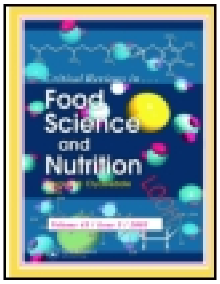

Critical Reviews in Food Science and Nutrition
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/bfsn20

Brassica Foods as a Dietary Source of Vitamin C: A Review

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Accepted author version posted online: 26 Mar 2013.

To cite this article: Critical Reviews in Food Science and Nutrition (2013): Brassica Foods as a Dietary Source of Vitamin C: A Review, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2011.626873

To link to this article: http://dx.doi.org/10.1080/10408398.2011.626873

Brassica Foods as a Dietary Source of Vitamin C: A Review

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Abstract

Brassica genus includes known horticultural vegetables with major economical importance worldwide, and involves vegetables of economical importance being part of the diet and source of oils for industry in many countries. Brassicales own a broad array of health-promoting compounds, emphasized as healthy rich sources of vitamin C. The adequate management of pre- and post-harvest factors including crop varieties, growth conditions, harvesting, handling, storage, and final consumer operations would lead to increase or preserve of the vitamin C content or reduced losses by interfering in the catalysis mechanisms that remains largely unknown, and should be reviewed. Likewise, the importance of the food matrix on the absorption and metabolism of vitamin C is closely related to the range of the health benefits attributed to its intake. However, less beneficial effects were derived when purified

compounds were administered in comparison to the ingestion of horticultural products such as *Brassicas*, which entail a closely relation between this food matrix and the bioavailability of its content in vitamin C. This fact should be here also discussed.

These vegetables of immature flowers or leaves are used as foodstuffs all over the world and represent a considerable part of both western and non-western diets, being inexpensive crops widely spread and reachable to all social levels, constituting an important source of dietary vitamin C, which may work synergistically with the wealth of bioactive compounds present in these foods.

Keywords: Vitamin C, *Brassica*, ascorbic acid, dehydroascorbic acid, pre-harvest, post-harvest, bioavailability, health.

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1. Introduction

The *Brassicaceae* crop plants (broccoli, cauliflower, Brussels sprouts, cabbages, turnips, etc.) are food staples used worldwide and represent a considerable portion of human diet (Jahangir *et al.*, 2009; Kusznierewicz *et al.*, 2010; Vallejo *et al.*, 2002b). A broad array of healthy properties have been attributed to *Brassica* species in recent years; such as anticarcinogenic, protective actions against cardiovascular diseases and ageing processes, prenatal pathologies, cataracts, etc. (Akhlaghi and Bandy, 2010; Emmert *et al.*, 2010; Jahangir *et al.*, 2009; Kataya and Hamza, 2008; Kim *et al.*, 2008; Tiku *et al.*, 2008). These benefits have been related to their high content in health-promoting phytochemicals namely: glucosinolates (and their hydrolysis products, isothiocianates), phenolic compounds (hydroxycinamic acids and flavonoids), carotenoids, vitamins (ascorbic acid, tocopherol, and folic acid), and minerals (Domínguez-Perles *et al.*, 2010; Fernandes *et al.*, 2007; Ferreres *et al.*, 2009; Heimler *et al.*, 2006; Pérez-Balibrea *et al.*, 2011; Taveira *et al.*, 2009; Vallejo *et al.*, 2002a; Yang *et al.*, 2010). Regardless of the rich profile in bioactive compounds of *Brassica* genus, current trials are

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focused on the potential role of isolated phytochemicals, including vitamin C, largely known as essential nutrient, that lacks an integrative approach to understand its functions on health along with the rest of bioactive constituents in their natural food concentrations and the conditioning of the food matrix on its bioavailability (Bjelakovic *et al.*, 2007; Blot *et al.*, 1993; Frei and Lawson, 2008; Kim *et al.*, 2008; Li and Schellhorn, 2007a; Loria *et al.*, 2000). Actually, it should be taken into account that *Brassicas* generally contain high amounts of vitamin C, even though the traditional source has also been the *Citrus* family. In fact, depending on consumer habits of different countries, *Brassica* vegetables can provide the 50% of the daily recommended dietary intake (RDI) of vitamin C, leading the sources of natural vitamin C for human populations (Pennington and Fisher, 2010).

Therefore, the aim of this review was to describe the existing variations in the contents of vitamin C among *Brassica* species, pointing out the effects of the pre-harvest (specie, variety, organ, and developmental stage) and post-harvest (handling, storage, and processing procedures) on this nutrient for high quality commodities. The relevance of the health benefits attributed to vitamin C derived from the *Brassica* consumption as affected by the food matrix, as well as its absorption and metabolism, will also be discussed.

