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Original article

# Influence of commercial freezing and storage on vitamin C content of some vegetables

**Berat Nursal Tosun* & Sevinç Yücecan**

Department of Nutrition and Dietetics, Hacettepe University, 06100, Sihhiye, Ankara, Turkey

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**Summary** Vitamin C levels of commercially frozen okra, potatoes, green beans, broccoli, spinach and peas, including the impact of processing and storage, were studied. Depending on the vegetable type, prefreezing operations caused a 19.1–51.5% decrease in the initial vitamin C levels. The freezing process alone did not influence the vitamin levels except in the cases of green beans and spinach. Total losses (%) were between 27.6 and 57.9 for the vegetables at the end of commercial frozen storage (6 months). All the data obtained from this study confirmed that, depending on the vegetable type, prefreezing operations have a major impact on the vitamin C contents and this influence persists in the frozen storage.

**Keywords** Freezing, processing, storage, vegetables, vitamin C.

## Introduction

The basic purpose of food producers is to provide good-health foods with the warranty of high quality and safety. Although this responsibility of food producers remains, new consumer demands are shifting towards more variety in the diet with low energy (low fat and salt) and high-fibre foods (Hurrell, 1989; Clydesdale *et al.*, 1991). One of the appropriate food groups that can meet this demand is vegetables with a high content of certain vitamins, minerals and phytochemicals.

Health improvement effects of these perishable, seasonal products are closely related to their freshness, which leads to the necessity to apply a preservation technique. During the last two decades, among the methods that are used to increase the stability of fresh produce with high quality, freezing seems to be one of the most common methods applied. It has been considered as the simplest and a natural method (Makhlouf *et al.*, 1995; Favell, 1998; Davey *et al.*, 2000). Although the nutrients in frozen products could be protected more than in other storage methods, there could be high levels of losses during the prefreezing and preconsumption periods (Fennema, 1988, 1993; Buescher *et al.*, 1999). Thus, the method of production has an impact on the bioactive ingredients' levels, activity and bioavailability (Hurrell, 1989; Clydesdale *et al.*, 1991; Nicoli *et al.*, 1999). Vitamin C, being the most sensitive vitamin, is used as an indicator to measure the degree of changes owing to production (Paulus, 1989; Giannakourou & Taoukis 2003).

*Correspondent: E-mail: bnursal@hacettepe.edu.tr

This research was planned to evaluate the vitamin C levels and the factors affecting the vitamin content of commercially frozen vegetables in Turkey. For this purpose, the research was conducted in the frame of prefreezing, freezing and frozen storage periods.

## Materials and methods

### Frozen vegetable samples and experimental design for the analyses

Vegetable samples were collected from one of the large-scale frozen vegetable manufacturing plants located in Bursa Province. The manufacturer stated okra, potatoes, green beans, broccoli, spinach and peas to be the top vegetables delivered to domestic markets. So, six kinds of vegetables were chosen as the study materials. All the vegetable samples were taken during three consecutive production shifts in order to see and reflect the variation.

*Prefreezing and freezing sampling*

For each of the vegetables, samples were taken at all the stages (washing, trimming, tip cutting, slicing, blanching, drying, cooling and freezing) that could affect the vitamin C levels.

Each of the samples (10–75 g, depending on the vegetable type) collected during prefreezing and freezing operations was separately put into a glass container containing 100 mL of a 3% metaphosphoric acid ($HPO_3$) and kept in a freezer (−18 °C) until the analyses, which were carried out at the Department of Nutrition

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and Dietetics Laboratories, Hacettepe University, Ankara. Before the analyses, all samples were homogenised for 1 min in a Waring blender and vacuum filtered through Whatman no. 42 filter paper. The first 5 mL of the filtrate was discarded and the remaining filtrate was used for the analyses after making the necessary dilutions. This procedure was repeated three times for each of the samples.

*Frozen storage sampling*

As the frozen storage period for the commercially frozen vegetables was approximately 6 months, vitamin C analyses were conducted on the 3rd and 6th months of storage.

In order to evaluate the effect of commercial frozen storage on vitamin C levels, vegetables (500–1000 g) after freezing were kept in the factory depots for 6 months and transferred to Ankara with cold chain at their analyses times (months 3 and 6). For the analyses, each frozen vegetable was treated as described previously in Prefreezing and Freezing Sampling section. The analyses were conducted in triplicate for each of the samples.

