seeds. And this concept could also be extended to other components of fruits and vegetables and follows in the discussion presented here.

According to Thane and Reddy (1997), the amount of carotenoids is also not affected by freezing, particularly rapid freezing. Deteriorative process occurs, although at a very low rate, during storage. This is desirable, of course, because of the high value placed on carotenoids as nutrients.

The effect of freezing on the total flavonoids and anthocyanin contents of red raspberries was studied by Mullen *et al*. (2002). In their study, raspberries were frozen within 3 hours of picking at -30^{o}C, without any additional treatment. The total flavonol content of fresh raspberries was not significantly different than in the frozen product (22.3 – 27.0 nmoles/g fresh weight). Six major anthocyanins were also analyzed separately and no significant differences either in the levels of the individual anthocyanins or in the overall anthocyanin content of the fresh and frozen raspberries were reported. De Ancos *et al*. (2000) showed that the freezing process had little effect on the ellagic acid, total phenol, vitamin C content, and antioxidant capacity on Spanish raspberries.

Even though most of the scientific reports indicate that the freezing step does not greatly affect the nutritional value and composition of fruits and vegetables, some do and should not be neglected. Cano *et al*. (1993) studied the effect of freezing on four Spanish kiwi fruit cultivars. In their study, the fruits were washed, peeled and sliced (6-8 mm) and frozen in an air-blast freezer at -40^{o}C, without any previous treatment. In general, the total acidity of the kiwi fruit slices decreased slightly during the freezing process, with one of the varieties tested (Monty) losing 20% when compared to the raw fruit total acidity. The amount of ascorbic acid was decreased by 10-25% depending on the cultivar considered, with only one variety (Bruno) not showing any reductions due to freezing. However, the soluble solids of frozen kiwi fruit slices did not change significantly during freezing. The amount of total and individual sugars also did not change much, except for one variety (Hayward) where it increased, and the authors related that to the different cell wall structure and higher moisture content of this variety.

Effects of Frozen Storage (Time and Temperature) on the Nutritional Value of Fruits and Vegetables and their Phytochemicals

An extensive body of literature is available on the effects of time and temperature storage on the nutritional value of fruits and vegetables. In general, foods are known to remain well preserved at -18^{o}C, but storage at higher temperatures and/or for long periods of time can cause vitamin losses and marked effects on color and flavor, which results in lower quality at the retail level. Vitamin loss during frozen storage also depends on the product, the type of packaging and the use of additives or sugar (Derse and Teply, 1958; Fennema, 1982).

According to a review done by Fennema (1982), losses of vitamins C, B_1 and B_2 during frozen storage are usually considerably less in blanched vegetables than in unblanched, with some data indicating that blanched losses are only 25 to 50% as much vitamin C when compared to unblanched products. However, the author highlights that it is not necessarily true that losses incurred by blanching are compensated for by the reduction in losses that would otherwise occur during freezing storage. Such compensation is, according to Fennema (1982), especially unlikely when products are stored for only a short time at -18^{o}C or lower. Data on the effect of subfreezing temperatures on the rate of vitamin C degradation in vegetables indicates that a 10^{o}C rise in temperature, within the range of -18 to -7^{o}C, accelerates vitamin C degradation by a factor of 6 to 20 times, while in fruits (peaches, boysenberries, and strawberries), it is increased by a factor of 30 to 70 times (Fennema, 1982).

Lee and Coates (1999) related the loss of vitamin C in fresh squeezed orange juice that had been stored frozen to oxidative enzyme reactions. During processing and storage, ascorbic acid can be enzymatically oxidized to dehydroascorbic acid, which has equal antiscorbutic activity; however it is not stable and is hydrolysed to 2,3-diketogulonic acid and further breakdown products (Selman, 1992). Eheart (1970) studied the effect of storage at -15^{o}C for up to 5 months on the composition of frozen broccoli. They found that after 5 months of storage, there were significant losses of reduced ascorbic acid (31%) and total ascorbic acid; while the amount of dehydroascorbic acid increased. Total acids also increased, while pH decreased during storage. Similar results were reported by Martin *et al.* (1960) when evaluating the factors affecting the ascorbic acid in broccoli during frozen storage. In their studies, broccoli was maintained at -18^{o}C for 25 weeks and during this period, an increase in dehydroascorbic acid was observed between weeks 15 and 17 of storage. They also reported an increase in the diketogulonic content of the product between weeks 2 and 13, along with a gradual decrease in reduced ascorbic acid with the storage time. As both dehydroascorbic acid and reduced ascorbic acid are biologically active, the decrease in reduced ascorbic acid is partially compensated for by the increase in dehydroascorbic acid, denoting the importance of measuring both forms during processing and storage studies (Martin *et al*., 1960).

During storage at -20^{o}C, Wu *et al.* (1992) reported that even after 16 weeks the ascorbic acid content of green beans and broccoli had not changed when compared to the levels immediately after freezing. However, after 30 months at -22^{o}C, the vitamin C content of frozen cauliflower was reduced by 62.2%. The 50% loss in vitamin C in the frozen cauliflower took place at approximately 26 months of storage, while the 25% loss occurred at about 13 months (Aparicio-Cuesta and Garcia-Moreno, 1988). Favell (1998) also studied the losses of ascorbic acid during frozen storage of vegetables and found that after 12 months of storage at -20^{o}C, the decrease in the ascorbic acid content of peas and broccoli was less than 10%, in green beans was less than 20%, and in spinach it was about 30%.