2. Pre-harvest conditions affecting vitamin C content in *Brassica* foods

The capital relevance of pre-harvest factors on the nutritional quality of *Brassica* foods has been widely reported and it is clear that the adequate management of the production factors affecting the plant growth may help to increase their content in bioactive compounds at harvest, not only by selecting the best species and varieties for any specific production area, but also by

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optimizing the growing conditions of the selected crops. Therefore, among the different pre-harvest factors conditioning the vitamin C content of *Brassica* vegetables, two groups could be established. First, those factors inherent to the considered crop: genetic (species and cultivars) and physiological factors (organ and developmental stage), as ‘internal’ factors. In this sense, the second group would include all the ‘external’ factors including the environmental and agronomic conditions and practices harvesting and handling procedures.

2.1. Genetic information: The major inherent internal factor to crucifers is the large variation among genotypes, and a good example can be founding *Brassica* genus (Table 1), for vitamin C concentrations ranging up to 4-folds differences among species: broccoli (*B. oleracea* var. *italica*), Brussels sprouts (*B. oleracea* var. *gemmifera*), kale (*B. oleracea* var. *acephala*), and mustard spinachs (*B. rapa* var. *perviridis*), exhibing higher contents (100, 107, 118, and 130 mg of vitamin C per 100 g fw on average, respectively), widely surpassed the black mustards (*B. nigra*), canola (*B. napus*), cauliflower (*B. oleracea* var. *botrytis*), collards (*B. oleracea* var. *viridis*), Indian mustards (*B. juncea* var. *rugosa*), turnips (*B. rapa* vars. *rapifera* and *rapa*), and cabbages (*B. oleracea* var. *capitata*, *B. rapa* var. *chinensis*, var. *parachinensis*, and var. *pekinensis*) that presented ranging 35-68 mg 100 g^{-1} fw (Table 1). Data of the variation of vitamin C contents of different *Brassica* species analyzed under equal conditions have been published by the United States Department of Agriculture (USDA), confirming this fact under the minimized influence of the analytical method (USDA, 2010).

Penintong *et al.* cited an alternative classification that showed collards, kale, turnip greens, and mustards as the *Brassicas* with the highest contents in vitamin C in comparison with broccoli, Brussels sprouts, cabbage, cauliflower, Chinese broccolis, and Chinese cabbages

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(Pennington and Fisher, 2010). In earlier works, the lowest values have been registered for some varieties of cabbage (5.7-25.3 mg 100 g^{-1} fw (Singh *et al.*, 2007)). Additionally, the comparison of the content of vitamin C in separate cultivars belonging to the same species has shown differences of up to 5% for broccoli, 3.7% for kale, 2.7% for collards, 2% for cauliflower, Indian mustards, cabbage, and turnips, and 1.5% for Brussels sprouts and Chinese cabbage (Table 1). The variation in the content of vitamin C among *Brassicaceae* members has been attributed to their inherent genetic background, while minor changes could be also attributed to differences in the experimental procedures or analytical methods. In addition, the fact that the species most widely integrated in the market and human consumption habits (broccoli, kale, collards, and cauliflower), and therefore which are subjected to more intense genetic breeding showed also the strongest variation, linking the genetic factor as responsible of the variation in their vitamin C contents. Furthermore, the experimental procedures in which variations in the analytical and storage conditions, represent a factor with marginal relevance, give additional support to the critical effect of the genetic influence on the vitamin C content in *Brassica* spp., with variations of up to 54% for broccoli, 12% for cauliflower, and 32% for cabbage (Borowski *et al.*, 2008; Ferreres *et al.*, 2006;Kurilich *et al.*, 1999; Sousa *et al.*, 2008; Vrchovská *et al.*, 2006). In this sense, Vallejo *et al.*, analyzed the content in vitamin C of 14 breeding and commercial broccoli varieties recording differences of up to 71% (Vallejo *et al.*, 2002b), even though they were grown, processed, and analysed under equal conditions, suggesting again the major relevance of the genetics and breeding in determining the *Brassicas* load of dietary vitamin C over the distinct experimental conditions. Despite the existing variations in vitamin C contents in *Brassicas*, we emphasize that the natural foods of this genus are a good source of vitamin C among a broad array of fruits and vegetables.