### Vitamin C analyses

Vitamin C levels were measured spectrophotometrically (8700 Model; Unicam, 8700 series, Cambridge, UK) by the method, in which 2,6-dichlorophenolindophenol dye is reduced by ascorbic acid (Roe, 1954; Anon., 1966). The details of the procedure are described elsewhere (Nursal & Yücecan, 2000).

### Statistical analysis

For the measured variables, mean and standard deviation ($\bar{x} \pm SD$) are given as the descriptive statistics. Kruskal–Wallis variance analyses were used to test any difference between the applications in terms of vitamin C levels, and the multiple comparisons method was used to define the parameter (application) that caused the significant difference (Conover, 1980).

## Results and discussion

Prefreezing operations carried out on the vegetables in this study were different, with the exception of blanching and cooling. The vitamin C contents varied according to the vegetable type and prefreezing applications.

The highest initial vitamin C content was determined in spinach with an average of 110.87 ± 3.549 mg per 100 g, followed by broccoli (68.18 ± 2.936 mg per 100 g), peas (28.63 ± 2.806 mg per 100 g), okra (26.59 ± 2.724 mg per 100 g), potatoes (22.49 ± 2.164 mg per 100 g) and green beans (11.51 ± 0.765 mg per 100 g). This ranking did not change after the freezing process, but vitamin C levels were decreased. After 6 months of frozen storage, broccoli (49.37 ± 1.694 mg per 100 g) and spinach (46.64 ± 2.926 mg per 100 g) replaced each other, followed by peas (17.41 ± 2.008 mg per 100 g), okra (12.83 ± 2.874 mg per 100 g), potatoes (8.66 ± 1.094 mg per 100 g) and green beans (5.80 ± 0.773 mg per 100 g) (Table 1).

### Okra

The initial vitamin C level of okra was 26.59 ± 2.724 mg per 100 g before entering to the production line (Table 1). This level decreased by 31.4% after blanching. Freezing resulted in a total of 45.7% loss and this percentage reached 51.8 at the end of 6 months of frozen storage. Vitamin C levels during the freezing process and subsequent storage period were significantly different ($P < 0.05$) in comparison with the initial value. In the applications that are followed, only the difference between the vitamin content of 'initial and blanching' was important ($P < 0.05$).

Before the freezing process, okra was blanched in water for 170 s at 96 °C, resulting in a loss of 31.4% (Table 1). Ekinci & Kılıç (1994) reported vitamin C losses as 15.3% and 18.0% in two different okra varieties after blanching in boiling water for 180 s and determined that the losses were showing variation according to the type of okra. During the frozen storage period, vitamin C values were not significantly different after 3 and 6 months. Vitamin C content of stored okra (12.83 mg per 100 g) was similar to the one (10.1 mg per 100 g) that was stored at −18 °C for 6 months (Ekinci & Kılıç, 1994).

### Potatoes

Peeling, washing, slicing, blanching, drying, frying and cooling were done to potatoes as prefreezing operations, which resulted in 51.5% vitamin loss; this being the most vulnerable period. Subsequent frozen storage caused a total of 61.5% loss. With the exception of 'peeling' period, all other applications resulted in important differences ($P < 0.05$) when compared with initial vitamin C levels. The difference between vitamin C values determined after 3 and 6 months storage was found to be statistically significant ($P < 0.05$) (Table 1).

In a study (Abdel-Kader, 1990), ascorbic acid loss in peeled potatoes was reported as 25% after blanching for 2 min at 100 °C. In this study, 40.9% vitamin loss was determined after blanching for 2.5–3 min at 80 °C (Table 1). Although the blanching temperature was lower in this study, the reason for higher vitamin loss may be attributed to the preblanching applications, such as peeling, washing and slicing, which can destroy vitamin C.