The effect of frozen storage has also been studied in fruits (strawberries, raspberries and kiwi), and fruit processed products (orange juice). When Sahari *et al.* (2004) evaluated the effect of low temperature on ascorbic acid, they reported that strawberries stored at -12, -18, and -24^{o}C showed significant decreases of 64.5%, 10.7%, and 8.9%, respectively, in the ascorbic acid content after 90 days of storage, with major losses occurring during the first 15 days of storage at -12^{o}C (31.4%). Frozen storage of raspberries for one year at -20^{o}C showed a continuous decrease in vitamin C with time, in all four cultivars studied, with loss of 33-55% at the end of the long-term frozen storage (De Ancos *et al*., 2000). The effect of frozen storage (1 year at -18^{o}C) on the ascorbic acid content of four Spanish kiwi cultivars was studied, and all cultivars showed some loss of this nutrient with storage; with the cultivar Bruno, showing the most significant decrease (37%) (Cano *et al*., 1993). Lee and Coates (1999) showed that after 24 months of storage at -23^{o}C, frozen, fresh-squeezed, and unpasteurized orange juice had its vitamin C content reduced from an initial value of 40.6 mg/100 mL to 32.8 mg/ 100 mL for a loss of 19.2% over the storage period. According to the authors, the estimated shelf-life of the product to meet the claimed levels of vitamin C on the label would be about 22 months.

The effects of frozen storage on the levels of vitamins and minerals in green beans, peas, strawberries and orange juice concentrate were studied by Derse and Teply (1958). They reported that after 12 months of storage at -18^{o}C, only green beans showed appreciable losses in ascorbic acid (50%), with results possibly indicating a variable decrease in folic acid, pantothenic acid, riboflavin, vitamin B_6 and in some of the minerals evaluated. According to Selman (1992), during storage at -18^{o}C over one year, the loss in the thiamin content of vegetables like asparagus, broccoli, green beans and peas was about 20%. Spinach and cauliflower seem to be more sensitive with losses up to 50%.

De Souza and Eitenmiller (1986) studied the effect of frozen storage on the amount of total folate activity (TFA) in spinach and broccoli, and reported a 72% retention of TFA in spinach after 3 months of storage and 83% in broccoli after 8 months of storage at -32.2^{o}C, when compared to the TFA in the products after water-blanching and just before freezing. Puupponen-Pimiä *et al*. (2003) mentioned the importance of enzymatic inactivation to prevent degradation of folate, even when vegetables are stored frozen. In their studies, freezer storage (-20^{o}C for 18 months) did not affect the amount of folic acid in peas, cauliflower, broccoli, cabbage and spinach.

When studying the effect of frozen storage on the levels of carotenoids in sliced carrots, Crivelli and Polesello (1973) reported a 60% loss after 12 months at -20^{o}C. Puupponen-Pimiä *et al*. (2003) showed that during frozen storage of peas (-20^{o}C for 18 months), 17% of the β-carotene content was lost; while in carrots the loss varied from 27 to 75% depending upon how the products had been processed (cubes or slices) and their harvest year (1997 or 1998). The effect of freezing and storage on the carotenoid composition of papaya slices was studied by Cano *et al*. (1996). In their studies slices of papaya fruit were vacuum-packed and frozen in an air-blast freezer at -40^{o}C, without any previous treatment. The frozen product was stored at -18^{o}C for 12 months and the results obtained showed that the carotenoid content of frozen papaya slices was significantly decreased. The reduction in carotenes was higher in female frozen slices (65%) than in hermaphrodite ones (14%), and the differences were attributed to different enzymatic behaviors shown by female and hermaphrodite frozen slices during storage.

When the effects of frozen storage (-20^{o}C for 4 months) on the amount of total anthocyanins in cherries was studied, Polesello and Bonzini (1977) observed a decrease varying from 34 to 73%, depending upon the cultivar and it was not related to their initial concentration. Chaovanalikit and Wrolstad (2004) also studied the effect of frozen storage in the anthocyanin content of cherries, and they reported that storage at -23^{o}C for 6 months caused up to 87% degradation, with an increased amount of polymeric color (from 12.5 in fresh cherries to 61% after frozen storage); while storage at -70^{o}C resulted in much greater anthocyanin stability with 88% remaining after 6 months. However, De Ancos *et al.* (2000) did not observe any change in the monomeric anthocyanin content of raspberries stored frozen for up to 1 year at -20^{o}C. Similar results were also reported by Hager *et al*. (2008) for monomeric anthocyanin and polymeric color in individually quick frozen blackberries stored for 6 months at -20^{o}C.

In cherries, the amount of total phenolics was evaluated throughout frozen storage for 6 months at -23^{o}C and -70^{o}C by Chaovanalikit and Wrolstad (2004), and they reported 25% degradation after 3 months and 50% after 6 months at the higher temperature, with minimal changes at the lower temperature. The levels of ellagic acid, a polyphenol antioxidant found in numerous fruits and vegetables during frozen storage of raspberries were studied by De Ancos *et al.* (2000). When the fruits were maintained at -20^{o}C for one year, the effect of frozen storage was similar for the four cultivars assayed. No major changes in the total phenolic content was observed along with a continuous decrease in the total ellagic acid content, with losses varying from 14 to 21%. The authors attributed the decrease in this polyphenolic compound to a possible release of the enzyme polyphenol oxidase from the cellular wall of the fruits during storage.

MACRO DATA

The goal of the macro analysis presented here was to use meta-analysis techniques to go beyond descriptive statistics and reveal inherent traits and tendencies pertaining to the nutritional value of frozen and non frozen fruits and vegetables. More specifically, statistical analyses were done in an attempt to evaluate variables (factors) present in the pre-freezing treatments, freezing, and frozen storage that would explain possible differences between the frozen and non-frozen products. Finally, through analyses of variance, statistical comparisons were made to identify differences in the nutritional value of specific components of a variety of fruits and vegetables, when sufficient data was available.