2.2. Organ and developmental stage: Other group of inner factors; including the physiological effects of the distinct plant organs, or the developmental stage at harvest, are also critical for the nutrient contents of fruits and vegetables. Considering broccoli as a model because of its intense characterization and interest as commercial brassica, significant changes occurred on vitamin C levels through its development, as for other bioactives. While in broccoli seeds, vitamin C is almost undetected, a progressive increase of the vitamin C in broccoli sprouts was described from 3 to 12 days of age (Pérez-Balibrea *et al.*, 2010; Pérez-Balibrea *et al.*, 2008). Later on, in adult plants during flowering, the vitamin C accumulation in broccoli inflorescences from the early flower bottom to the mature head reached even a five-fold increased amount (Omary *et al.*, 2003; Vallejo *et al.*, 2003a). Another remarkable increase was observed in leaves and stalks in adult plants. Indeed, *Brassica* byproducts (harvest remains) are foodstuffs rich in health-promoting nutrients including vitamins and minerals, with even higher values that those found in marketable heads (Domínguez-Perles *et al.*, 2010; Martínez *et al.*, 2009; Omary *et al.*, 2003). Consequently, the stage of plant development conditions the content of phytochemicals including vitamin C.

2.3. Environmental factors: Concerning 'external' environmental and agronomic factors that influence the vitamin C contents of *Brassica* crops (Howard *et al.*, 1999), sun light, aerial temperature, and soil salinity have been highlighted as critical factors for vitamin C, and therefore modifiers of the nutritional quality of *Brassicas* (DomÃnguez-Perles *et al.*, 2010; López-Berenguer *et al.*, 2009; Lee and Kader, 2000; Moreno D.A., 2007). With regard to sunlight, although vitamin C synthesis in plants is not directly depending on light, ascorbic acid (AA) is synthesized from glucose obtained through the photosynthesis, which let to an indirect relationship between both, amount and intensity of sunlight and the vitamin C content (Lee and Kader, 2000). In the same way, Perez-Balibrea *et al.* recorded higher contents of vitamin C in broccoli sprouts grown under a 16/8 hours light/dark cycle, that significantly surpassed those of the sprouts grown in the dark, by 83% on average (Pérez-Balibrea *et al.*, 2008). Likewise, the relationship between air temperature and AA content has also been reported for *Brassica* vegetables and, in general, growing under low temperature regimes has as consequence a higher vitamin C contents in plants (Lee and Kader, 2000).

Considering abiotic stress such as salinity in the irrigation water, its concentration is crucial for the vitamin C content of edible parts of *Brassicas*, including broccoli, decreasing proportionally to the water physiological deficiency or hydric stress (Toivonen *et al.*, 1994). Several production areas of semiarid climates worldwide are affected by water shortage, and characterized by high-salt concentrations in the available irrigation water, which has been pointed out as responsible of the variations in the nutritional value of *Brassica* foods. However, the variation in vitamin C content, as a consequence of the irrigation using saline water, is closely related to the organ considered: while broccoli inflorescences and stalks were not affected, the broccoli leaves showed a decrease (15% as average) in vitamin C at 100 mM NaCl (DomÃnguez-Perles *et al.*, 2010; López-Berenguer *et al.*, 2009).

Fertilization practices are also critical for growth and the nutritive composition of crops, and the effects on the vitamin C of *Brassica* plants depends on type of nutrient and the applied dose. The sulfur fertilization (60-200 Kg Ha^{-1}) at low or too high rate at different flowering moments resulted in distinct vitamin C contents with a positive effect of rich sulfur fertilization, at the beginning of the inflorescence development, undergoing a progressive reduction in concentration during heads formation (Vallejo *et al.*, 2003a; Vallejo *et al.*, 2003b). For nitrogen, its application (100-400 Kg Ha^{-1}) severally leads to higher vitamin C concentrations in vegetables (Stefanelli *et al.*, 2010), and among *Brassicas*, cauliflower and white cabbage have displayed an increased vitamin C content when the nitrogen based fertilization was at low rates (Lisiewska and Kmiecik, 1996; Sorensen, 1984). However, it has not been registered significant differences for vitamin C content of broccoli, suggesting the relative effect of fertilization practices on its content, as well as the contribution of climate and water status together with the fertilization effects (Lisiewska *et al.*, 2008; Sorensen, 1984; Stefanelli *et al.*, 2010). The AA appeared to be strongly affected by a fast oxidation to DHA under non adequate growth conditions for broccoli. Indeed, both seasonal and annual variations of the AA and total vitamin C have also been observed (between 13.37-110.30 and 57.35-131.35 mg/100 g fw, respectively), for example in broccoli harvested in separated seasons for two consecutive years (Koh *et al.*, 2009).