**Table 1** Vitamin C levels () and losses (%) of frozen vegetables due to the processing applications

| Processes | Vitamin C (mg per 100 g) | Loss (%) |
|---|---|---|
| *Okra* | | |
| Initial | 26.59 ± 2.724$^{a}$ | 00.0 |
| Blanching | 18.24 ± 1.991$^{b}$ | 31.4 |
| Cooling | 16.24 ± 2.178$^{b,c}$ | 38.9 |
| Freezing | 14.43 ± 3.039$^{c,d}$ | 45.7 |
| 3 months storage | 13.32 ± 2.989$^{d,e}$ | 49.9 |
| 6 months storage | 12.83 ± 2.874$^{e}$ | 51.8 |
| *Potatoes* | | |
| Initial | 22.49 ± 2.164$^{a}$ | 00.0 |
| Peeling | 19.99 ± 2.441$^{a,b}$ | 11.1 |
| Washing | 16.88 ± 2.034$^{b,c}$ | 25.0 |
| Slicing | 15.64 ± 2.093$^{c,d}$ | 30.5 |
| Blanching | 13.29 ± 1.416$^{d,e}$ | 40.9 |
| Drying | 12.05 ± 1.838$^{e,f}$ | 46.4 |
| Frying + cooling | 10.90 ± 1.438$^{f,g}$ | 51.5 |
| Freezing | 9.71 ± 1.918$^{g,h}$ | 56.8 |
| 3 months storage | 9.08 ± 1.154$^{h}$ | 59.6 |
| 6 months storage | 8.66 ± 1.094$^{i}$ | 61.5 |
| *Green beans* | | |
| Initial | 11.51 ± 0.765$^{a}$ | 00.0 |
| Tip cutting | 10.28 ± 0.602$^{a}$ | 10.7 |
| Blanching + cooling | 8.41 ± 0.775$^{b}$ | 26.9 |
| Freezing | 7.11 ± 0.826$^{c}$ | 38.2 |
| 3 months storage | 6.74 ± 1.037$^{c}$ | 41.5 |
| 6 months storage | 5.80 ± 0.773$^{d}$ | 49.6 |
| *Broccoli* | | |
| Initial | 68.18 ± 2.936$^{a}$ | 00.0 |
| Stalk cutting | 64.38 ± 2.165$^{a,b}$ | 5.6 |
| Blanching | 61.25 ± 2.048$^{b}$ | 10.2 |
| Cooling | 55.16 ± 2.826$^{c}$ | 19.1 |
| Freezing | 53.26 ± 2.120$^{c}$ | 21.9 |
| 3 months storage | 51.11 ± 2.083$^{d}$ | 25.0 |
| 6 months storage | 49.37 ± 1.694$^{e}$ | 27.6 |
| *Spinach* | | |
| Initial | 110.87 ± 3.549$^{a}$ | 00.0 |
| Washing | 93.61 ± 4.235$^{b}$ | 15.6 |
| Blanching | 84.68 ± 1.878$^{c}$ | 23.6 |
| Cooling | 76.68 ± 2.446$^{d}$ | 30.8 |
| Freezing | 70.53 ± 3.083$^{e}$ | 36.4 |
| Glazing | 61.25 ± 2.746$^{f}$ | 44.8 |
| 3 months storage | 59.73 ± 2.116$^{g}$ | 46.1 |
| 6 months storage | 46.64 ± 2.926$^{h}$ | 57.9 |
| *Peas* | | |
| Initial | 28.63 ± 2.806$^{a}$ | 00.0 |
| Blanching | 22.68 ± 3.035$^{b}$ | 20.8 |
| Cooling | 20.80 ± 2.606$^{b,c}$ | 27.3 |
| Freezing | 20.31 ± 2.738$^{c,d}$ | 29.1 |
| 3 months storage | 18.90 ± 2.489$^{d,e}$ | 34.0 |
| 6 months storage | 17.41 ± 2.008$^{e}$ | 39.2 |

Values bearing different superscripts in the same column for each type of vegetable are statistically significant ($P < 0.05$).