The data reported in the literature for the nutritional content of fruits and vegetables includes many inherent variables, such as origin of the product, the harvesting year, storage time and conditions, pretreatment, processing time and conditions, and method of analysis. The macro data set was prepared by recording information about these factors from both the horizontal and vertical searches in a spreadsheet format in a way that numerical analysis was feasible, yet retaining enough information in each row of data that would enable the reader to understand the content of the original paper (except for the original qualitative interpretation). The retained information from the articles was recorded in 81 variables such as:

- Fruit or vegetable name (common or botanical)
- Variety
- Vegetable or fruit
- Vegetable/fruit form (e.g. frozen, canned, fresh, dried)
- Processing technology
- Storage time and temperature
- Wet, dry or fresh basis
- Pretreatment (blanching, etc.)
- Type of container if processed (enamel-coated, tin-plated, etc.)
- Nutrient quantities
- Geographic location
- Year published

- Year of comparison
- Sample size

Data Aggregation

Because of the number of variables previously mentioned, and the limited amount of information in the literature concerning each of those variables, data aggregation was necessary in order to facilitate the analysis and statistical inference. Several layers of aggregation were performed:

1. Nutrient types – a total of 206 different nutrient/mineral/antioxidant types measured in the articles were combined into 25 general groups (e.g. Arabinose, Mannose, Rhamnose, Uronic Acids, Water-Soluble Pectin, and Xylose were combined in one group called "Soluble Fiber").

2. Measurement units – when possible, units were converted into the ones most commonly used in a particular group ("nutrient types" as defined in step 1 above). For example, for vitamin C, the measurement units used by different authors were g/kg, mEq/100g, mg/100g, mg/g, nanomoles of GAE, and µmol/g. From this list, mg/100g was the most commonly used unit of measure (473 times), therefore measurements done in g/kg and mg/g were converted into mg/100g by using attenuation factors of 100 and 0.01, respectively. The rest of the measurement units were left unchanged. Afterwards, all measurement units were classified on a dry or wet weight (fresh weight) basis.

3. A simple linear transformation was performed to convert nutrient quantities reported in wet or fresh weight bases to those in dry weight basis, where moisture contents were reported as well.

4. Vegetable/fruit name – over 300 different vegetable and fruit varieties were aggregated into 105 distinct vegetable or fruit groups. For example, asparagus of different varieties (no variety identified, Libras 10 variety, and Viking 2G) were all combined in one "Asparagus" group. (Please note that White Asparagus comprises a distinct group.)

In the process of aggregating the data, some specific information concerning the nutrient type, vegetable or fruit variety, and/or measurement unit was not described in the tables presented in this review. To obtain such specific information, the readers should refer to the original papers. Corresponding references are made in the footnotes of each table.

The macro data presented in Tables 3 – 7 are arranged in such a manner as to preserve the uniform presentation of the data as much as possible. The data are presented by fruit or vegetable form, such as fresh, frozen, canned or juiced. Fresh and frozen products are further divided into "cooked" and "uncooked" categories. The data are presented as statistical means, with an interval of one standard deviation around the mean, followed by the sample range and size. It should be noted that the data points that contribute to the means, standard deviations and the range reported in the macro dataset, may represent separate trials or averages of several trials as different authors present their findings in different formats. In addition, the statistics are calculated using different numbers for sample size. Therefore, any point estimates, such as the means of even the same fruit or vegetable across their forms of fresh, frozen, canned or juiced should be interpreted with care. A more appropriate comparison could be made by using intervals and other sample location statistics such as the minima, maxima and medians. It is important to consider that the variation in reported values is due to variations within a single research paper and among different research papers. For example, variation in quantities of a particular nutrient in a particular product are expected to be smaller when reported by just one or a few articles as compared to quantities reported by numerous articles, *ceteris paribus*. Because of this, in the presence of high variation in nutrient quantities, other location and spread statistics are presented as well.

For some products with relatively large sample size, statistical tests are provided for comparison of corresponding mean values of "cooked" or "uncooked" products: t-statistics and their *p*-values. The 1-tailed heteroskedastic t-test statistic with unequal sample sizes is calculated as:

$$t = \frac{\overline{X_F} - \overline{X_{NF}}}{s_{\overline{X_F}-\overline{X_{NF}}}}$$

where $\overline{X_F}$ and $\overline{X_{NF}}$ are the means of the respective frozen and non-frozen product in cooked or uncooked form,

and

$$s_{\overline{X_F}-\overline{X_{NF}}} = \sqrt{\frac{s_F^2}{n_F} + \frac{s_{NF}^2}{n_{NF}}}$$

with the degrees of freedom of

$$d.f. = \frac{\left(\frac{s_F^2}{n_F} + \frac{s_{NF}^2}{n_{NF}}\right)^2}{\frac{\left(\frac{s_F^2}{n_F}\right)^2}{n_F - 1} + \frac{\left(\frac{s_{NF}^2}{n_{NF}}\right)^2}{n_{NF} - 1}}$$

where, s_F , s_{NF} , n_F and n_{NF} are the standard deviations and sample sizes of frozen and non-frozen products, respectively.

By definition all variables for all the products have distributions with lower bound of 0, since the variables represent actual quantities of nutrients and therefore cannot take negative values, and an upper bound of a real number. Assumptions concerning the shape, symmetry or any other moment characteristics that the distributions might have are not made. For verification purposes, the values from the data set were compared to the corresponding values provided by USDA National Nutrient Database for Standard Reference, Nutrient Data Laboratory, Agricultural Research Service, USDA.

Macro Data: Trends and Interpretation

Ascorbic Acid

Ascorbic acid is an essential part of the everyday diet and is present in leafy green vegetables, broccoli, tomatoes, etc. Although the macro data on ascorbic acid are available on a dry or wet (fresh) weight basis, comparisons between the two groups of data is not possible, therefore this report presents data recorded only on a dry weight (DW) basis (data either reported in dry weight basis or converted to dry weight basis by the authors of this review) (Table 3).