Harvesting marks the limit between pre- and post-harvest.Manipulations at harvest may cause damages on the integrity of *Brassica* tissues as a result of bruising, surface abrasions, and cuts. Consequently, harvesting methods may have pernicious effects on vitamin C content, accelerating its loss or degradation by exposing it to external oxidative atmospheres. Like this, the method employed for harvesting, either by hand or using machinary, can determine the severity of the damages caused to the marketable products. Therefore, harvesting procedures and practices should be the less damaging as possible to avoid vitamin C losses and keep the integrity of the item and its content and, in addition, must be stored at low temperatures (Lee and Kader, 2000; Sikora *et al.*, 2008).

3. Post-harvest conditions affecting vitamin C content in *Brassica* products

Post-harvest products would determine the potential amount of nutrients and health promoting bioactives for dietary intake by final consumers and, hence, their properties for consumers wellbeing. The food composition would be greatly influenced by the processes at this stage. Once harvested, the biological processes that continue in food, are closely linked to the variation of phytochemical composition during handling and storage. Because of this, preserving the phytochemicals in *Brassica* vegetables through careful post-harvest practices means to guarantee their high nutritional quality and safety (Allende *et al.*, 2006).

In this sense, vitamin C has been considered a bio-indicator of adequate handling and processing procedures because of its sensivity to degradation (it is easily oxidized by both enzymatic and non-enzymatic pathways) (Clegg *et al.*, 1976; Morrison, 1974) and, in general, fresh *Brassica* foods contain higher vitamin C contents than stored foods, not only as a result of the slight increase of vitamin C occurred in some species during first days after harvesting (Eheart and Odland, 1972; wu, 1992), but also because it is not possible to stop the degradation processes after harvest. Vitamin C losses begin during pre-market preparations of *Brassica* vegetables, which may include bruising, trimming, and cutting, which can display an intense reduction as a result of these processes that entails a weak commercial and healthy value (Lee and Kader, 2000; Sikora *et al.*, 2008). Moreover, there are a broad array of post-harvest factors affecting vitamin C content of *Brassica* vegetables such as storage temperature, packing atmospheres, edible coatings, and cooking methods. In fact, the combination of all these factors will notably affect the final vitamin C content of foods-as-eaten, as it has already been noted for some *Brassica* vegetables including Broccoli (Lemoine *et al.*, 2007; López-Berenguer, 2007; Puupponen-Pimiä *et al.*, 2003), collards (Vanderslice *et al.*, 1990), cabbage (Kader; Puupponen-Pimiä *et al.*, 2003; Vanderslice *et al.*, 1990), mustard greens (Vanderslice *et al.*, 1990), and cauliflower (Puupponen-Pimiä *et al.*, 2003). These reports have showed that the chain of factors from the producer to the consumer let to degradation of vitamin C to different extends for *Brassicas*.

3.1. Storage temperature: This factor is critical for the maintenance of the vitamin C level in *Brassica* spp. foods. Refrigeration of *Brassica* derived foods is used to maintain the vitamin C concentration and temperature regimes <4 ºC guaranteed a minor decrease, whereas higher temperatures entailed significant reductions (Ezell and Wilcox, 1959). It is generally accepted that storage, at controlled low-temperatures, reduces the degradation of vitamin C, but the *Brassica* species considered, the storage period, and the fluctuations of temperatures may also act as modulators for this vitamin losses (Adisa, 1986). In this aspect, for example; the content in vitamin C of kale and cabbage underwent an accelerated reduction stored at temperatures higher than 8 ºC (Ezell and Wilcox, 1959).

3.2. Duration of storage: Differences between short and long-time periods of storage are critical for the vitamin C content. Among the separate *Brassica* products depending on the specie considered (roots, leaves or inflorescences), short-time storage at temperatures below 8 ºC allowed a quite stable concentration of vitamin C (Ezell and Wilcox, 1959; wu, 1992). However, for long-time storage (3-6 weeks) at 1-2ºC, the fall of vitamin C contents was dependent on the species. Thus, these losses varied from 5-10%, for broccoli, Brussels sprouts, and Chinese cabbage, to a much severe reduction of more than 50% for kale (Albrecht, 1990; Hagen *et al.*, 2009; Klieber, 2000). In addition to the decrease of vitamin C under long-time refrigerated storage, an increase in the proportion of DHAA with respect to AA has been described owed to the degradation of AA, rendering DHAA (Hagen *et al.*, 2009; Lee and Kader, 2000; Wills *et al.*, 1984). In spite of this, the reported losses of AA in cruciferous vegetables are minimal in comparison to other horticultural products, due to the high contents of these plants in glutathione and other sulfur molecules involved in the reduction of DHAA to AA that, hence, allows a higher capacity for AA retention during storage that reach between 65% and 95% of initial levels, depending on the considered specie (Albrecht, 1990; Lee and Kader, 2000).