## Green beans

Freezing of fresh green beans resulted in 38.3% vitamin C loss. Tip cutting, blanching and cooling were applied as prefreezing operations. The time period before blanching was 24 h after the arrival of newly harvested green beans to the factory and during this period, tip cutting was done manually. While the vitamin loss (10.7%) determined for this period was found to be statistically insignificant ($P > 0.05$), blanching at 94–96 °C for 2.5 min caused a difference ($P < 0.05$) (Table 1). The vitamin loss determined after blanching (26.9%) was in good agreement with some of the other study results (Oruna-Conha *et al.*, 1998; Howard *et al.*, 1999). Vitamin C loss was 85.5% in a study, in which the green beans were washed, sliced and blanched. (Lee *et al.*, 1976). In this study, green beans were not washed separately, blanching replaced washing and vitamin loss was 26.9%. It is apparent that water-soluble nutrients like vitamin C are more prone to leaching effects, especially after being physically disrupted (slicing, cutting, etc.) and heated in water (Somogyi, 1990; Clydesdale *et al.*, 1991; Selman, 1994).

The storage period resulted in a total loss of 49.6% in green beans, which was similar to the results in some studies (Wu *et al.*, 1992; Ericson, 1997) and higher (Müftügil & Yiğit, 1984; Bender, 1993; Favell, 1998; Oruna-Conha *et al.*, 1998) or lower (Bilişli *et al.*, 1982; Howard *et al.*, 1999) than the others. Although there was no important change in vitamin C content between freezing and 3 months of storage, a considerable ($P < 0.05$) decrease was detected after 6 months of storage (Table 1). It was reported that during frozen storage, in order to minimise the vitamin C loss, proper inactivation of the oxidases and prevention of storage temperature fluctuations are the key issues to be considered (Wu *et al.*, 1992; Howard *et al.*, 1999).

## Broccoli

The initial vitamin C level (68.18 ± 2.936 mg per 100 g) of broccoli decreased by 10.2%, 21.9% and 27.9% after blanching, freezing and 6 months of storage, respectively. Each application (except stalk cutting) was found to cause statistically important ($P < 0.05$) difference in the vitamin content when compared with the initial value (Table 1).

Hussein *et al.* (2000) found that vitamin C of broccoli was not influenced unless the vegetable tissue was damaged, which causes the release of substrates necessary for unwanted enzymatic activities. In this study, vitamin C loss (10.2%) after blanching at 96 °C for 3.5 min was much lower than the loss obtained in some of the studies in which blanching time was between 4 and 5 min (Brewer *et al.*, 1995; Lisiewska & Kmiecik, 1996).

Although the decrease in the vitamin C contents of broccoli samples during the storage period was found to be important ($P < 0.05$), total vitamin loss was only 27.6% (Table 1). Howard *et al.* (1999) reported a similar amount of loss in frozen broccoli and Favell (1998) determined a 30% loss at −20 °C after 12 months of storage, concluding that the maximum losses occurred in prefreezing operations.

### Spinach

The initial vitamin C content (110.87 ± 3.549 mg per 100 g) of spinach samples decreased by 15.6% after washing (Table 1). The roots of the spinach were cut in the field after harvesting and the spinach lots were transported to the factory, and washed four times which resulted in a statistically significant vitamin loss ($P < 0.05$). The factors causing a difference in vitamin contents during this period can be related both to the enzymatic destruction started on the cut surface and to the leaching of vitamin C during washing (Shewfelt, 1990; Somogyi, 1990). Blanching at 95 °C for an average of 140 s resulted in a total of 23.6% vitamin loss in spinach samples (Table 1). As green leafy vegetables have high surface to volume ratio in comparison with the other vegetables, they have been reported to be more susceptible to blanching which can cause 20–70% vitamin C loss (Selman, 1994; Lisiewska & Kmiecik, 1996; Favell, 1998; Negi & Roy, 2000; Prochaska *et al.*, 2000).

In some studies, it has been shown that during storage of frozen green leafy vegetables, vitamin C losses can reach high levels (60–70%) (Ericson, 1997; Lisiewska & Kmiecik, 1997). In this study, vitamin C content was reduced by 46.1% and 57.9% after 3 and 6 months of frozen storage, respectively ($P < 0.05$) (Table 1). While Labib *et al.* (1997) reported a similar vitamin loss (46%) in frozen spinach after 3 months of storage, Favell (1998) found a 62% loss after 12 months of storage at −20 °C.