Average ascorbic acid point estimates are larger for uncooked products compared to their cooked counterparts, as expected. Frozen uncooked broccoli and Brussels sprouts have the highest quantities of ascorbic acid at 968.97 and 618.43 mg/100g DW, respectively. For verification purposes, these numbers were compared to the corresponding values provided by USDA National Nutrient database. The corresponding values (converted from wet weight to dry weight basis by the authors of this review) for ascorbic acid for broccoli and Brussels sprouts are 722.75 and 573.09, drawn from samples of 39 and 28 trials (labeled “Number of Data Points” in the USDA database), respectively. These values, although on the lower side, are well within the data range in this database. From Table 3, broccoli and cauliflower have the highest ascorbic acid quantities among fresh uncooked vegetables with 890.16 and 1038.01 mg/100g DW, respectively. The corresponding USDA database values for these vegetables are 833.65 and 607.82, drawn from 19 and 28 trials, respectively. The relatively high value for fresh uncooked cauliflower is possibly the result of a small number of trials ($n = 4$) and articles (3 articles) that reported values for this analysis. Frozen cooked broccoli and asparagus, and fresh cooked broccoli and cauliflower have the highest values in their corresponding categories (Table 3).

Statistical measures for frozen and fresh cooked asparagus reveal no statistical difference (t-value = -0.1370, p-value = 0.8950) between their mean estimates of 285.52 and 291.25 mg/100g DW, respectively. Similar results were obtained when comparing uncooked frozen and fresh green beans (t-value = 0.0547, p-value = 0.4786). Alternatively, the null hypothesis that the mean of cooked frozen and fresh green bean values are statistically identical was rejected (t-value = 2.2943, p-value = 0.0181), revealing that frozen cooked green beans have higher average ascorbic acid contents than their fresh counterparts.

The statistical analysis failed to reject the null hypotheses that frozen and fresh cooked and uncooked broccoli, frozen and fresh cooked green peas mean values are equal. The mean ascorbic acid levels in cooked frozen carrots were significantly higher than the mean values for fresh carrots (t-value = 29.49, p-value = 0.0000). On the other hand, mean ascorbic acid levels in cooked frozen spinach are significantly lower than the mean values for frozen spinach (t-value = -5.0466, p-value = 0.0008).

B Vitamins

The B vitamin family is another essential part of the diet. This family includes thiamin, riboflavin, niacin, pantothenic acid, biotin and folacin, also referred to as vitamins B_1, B_2, B_3, B_5, B_7, and B_9, respectively. The macro dataset presented in Table 4 contains means, standard deviations and sample sizes for thiamin, riboflavin and niacin only, expressed in mg/100g DW. Since the sample sizes were not sufficient for a formal statistical analysis, the data on Table 4 can only indicate general levels of vitamin B in vegetables.

The B vitamin family data came from two articles only (see the footnote to Table 4). Due to small number of observations per product the sample data range is not reported in Table 4. The comparison of the means in Table 4 to the USDA National Nutrient database reveal remarkably close values, which is surprising given the extremely small sample sizes in both the USDA and this data sets.

Based on this limited data, the highest values for thiamin were observed in asparagus, green peas, spinach, cauliflower, and carrots, with uncooked having higher values than cooked vegetables. This is not unexpected given the instability of thiamin in thermal processing. For riboflavin (vitamin B_2), the highest values were observed in spinach, asparagus, broccoli and cauliflower. Once again, higher values in uncooked when compared to cooked vegetables were observed. Asparagus, squash, spinach, broccoli, green peas and cauliflower showed the highest contents for niacin with the tendency for higher quantities in uncooked vegetables. Potatoes, corn and beets do not seem to have high values of vitamin B based on the data shown.

Table 3: Average Ascorbic Acid[1] levels (mg/100g Dry Weight) in a variety of vegetables.

	Frozen		Fresh		Canned
Vegetable	Uncooked	Cooked	Uncooked	Cooked	
Asparagus					
Mean±StDev		285.52[a]±64.57	474.00	291.25[a]±60.44	
Range	-	180.00 – 340.00		201.00 – 329.00	-
Count		5	1	4	
White Asparagus					
Mean±StDev			48.00±31.10		21.87±8.86
Range	-	-	21.00 – 82.00	-	12.80 – 30.50
Count			3		3
Green Beans					
Mean±StDev	159.24[a]±48.34	138.80[a]±52.26	157.31[a]±115.64	81.35[b]±61.26	
Range	22.00 – 213.00	66.67 – 221.90	19.80 –395.42	14.60 – 176.47	-
Count	18	13	12	9	
Lima Beans					
Mean±StDev		38.62±3.58			
Range	-	33.15 – 42.78	-	-	-
Count		6			
Beets					
Mean±StDev			45.80	38.50±3.90	
Range	-	-		33.90 – 43.00	-
Count			1	4	
Broccoli					
Mean±StDev	968.97[a]±221.96	625.01[a]±48.61	890.16[a]±194.92	688.63[a]±237.71	
Range	706.96 – 1408.00	574.07 – 685.19	394.91 – 1339.45	425.00 – 1000.00	-
Count	19	4	34	6	
Brussels Sprouts					
Mean±StDev	618.43±135.94				
Range	522.31 – 714.55	-	-	-	-
Count	2				
Cabbage					
Mean±StDev			624.94±56.22	472.71±84.32	
Range	-	-	549.63 – 759.00	336.00 – 588.00	-
Count			11	6	
Carrots					
Mean±StDev		85.89[a]±3.78	66.58±16.75	25[b].15±2.35	
Range	-	81.76 – 89.61	34.70 – 100.00	21.90 – 27.40	-
Count		5	15	4	
Cauliflower					
Mean±StDev			1038.01±174.31	597.46±128.31	
Range	-	-	872.00 – 1232.36	412.00 – 735.85	-
Count			4	6	

[1] Kylen *et al*., 1961; Krehl and Winters, 1950; Drake *et al*., 1981; Martin-Belloso and Llanos-Barriobero, 2001; Eheart and Odland, 1972; Albrecht *et al*.,1990; Drake and Carmichael, 1986; Lane *et al.*, 1984; Wu *et al*, 1992; Van Duyne *et al.*, 1944; Barth *et al.*, 1990.