3.3. Physical pre-treatments: Together with the low temperature-based storage, other physical treatments can help to preserve the nutritive value of *Brassica* vegetables stored for long periods. In this way, it has been reported the beneficial effects of hot air or ultraviolet light treatments (UV-C) on minimally processed broccoli florets prior to refrigeration, allowing a smaller decrease of both AA and DHAA in treated broccoli than in controls (Lemoine *et al.*, 2007; Lemoine *et al.*, 2010). On the other hand, Ansorena *et al*. recently described that broccoli inflorescences treated with edible coatings presented even two-times higher AA retention than those uncoated. Among different coating tested, chitosan displayed the best performance and, next to other advantageous impacts on broccoli quality, this effect was enhanced when it was combined with a mild heat-shock, constituting a promising technique for *Brassica* manufacturing industry (Ansorena *et al.*).

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3.4. Freezing: The storage of *Brassica* vegetables at -30ºC for long periods (12 months) resulted in reduced vitamin C contents, in the range of 15-18% for broccoli, 6-13% for cauliflower, and 32% for cabbage (Lisiewska and Kmiecik, 1996; Puupponen-Pimiä *et al.*, 2003). The main cause of vitamin C reduction in frozen *Brassica* foods has been the effect of the freezing process in the internal structure of the vegetables. Differences in vitamin C concentrations between fresh and frozen cauliflower and cabbage were recorded, and varied from 16 to 30%, respectively (Puupponen-Pimiä *et al.*, 2003). Contrary to this, controversial results have been shown for fresh and frozen broccoli inflorescences. While some authors indicated an important decrease (about 50%) as consequence of freezing (Lisiewska and Kmiecik, 1996; Murcia *et al.*, 2000), other reports remark the protective effect of blanching on the vitamin C losses. In this way, broccoli heads blanched prior to freezing underwent a reduction of the vitamin C losses of 83% (Patras *et al.*, 2011). In fact, blanching, far of being considered harmful, protects vitamin C from degradation. Nonetheless, blanching also reduces the content of vitamin C, mainly because of denaturation by heat and diffusion to the blanch-hot water (Vanderslice *et al.*, 1990), but the decreases produced by the further freezing are minimal for kale, broccoli, cauliflower, or Brussels sprouts in comparison with that observed in vegetable directly frozen (Patras *et al.*, 2011; Sikora *et al.*, 2008). The reason why vitamin C preservation, in blanched *Brassica* foods is less affected by frozen-storage than those non-blanched, was suggested as result of the effect on denaturation of catabolic enzymes present in fresh vegetables (Howard *et al.*, 1999; Lee and Kader, 2000; Patras *et al.*, 2011; Sikora *et al.*, 2008). Consequently, the combination of distinct temperature-based preservative procedures, blanching and freezing, enables the reduction of

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vitamin C losses when freezing is used and, thus, help to guarantee high vitamin C contents in frozen *Brassica* foodstuffs.

3.5. Controlled or modified atmospheres of packing: The technological approaches to reduce the vitamin C losses of *Brassica* vegetables during storage, include the use of low partial pressures of O_2 and high partial pressures of CO_2, in order to decrease the metabolic activity of plant tissues to avoid the degradation of the marketable and nutritional quality (Kader). *Brassica* species showed different tolerance to modified atmosphere packing (MAP), mainly because of the distinct resistance of the edible organ used or processed (inflorescences, baby leaves, leaves, stems, bulbs, roots, etc.), the physiological state at harvest, and the concomitant storage factors (temperature, humidity, and duration) (Ahvenainen *et al.*, 1998; Martínez-Sánchez *et al.*, 2006). Therefore, modified or controlled atmosphere (CA) for *Brassica* products must be specifically designed. Nevertheless, promising approaches have been performed indicating not only that a retention of vitamin C, as in kale or turnip tops, is possible, but also an increase during storage as found in broccoli (Cefola *et al.*, 2010; Fonseca *et al.*, 2005; Wold *et al.*, 2007). Additionally to the use of MAP, the conditioning of broccoli inflorescences with cytokinin (50 ppm of benzyl adenine), a plant hormone with antioxidant properties involved in the delay of the senescence and the decrease of the sensitivity to ethylene (Chang *et al.*, 2003), helped to reduce the fermentation of packaged broccoli heads, preventing the degradation of vitamin C (Khalili *et al.*, 2008).