### Peas

The first application that caused a significant difference ($P < 0.05$) in the vitamin C content of peas was blanching (Table 1). A range of 4–45% vitamin C loss after blanching was determined in some of the studies and all the losses were attributed to seed size and pea variety independent of the blanching (Lee *et al.*, 1976; Selman, 1994; Cano, 1996). Although initial vitamin C content of peas was decreased by 39.2% at the end of frozen storage period, there was not any significant difference in vitamin contents during 6 months of storage (Table 1). Bilişli *et al.* (1982) found a 59% loss at −18 °C after 6 months of storage, which they associated this loss with the processing conditions and storage temperature.

It is well known that blanching, which is largely responsible for the vitamin C losses, is absolutely necessary for the quality of frozen vegetables (Barret & Theerakulkait, 1995; Hoard, 1997). The destructive effect of blanching temperature on the physically damaged tissues and thus increased vitamin oxidation and water solubility of vitamin C account for the negative effects of blanching (Fennema, 1988; Lee & Kader, 2000; Prochaska *et al.*, 2000). Preblanching applications, such as peeling, trimming and/or slicing, can contribute to the negative effects of physical damage, which may lead to more leaching of vitamin C (Selman, 1994; Buescher *et al.*, 1999). In this study, it was found that potatoes with 51.5% vitamin loss were the most affected vegetable because of the applications done before freezing (Table 1).

Broccoli and spinach were the only two vegetables affected significantly ($P < 0.05$) from cooling process after blanching (Table 1). As the surface area subject to water and heat is higher in these two types of vegetables, ascorbic acid losses can be higher than in the other vegetables. For this reason, blanching and cooling techniques without any water have been recommended for broccoli and spinach (Fennema, 1988; Wu *et al.*, 1992; Howard *et al.*, 1999).

It has been well shown that if raw material that is in good quality is used and proper prefreezing operations are applied, freezing alone has no negative effect on the vitamin content (Fennema, 1993; Selman, 1994). In this study, freezing did not cause any significant difference to the vitamin C contents of the vegetables except green beans and spinach (Table 1). In green beans, the factors which may cause the difference in vitamin content after freezing could be hosing and subsequent precooling, which were carried out between blanching and freezing. In spinach samples, the postblanching applications that may account for the difference in vitamin content were cooling in water tank, selection, plating and freezing for 10 h.

Average vitamin C values of different Turkish brand frozen spinach, peas, green beans and okra were recorded as 33.3, 14.2, 15.7 and 23.8 mg per 100 g, respectively (Nursal & Yücecan, 1996). Açkurt *et al.* (1998), in another piece of national research, reported the vitamin C levels of frozen spinach as 29.30 mg per 100 g, broccoli as 69.23 mg, green beans as 14.41 mg and okra as 21.81 mg. It can be seen from the results that some of the results are similar and some of them are not. The variables that underlay these differences are mainly vegetable type, initial vitamin content, period before freezing, prefreezing applications, as well as method of analyses and sample size. Although it is impossible to make proper comparisons with all these unknown parameters, it can only be said that vitamin C contents are ranging from 50 to 67 mg per 100 g for frozen broccoli, 13–61 mg per 100 g for spinach, 14–24 mg per 100 g for okra, 11–28 mg per 100 g for peas, 2–29 mg per 100 g for green beans and 9–11 mg per 100 g for potatoes (Makhlouf *et al.*, 1995; Nursal & Yücecan, 1996;

Lisiewska & Kmiecik, 1996; Hoard, 1997; Açkurt *et al.*, 1998; Favell, 1998; Giannakourou & Taoukis, 2003).

## Conclusions

Generally, it can be concluded that vitamin C contents of commercially frozen vegetables were affected mostly by prefreezing operations and freezing process alone did not cause an important vitamin loss. Although vitamin losses after frozen storage was lower than the prefreezing ones, frozen storage also resulted in noticeable changes in the vitamin C values of the vegetables.

Prefreezing applications, which damage the tissue integrity, must be minimised and in order to retain more water-soluble nutrients, these kinds of applications should be done just after the processes, which require water. Besides, frozen storage and frozen chain have to be monitored very carefully, as time–temperature relation during this period has a direct impact on the shelf life, and hence the nutritional quality of frozen vegetables.

The nutrient losses in vegetables, which are regarded as 'hidden losses', can occur between harvesting and consumption. Thus, to prevent nutrient losses, processing should be optimised by determining critical control points and scrutinised by making necessary comparisons with the scientific research results.

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