Different superscript letters denote a significant statistical difference ($p<0.10$) between the means for fresh and frozen, uncooked, for each vegetable.

Table 3: Continued

	Frozen		Fresh		Canned
Vegetable	Uncooked	Cooked	Uncooked	Cooked	
Corn					
Mean±StDev		51.27±4.19	53.70±13.99	27.73±2.60	
Range	-	46.91 – 57.45	41.10 – 73.17	24.70 – 30.80	-
Count		5	5	4	
Eggplant					
Mean±StDev			79.17±11.79		
Range	-	-	70.83 – 87.50	-	-
Count			2		
Mustard Greens					
Mean±StDev			97.70	42.97±1.88	
Range	-	-		40.80 – 44.20	-
Count			1	3	
Green Peas					
Mean±StDev		66.77[a]±8.78	110.27±57.95	77.93[a]±48.64	
Range	-	50.27 – 84.32	24.70 – 219.78	17.60 – 139.42	-
Count		11	14	10	
Potatoes					
Mean±StDev	-				
Range		-	129.23±43.12	57.10±16.81	-
Count			5	4	
Rhubarb					
Mean±StDev			146.98±7.73		
Range	-	-	140.48 – 156.52	-	-
Count			4		
Savoy Cabbage					
Mean±StDev			862.64±152.17		
Range	-	-	719.04 – 934.24	-	-
Count			2		
Soybean					
Mean±StDev			82.94±16.68	58.57±0.36	
Range	-	-	63.58 – 118.52	58.31 – 58.82	-
Count			15	2	
Spinach					
Mean±StDev	325.52±58.79	183.77[a]±28.65	774.42±141.94	355.45[b]±75.58	
Range	283.95 – 367.09	155.34 – 223.21	545.00 – 945.95	268.00 – 468.47	-
Count	2	4	6	6	
Squash					
Mean±StDev	-		285.00	183.25±28.74	
Range		-		144.00 – 213.00	-
Count			1	4	
Tomatoes					
Mean±StDev			11.77±3.98		7.55±1.48
Range	-	-	8.10 – 16.00	-	6.04 – 9.00
Count			3		3

Table 4: Average data for B vitamins[2] (mg/100g Dry Weight) in a variety of vegetables

Vegetable	Form of Vegetable	Thiamin (B_1)	Riboflavin B_2	Niacin B_3
Asparagus	Fresh Uncooked	1.58 1	2.24 1	15.50 1
	Fresh Cooked	1.20±0.24 4	1.53±0.18 4	12.32±2.13 4
Green Beans	Fresh Uncooked	0.61 1	1.18 1	6.47 1
	Fresh Cooked	0.56±0.07 4	0.95±0.13 4	5.28±0.78 4
Beets	Fresh Uncooked	0.28 1	0.36 1	3.00 1
	Fresh Cooked	0.21±0.04 4	0.30±0.03 4	2.56±0.33 4
Broccoli	Fresh Uncooked	0.70 1	1.59 1	6.99 1
	Fresh Cooked	0.56±0.07 4	1.26±0.15 4	5.23±1.49 4
Cabbage	Fresh Uncooked	0.90 (1)	0.83 (1)	3.77 (1)
	Fresh Cooked	0.65±0.10 4	0.60±0.14 4	2.64±0.60 4
Carrots	Fresh Uncooked	1.10 1	0.50 1	5.42 1
	Fresh Cooked	0.92±0.10 4	0.43±0.05 4	4.76±0.57 4
Cauliflower	Fresh Uncooked	1.18±0 1	1.46 1	6.79 1
	Fresh Cooked	0.84±0.17 4	1.09±0.15 4	5.15±0.79 4
Corn	Fresh Uncooked	0.42 1	0.42 1	6.54 1
	Fresh Cooked	0.34±0.04 4	0.32±0.08 4	4.95±1.13 4
Green Peas	Fresh Uncooked	1.25 1	0.77 1	8.24 1
	Fresh Cooked	0.98±0.18 4	0.65±0.07 4	6.90±1.01 4
Potatoes	Fresh Uncooked	0.42 1	0.17 1	4.28 1
	Fresh Cooked	0.34±0.03 4	0.14±0.02 4	3.30±0.47 4
Spinach	Fresh Uncooked	1.22 1	2.86 1	7.53 1
	Fresh Cooked	0.87±0.19 4	2.06±0.34 4	5.18±1.54 4
Squash	Fresh Uncooked	0.85 1	0.11 1	13.30 1
	Fresh Cooked	0.66±0.10 4	0.09±0.01 4	10.37±1.42 4

[2] Martin-Belloso and Llanos-Barriobero, 2001; Krehl and Winters, 1950.

Fiber

Total, soluble, and insoluble fiber have been researched mostly in fresh fruits and vegetables as evidenced by this review. While reviewing the literature, nine studies on total fiber and ten studies on soluble and insoluble fiber components in fruits and vegetables were found. Among processed products, more studies analyzed total fiber in canned vegetables and fruits than in frozen ones; therefore there were limited data available for a formal statistical analysis. For this reason, the data on Table 5 can only indicate general levels of total fiber in cooked and uncooked fruits and vegetables.

Frozen raw blackberry, green beans, broccoli, cabbage, kale, and spinach showed higher values of total fiber – 38.27, 32.46, 31.70, 32.80, 33.48 and 33.73 g/100g DW, respectively. For fresh, uncooked fruits and vegetables, raspberry, cauliflower and spinach showed the highest values of total fiber ranging from 33.55 to 38.05 g/100g DW. In the canned category, asparagus and carrots had the highest values of fiber, 32.23 and 31.25, respectively. The total dietary fiber mean values, standard deviations, sample data ranges and sample sizes are reported in Table 5.