3.6. Domestic cooking: Prior to consumption, every cooking method affects vitamin C differently and have critical consequences on the protective intake of vitamin C from *Brassica* vegetables. Likewise, while microwave cooking method reduces the content in vitamin C of broccoli from

20% to 40% as compared to raw broccoli (López-Berenguer, 2007; Vallejo *et al.*, 2002a), boiling, which is the most classical domestic cooking for *Brassicas*, reduces vitamin C almost 2-times more than the microwave, probably due to the release of vitamin C into the cooking water (López-Berenguer, 2007; Sikora *et al.*, 2008). Actually, boiling has been reported to induce a great decrease in vitamin C levels of the *Brassicas*, these losses have been quantified in 24% and 80% for green cauliflower and kale, respectively. Moreover, boiled-frozen vegetables showed even higher losses, owed to the lack of structural integrity, than occurred when freezing without previous treatments (Sikora *et al.*, 2008). Relating to the effect of stir-frying on vitamin C content of broccoli, Moreno *et al.* showed the critical relevance of the kind of edible oil used for cooking on the reduction of vitamin C contents. The decreases registered reached the 8 and 81% for extra virgin olive oil and refined olive oil, respectively. (Moreno *et al.*, 2007). Steaming, by the contrary, has been shown as the thermal cooking process that causes the lowest vitamin C loss in *Brassica* foods (Francisco *et al.*, 2010; Vallejo *et al.*, 2002a; Volden *et al.*, 2009).

The cooking time is also relevant, because of the exposition time to the high temperatures during cooking as well as the long time between preparation and consumption, that are all factors that reduces the vitamin C, should be reduced to the minimum (Campos *et al.*, 2009; Lee and Kader, 2000).

As seen in this section, a broad array of post-harvest factors affects the vitamin C of *Brassica* vegetables are not fully addressed. Regardless the many studies that have been carried out focused in either only one or a few processes or factors, not enough multifactorial, integrative, and translational research has been taken, in order to clarify how handling, storage, and final consumer operations modify the vitamin C content of the healthy horticultural products.

Therefore, aiming to offer the highest and most complete health-promoting phytochemical composition of foods, both the implementation of the most consecutive post-harvest practices and the communication to consumers of the best guidelines for the proper processing of *Brassica* foodstuffs should be encouraged.

4. Bioavailability, metabolism, and excretion of dietary vitamin C

Vitamin C is an essential nutrient involved in the cell physiology and several crucial processes for human health. Because of evolutive selection has produced the lack of the enzyme that catalyze the last step for AA synthesis, L-gulonolactone oxidase (GulL-ox), humans are unable to synthesize it and, thus, vitamin C has to be incorporated in through its dietary intake (Nishikimi *et al.*, 1994).

This essential nutrient is generally available from fruits and vegetables as it has been aforementioned; *Brassicas* are a good rich source of vitamin C. Despite its elevated content in these vegetables, differences concerning the absorption of vitamin C from *Brassicas* could be due not only to the content in the final product, but also to the simultaneous presence of other interfering compounds as phenolics. In addition, different sources of vitamin C may entail variations in its gastrointestinal absorption and, thus, affecting its bioavailability and physiological effects (Mangels *et al.*, 1993; J. B. Park and Levine, 2000; Song *et al.*, 2002). The comparative analysis of the bioavailability of vitamin C from different dietary sources including *Brassica* spp., *Citrus* spp., and pure compound (synthetic AA) did not show relevant differences among foods, except for raw broccoli (Mangels *et al.*, 1993). Interestingly, distinct foods (mainly *Citrus* spp.) and cooked broccoli displayed similar vitamin C bioavailability, higher than the registered after the raw broccoli intake. This fact has been attributed to both the distinct release of vitamin C in the intestinal lumen and its availability for organic uptake as affected by the food matrix. Consequently, the work of Van Het Hof *et al.* suggests that the consumption of *Brassicas,* exposed to thermal or domestic processing, are better than eating raw foods in terms of vitamin C intake, and could yield a higher, albeit not so significant, bioavailable vitamin C (Van Het Hof *et al.*, 1999).

4.1. Bioavailability and metabolism of vitamin C: focus on the role of other Brassica *phytochemicals.*

Vitamin C, both in reduced (AA) and oxidized form (DHAA), undergoes several steps from the initial ingestion through its elimination out of the human body. Initially, the uptake occurs, for both AA and DHAA, in the epithelial cells of the small intestine but in different physical locations, and different transporters based in substrate-saturable mechanisms are used for both forms (Li and Schellhorn, 2007a).