Due to very limited sample size, hypothesis testing with t statistic was not performed, as the power of the test declines with the sample size. Instead, fiber content means and intervals were relied upon for comparisons when frozen and non-frozen values were available. The mean level of dietary fiber for frozen uncooked broccoli, cabbage, carrots, green peas and spinach compared favorably to their fresh counterparts (Table 5). In contrast, fresh uncooked cauliflower and potatoes have higher mean levels of fiber than their frozen counterparts. Once again these values are similar to corresponding values in frozen and fresh uncooked products obtained from the USDA National Nutrient database (converted from wet weight basis to dry weight basis when necessary).

Table 5: Average data for Total Fiber[3] (g/100g Dry Weight) in a variety of fruits and vegetables

Fruit /	Frozen		Fresh		Canned
Vegetable	Uncooked	Cooked	Uncooked	Cooked	
Apple					
Mean±StDev			13.67±1.37		
Range	-	-	11.76 – 15.03	-	-
Count			5		
Applesauce					
Mean±StDev					11.97±1.44
Range	-	-	-	-	10.43 – 13.29
Count					3
Apricot					
Mean±StDev			13.72±0.63		
Range	-	-	13.27 – 14.16	-	-
Count			2		
Asparagus					
Mean±StDev					32.23
Range	-	-	-	-	
Count					1
White Asparagus					
Mean±StDev					10.44
Range	-	-	-	-	
Count					1
Banana					
Mean±StDev			7.61±0.24		
Range	-	-	7.35 – 7.83	-	-
Count			3		
Green Beans					
Mean±StDev	32.46±1.68				
Range	31.27 – 33.65	-	-	-	-
Count	2				
Yellow Beans					
Mean±StDev			28.33±0.79	28.57±2.89	29.33±1.89
Range	-	-	27.78 – 28.89	26.53 – 30.61	28.00 – 30.67
Count			2	2	2
Beets					
Mean±StDev				332.22±80.14	24.57±0.26
Range	-	-	-	275.56 – 388.89	24.27 – 24.72
Count				2	3
Blackberry					
Mean±StDev	38.27±1.19				
Range	37.43 – 39.11	-	-	-	-
Count	2				
Blueberry					
Mean±StDev			17.68±0.05		
Range	-	-	17.64 – 17.71	-	-
Count			2		

[3] Marlett and Vollendorf, 1994; Anderson and Bridges, 1988; Mongeau and Brassard, 1989; Martin-Belloso and Llanos-Barriobero, 2001; Marlett and Vollendorf, 1993; Kmiecik *et al.*, 2001; Khanum *et al.*, 2000; Puupponen-Pimiä *et al.* 2003.

Table 5: Continued

Fruit / Vegetable	Frozen Uncooked	Frozen Cooked	Fresh Uncooked	Fresh Cooked	Canned
Broccoli					
Mean±StDev	31.70±1.84		29.15±3.10		
Range	30.40 – 33.00	-	26.95 – 31.34	-	-
Count	2		2		
Brussels Sprouts					
Mean±StDev	26.94				
Range		-	-	-	-
Count	1				
Butternut Squash					
Mean±StDev				18.60±5.26	
Range	-	-	-	14.88 – 22.31	-
Count				2	
Cabbage					
Mean±StDev	32.80		25.91±5.86	25.00±0.00	
Range		-	20.66 – 39.60	25.00 – 25.00	-
Count	1		8	2	
Cantaloupe					
Mean±StDev			7.33±0.06		
Range	-	-	7.29 – 7.37	-	-
Count			2		
Carrots					
Mean±StDev	28.24±2.96		25.87±5.16	31.36±3.21	31.25±0.98
Range	24.20 – 31.70	-	23.36 – 39.50	29.09 – 33.64	30.56 - 31.94
Count	5		9	2	2
Cauliflower					
Mean±StDev	30.00±4.67		38.05±11.10		
Range	26.70 – 33.30	-	30.20 – 45.90	-	-
Count	2		2		
Celery					
Mean±StDev			27.46±2.61		
Range	-	-	25.61 – 29.30	-	-
Count			2		
Cherry					
Mean±StDev			7.25±1.16		
Range	-	-	6.44 – 8.01	-	-
Count			2		
Corn					
Mean±StDev				5.33±0.78	7.64±1.65
Range	-	-	-	4.78 – 5.88	6.18 – 9.43
Count				2	3
Cranberry					
Mean±StDev					3.17±0.54
Range	-	-	-	-	2.79 – 3.55
Count					2
Cucumbers					
Mean±StDev			18.19±0.20		
Range	-	-	18.06 – 18.33	-	-
Count			2		