The efficiency in the absorption constitutes an essential factor conditioning the further bioavailability of vitamin C. The AA uptake constitutes the major source of vitamin C supply, as the efficiency of its uptake is higher than for the DHAA, because of the high affinity of AA for its receptor, contrary to the DHAA (Malo and Wilson, 2000). The AA is absorbed through a sodium-dependent vitamin C transporter type I (SVCT1) located in the apical brush-border of the ileum (Malo and Wilson, 2000; Martí *et al.*, 2009), and also through a sodium-dependent vitamin C transporter type II (SVCT2), found in cells of most other tissues, suggesting its implication in the transport to the intracellular compartment.

On the other hand, cellular uptake of DHAA is performed by ubiquitous glucose transporters of the GLUT family in duodenum and jejunum (Deutsch, 2000) and, hence, as a likely consequence of sharing the same transporters, changes in glucose serum levels, characteristic of same metabolic diseases coursing with glycemic deviation as diabetes, may reduce the DHAA bioavailability (Agus *et al.*, 1997; Rumsey *et al.*, 1997). Furthermore, regardless that the AA and the glucose are absorbed in distinct segments of the small intestine and through different transporters, glucose also could interfere with AA uptake since ascorbate transport depends on an electrogenic process modulated by glucose (Malo and Wilson, 2000). Therefore, glucose content of foods and glycemic state of the subject also may modify the total vitamin C bioavailability, which must be taken into account in order to guarantee the accurate vitamin C nutritional status upon the variations in dietary habits.

Other factors altering the vitamin C absorption are the phenolic compounds present in *Brassica*, secondary metabolites with health-promoting effects that modify metabolic processes (Moreno *et al.*, 2006; Vallejo *et al.*, 2002b; Velasco *et al.*, 2011; Williams *et al.*, 2004). In fact, antagonistic effects on ascorbic acid uptake have been exhibited by different flavonoids including flavanols, flavones, and isoflavones through the inhibition of SVCT1 (J. B. Park and Levine, 2000; Song *et al.*, 2002). On the other hand, flavonoids and phenolic acids have also been considered as blockers of intestinal glucose transporter isoform 2 (GLUT2) and, therefore, able to regulate the glucose transport (Manzano and Williamson, 2010; C. Park *et al.*, 1999; Song *et al.*, 2002). Hence, in relation to this effect on the glucose metabolism, another indirect interaction between phenolics and vitamin C might be established owing to the role of glucose in vitamin C absorption. Nevertheless, further trials should be designed in order to assess the effects of *Brassica* polyphenols on vitamin C bioavailability.

Glucosinolates, the other group of compounds characteristics of *Brassica*, and their cognate bioactives, isothiocyanates, could also affect the dietary availability of vitamin C. To this date, there no a report or communication linking both directly, either glucosinolates or isothiocyanates, to AA or DHAA absorption. However, isothiocyanates have been suggested to alter the behaviour of glucose transporter GLUT4 *in vitro*, and thereby varying the glucose transport (Goto *et al.*, 1992; Sujatha *et al.*, 2010). Similarly, DHAA absorption could also be affected because of the shared uptake mechanism used by both DHAA and glucose (Deutsch, 2000). Therefore, new studies should be performed to investigate whether *Brassica* glucosinolates may vary the bioavailability of the vitamin C contained in the food matrix, presumably by modifying the glucose metabolism.

After absorption, vitamin C forms are transported to the cells by blood vessels, and during this distribution to the tissues, they must be protected from oxidative reactions, being its interaction with metal ions such as copper, iron, molybdenum, or cobalt the major risk factors for AA oxidation. In fact, to prevent deleterious reactions, ions reactivity is controlled by specific chaperones (Harrison *et al.*, 2000).