Table 5: Continued

Fruit / Vegetable	Frozen Uncooked	Frozen Cooked	Fresh Uncooked	Fresh Cooked	Canned
Grapefruit					
Mean±StDev			13.22±1.50		
Range	-	-	11.80 – 14.79	-	-
Count			3		
Grape					
Mean±StDev			4.91±0.83		
Range	-	-	4.19 – 6.10	-	-
Count			4		
Grass peas					
Mean±StDev			25.14±30.70	11.52±2.34	13.05±3.34
Range	-	-	9.30 – 80.00	8.50 – 14.10	8.50 – 16.50
Count			5	5	10
Green Peas					
Mean±StDev	24.65±1.39		23.08±2.48		
Range	22.90 – 26.30	-	20.00 – 25.90	-	-
Count	4		4		
Green Peppers					
Mean±StDev			27.90±0.72		
Range	-	-	27.39 – 28.41	-	-
Count			2		
Kale					
Mean±StDev	33.48				
Range		-	-	-	-
Count	1				
Lettuce					
Mean±StDev			25.19±4.04		
Range	-	-	21.02 – 29.09	-	-
Count			3		
Onion					
Mean±StDev		4.13±0.43	14.23±0.58	17.14±0.88	
Range	-	3.83 – 4.44	13.51 – 14.80	15.96 – 18.09	-
Count		2	5	4	
Orange					
Mean±StDev			11.91±1.11		1.55±0.44
Range	-	-	10.20 – 13.68	-	1.24 – 1.86
Count			7		2
Peach					
Mean±StDev			12.98±1.39		12.38±5.56
Range	-	-	10.48 – 14.29	-	8.86 – 18.80
Count			6		3
Pear					
Mean±StDev			11.82±0.43		32.18
Range	-	-	11.51 – 12.12	-	
Count			2		1
Pineapple					
Mean±StDev					7.13±2.09
Range	-	-	-	-	5.80 – 9.54
Count					3

Table 5: Continued

Fruit / Vegetable	Frozen Uncooked	Frozen Cooked	Fresh Uncooked	Fresh Cooked	Canned
Plum					
Mean±StDev			11.08±1.67		12.42±9.02
Range	-	-	9.47 – 13.25	-	6.67 – 22.81
Count			4		3
Potatoes					
Mean±StDev	4.90±0.57		8.05±3.63	7.87±1.12	
Range	4.50 – 5.30	-	4.70 – 12.50	6.00 – 10.00	-
Count	2		4	14	
Raspberry					
Mean±StDev			34.55±1.72		
Range	-	-	33.33 – 35.77	-	-
Count			2		
Red Lettuce					
Mean±StDev			23.58±1.33		
Range	-	-	22.64 – 24.53	-	-
Count			2		
Spinach					
Mean±StDev	33.73±7.04		33.55±13.57	27.71±5.11	
Range	28.75 – 38.70	-	21.36 – 51.70	24.10 – 31.33	-
Count	2		4	2	
Squash					
Mean±StDev	19.79			20.71±3.28	
Range		-	-	17.02 – 24.44	-
Count	1			4	
Strawberry					
Mean±StDev	11.43±6.28				
Range	5.88 – 17.76	-	-	-	-
Count	4				
Tomatoes					
Mean±StDev			15.86±2.88		9.64
Range	-	-	13.13 – 21.00	-	
Count			6		(1)

Calcium

Despite the fact that several minerals such as calcium, iron, magnesium, phosphorus, and sodium have been addressed by studies reviewed by this project, calcium was the only one where enough observations were found to be included in the dataset. The included articles had their calcium analyses mostly done on fresh fruits and vegetables. Calcium is a very important part of the diet and according to the Continuing Survey of Food Intakes by Individuals (CSFII) and National Health and Examination Survey, National Center for Health Statistics (NHANES), USDA is chronically underconsumed. This could be a reason why so many reports in the literature address this mineral.

The data in Table 6 indicate that fresh uncooked broccoli, spinach, green beans, squash and cabbage are sources of non-dairy calcium with 1364, 1140, 725, 720 and 622 mg/100g D W, respectively. From the data reported in Table 6, higher average levels of calcium were observed in uncooked when compared to cooked vegetables. It should be noted that these data are merely one point estimates from a whole distribution, and as such may or may not be meaningful approximations to distributional traits, such as the mean location. Similar shortcomings, but to a lesser degree, affects the mean calcium values of cooked fresh products. In general the values for both cooked and uncooked products do not compare well to the corresponding converted values obtained from the USDA National Nutrient database.

Table 6: Average data for Calcium[4] (mg/100g Dry Weight) in a variety of vegetables

Vegetable	Frozen		Fresh	
	Uncooked	Cooked	Uncooked	Cooked
Asparagus	-	-	315 1	296±15.56 4
Green Beans	-	-	725 1	684.50±36.95 4
Beets	-	-	268 1	247±17.45 4
Broccoli	-	-	1364 1	1177.25±61.08 4
Cabbage	-	-	622 1	551±43.95 4
Carrot	-	-	350 1	310.25±21.19 4
Cauliflower	-	-	336 1	293.50±13.30 4
Corn	-	-	32.10 1	27.73±1.69 4
Green Peas	-	-	99.60 1	86.18±6.25 4
Potatoes	-	-	61.60 1	46.35±8.63 4
Spinach	-	-	1140 1	930.75±70.84 4
Squash	-	-	720 1	547±98.44 4

[4] Martin-Belloso and Llanos-Barriobero, 2001; Krehl and Winters, 1950.

Carotenoids

Carotenoids are micronutrients found primarily in fruits and vegetables such as carrots. Carotenoids have been extensively addressed in the literature and the alpha and beta carotene contents for a variety of vegetables (carrots, corn, hot peppers and spinach) are shown in Table 7. Based on the data reported in the table, corn and carrots have the highest frozen uncooked beta carotene levels, with 9.53 and 6.75 mg/100g fresh weight, respectively. Based on the corn data in Table 7, there is limited evidence that frozen corn has higher levels of alpha and beta carotene than canned corn.

The corresponding values for the USDA National Nutrient Database for frozen uncooked and fresh cooked carrots are 7.05 and 3.78 mg/100g Fresh Weight, respectively, which compare well with the values from this data set: 6.75 and 4.75 mg/100g Fresh Weight, respectively. However, corn and spinach do not compare closely with the corresponding values from the USDA National Nutrient Database.

Table 7: Average data for Alpha and Beta Carotene (mg/100g Fresh Weight) in a variety of vegetables

Vegetable	Form of Vegetable	Beta carotene[5]	Alpha carotene[6]
Carrots	Frozen Uncooked	6.75±2.05 2	-
	Frozen Cooked	-	-
	Fresh Uncooked	-	-
	Fresh Cooked	-	4.75±1.48 2
	Canned	-	-
Corn	Frozen Uncooked	9.53±10.12 2	3.52±4.65 2
	Frozen Cooked	-	-
	Fresh Uncooked	8.26±10.51 2	5.87±8.24 2
	Fresh Cooked	-	-
	Canned	6.17±7.76 2	2.23±3.08 2
Spinach	Frozen Uncooked	2.45±1.06 2	-
	Frozen Cooked	-	-
	Fresh Uncooked	-	-
	Fresh Cooked	-	-
	Canned	-	-

[5] Scott and Eldridge, 2004; Borchgrevnik and Charley, 1966; Sweeney and Marsh, 1971; Mejia *et al.*, 1988.

[6] Zhang and Hamauzu, 2004; Scott and Eldridge, 2004; Padula and Rodriguez-Amaya,1986; Wu *et al.*, 1992; Borchgrevnik and Charley, 1966; Sweeney and Marsh, 1971; Mejia *et al.*, 1988.

CONCLUSIONS

After extensively reviewing the literature on the effects of freezing and frozen storage of fruits and vegetables, some points of concern were raised. The amount of data that directly compares fresh and frozen fruits and vegetables is very limited, with most of the data dating back at least 20-30 years when some of the methodology for determination of vitamins and other nutritional compounds was also limited. Also, many of the articles make comparisons of specific compounds of fruits and vegetables using a wet weight basis without giving the reader an insight on the moisture content of the products in discussion. Some papers even mention that the differences found could be caused by loss of water in one of the processing steps. Simply by providing the moisture content of the products or reporting the results on a dry weight basis would solve much of the problem and even allow for better cross-comparison of data among articles.

Several articles compare the nutritional value of fresh and frozen fruits and vegetables available at retail stores, without considering the source of those products (harvesting location, harvesting year, maturity, and method of processing). Although these comparisons are valid to indicate the availability of nutrients and phytochemicals offered by the products surveyed it does not truly represent the effects of freezing and frozen storage. Variation on the chemical and nutritional composition of cauliflower was evaluated by Nilsson (1980) based on soil type, nitrogen and irrigation. The results showed that all variables affected the chemical composition of cauliflower, with the effects of nitrogen and irrigation varying from one soil to another. Morrison (1975) reported that the vitamin C content of green beans may change with maturity and also the variability of this compound within one variety when multiple samples were taken before and after freezing.

Another area within the body of literature that needs further exploration is the effects of the freezing process and frozen storage on processed fruits and vegetables in the form of juice, concentrate, or pulp. This is especially important in a global economy because of the volume of fruit products (pulp and concentrates) that are exported and imported around the world. Most originate in tropical areas and are consumed months later in areas where the cultivation of these plants is less favorable or impossible. These products are commercially available directly to consumers at retail stores, but the knowledge about their true nutritional value and the bioavailability of important phytochemicals becomes even more essential for the food industry that uses these products as ingredients in a variety of other processed foods. Evaluating how the nutritional value of these products may change during frozen storage and transport from supplier to end user (consumer or processor) is essential to determine if improvements in the system are necessary.

Regarding the effects of storage, some authors have indicated the lack of research covering the -3 to -10^{o}C range, which is very detrimental and does frequently occur in real-world transport and retail storage along the frozen chain. Shelf-life modeling under temperature fluctuations would help address these concerns in a reliable way. The establishment of kinetic equations that would cover the relevant range of temperature and be validated under dynamic, non-isothermal conditions is essential to the assessment of the nutritional value of a product based on its temperature history (Giannakourou and Taoukis, 2003).

The goal of compiling the macro data set is to determine possible causal relationships between certain nutritional levels in fruits and vegetables and factors contributing to those levels and draw statistical inferences. From those factors, the state of the product being frozen or non-frozen is the central objective of this review. The macro data set also helps to create distributions of nutritional contents, such as vitamins B and C, alpha and beta carotenes, calcium and fiber, for some key fruits and vegetables.

Many factors contribute to the variability of the nutritional content of fruits and vegetables reported in the literature. These factors, which include but are not limited to the complexity of the subject matter, the analytical method used even within a certain class, and purely statistical data-related problems (e.g. missing observations, influential data points, insufficient number of observations), contributed to the infeasibility of regression analysis of the data. Preparation, storage times, and methods are examples with extremely wide distribution, which increases the dispersion and reduces the sample sizes so severely that it is practically impossible to perform regression analyses on the data. These factors limited the ability to draw regression inferences on the nutritional contents of fruits and vegetables, and resulted only in the performance of distributional analyses of means and dispersions of the data.

When possible, the means in the dataset were verified by comparing them to those reported in other studies or by government agencies. Verifying the trends is challenging as there are few, if any, sources performing similar analyses as this review. Because of the variability previously discussed, even if such contemporary data was available, it may not justify direct comparisons. For example, comparing the statistical average of some data points found in the last 80 years or so to an average of several trials reported in any single study, or even to an average by several studies from a different time span may not be appropriate. In summary, the results of the macro data analysis present statistical means and dispersions of findings in the literature, without explaining the factors causing the variations in those means.

In conclusion, the frozen foods industry is a multibillion dollar industry that provides safe, wholesome fruits and vegetables to consumers that overall, maintain much of their nutritional quality. Today an increasing demand for frozen foods already exists and further expansion of the industry is primarily dependent on the ability of food processors to develop higher quality in both process techniques and products. Therefore, improvements can only be achieved by focusing research on new market trends and investigating the poorly understood areas discussed here that influence the quality of frozen fruits and vegetables. Studies on the variable effects of storage conditions, a standardization of analytical techniques, and investigations of the nutritional content of new or exotic fruits and vegetables are all areas of future research that will help improve and drive the marketability of frozen produce.

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