Once inside the cells, AA acts as co-factor and electron donor in a broad number of enzymatic and non-enzymatic processes in all cellular compartments. These reactions yield ascorbate free radical (AFR) (De Tullio and Arrigoni, 2004) that is processed to DHAA into the endoplasmic reticule as the main route by which AA is oxidized to DHAA (Arrigoni and De Tullio, 2002). Later on, AFR may take part of other metabolic processes intended for its reduction back to AA: by NADH-dependent AFR-reductase in the endoplasmic reticule and mitochondria (Green and O'Brien, 1973) and by NAD(P)H in an electron transport system mediated by CoQ in the plasma membrane (Gómez-Díaz *et al.*, 1997; Villalba *et al.*, 1995). Even so, the human organism is able to recycle the oxidized AA (DHAA) to the reduced form (AA), but this path is not enough for supplying the metabolic requirements and, hence, additional external contributions by dietary sources are necessary. Consequently, Davey *et al*, 2000,. proposed that increasing half-life and efficiency of each ascorbate molecule by the increase of the DHAA recycling from erythrocytes, through improving erythrocyte glutathione (GSH) levels, could be an strategy to enhance AA bioavailability (Davey *et al.*, 2000). In recent years, despite a GSH rise has been asserted in both *in vitro* models and humans trials after *Brassica* foods ingestion and phytochemical supplementations (M. F. Chen *et al.*, 1995; Emmert *et al.*, 2010; Pappa *et al.*, 2007; Wark *et al.*, 2004), other studies with human subjects displayed controversial results (Nijhoff *et al.*, 1995; Riso *et al.*, 2009). These differences could be due to the glutathione-S-transferase (GST) genotypic polymorphisms and, thus, it seems reasonable that *Brassica* foods can increase cellular levels of GSH and/or GST in certain human genotypes (Wark *et al.*, 2004). Therefore, vitamin C intake related to *Brassica* consumption might improve the bioavailability of this essential nutrient by reducing the DHAA, owing to an augment of GSH levels. Nevertheless, this hypothesis should be carefully evaluated since it is currently believed that AA recycling is addressed to limit DHAA formation as a tool to prevent deleterious or toxic effect of DHAA, prior to being an efficient tool to provide AA requirements. In fact, pernicious effects of DHAA on cells have been reported when high levels are available, leading to mitochondria damage (Arrigoni and De Tullio, 2002; Martensson and Meister, 1991). But, interestingly, severe damage is only presented under both GSH and ascorbate deficit (Martensson and Meister, 1991), which constitutes an easily reversible status through *Brassica* supplementation thanks to the high vitamin C content in *Brassica* products as well as to the ability of *Brassica* phytochemicals to increase the GSH levels (M. F. Chen *et al.*, 1995; Emmert *et al.*, 2010; Pappa *et al.*, 2007; Pennington and Fisher, 2010; Wark *et al.*, 2004). Hence, the likely improved reduction of physiological DHAA after *Brassica* consumption, far from being pernicious, might entail an improved bioavailability of vitamin C.

Finally, for the urinary excretion of vitamin C, the circulating AA is filtered in kidneys and part of the primary AA excreted is further reabsorbed into the capillary bed surrounding the proximal convoluted tubules (Nelson *et al.*, 1978). The physiological machinery (digestive, circulatory, and renal systems) works together guarantying the supply of essential vitamin C. In this way, when the intake of foods rich in vitamin C is low, the majority of the vitamin contained in the food matrix is rapidly absorbed into the small intestine and reabsorbed into the kidneys. However, when high concentrations of vitamin C are ingested, the efficiency of the absorption and reabsorption is modulated, turning to a 'less-efficient mechanism' in order to guarantee the optimum vitamin C serum level (60-100 µmol L^{-1}) for the normal development of physiological functions, avoiding the pernicious effect of its excess (Levine *et al.*, 1996).

4.2. Human requirements for vitamin C

Physiological stage, health condition, age, sedentary habits, smoking, etc., are a plethora of factors that determine the necessary dietary intake of vitamin C. The physiological mean concentration of vitamin C has been established in 20 mg Kg^{-1} of body weight in well nourished humans being, whereas saturation level is reached at 33 mg Kg^{-1}. Likewise, vitamin C disappears of the organism at a rate of 3% per day, appearing deficiency-related symptoms when levels fall below 7 mg Kg^{-1} during depletion of vitamin C-rich foods (Blanchard, 1991; FAO, 2010). Considering both absorption efficiency and catabolic rate of vitamin C, the dose of 10 mg per day constitutes the minimal supply for guarantying the physiological necessities, or to revert any pathological sign linked to its deficiency. Consequently, vitamin C recommended dietary allowance (RDA) was established from 10 to 60 mg per day (Krebs-Smith and Clark, 1989). Nevertheless, this recommended dose is currently under reevaluation because of available novel epidemiological data relating vitamin C consumption to new physiological functions. Therefore, the necessity of dietary intake ranges from 90 to 100 mg per day to prevent cardiovascular diseases and cancer. Indeed, the recommendation raised the level to 120 mg per day for preventing specific pathological conditions such as cataracts, although this extremely high level needs to be experimentally supported with further studies (Carr and Frei, 1999; FAO, 2010). Additionally, other health disorders including diabetes, cachexia, drugs dependence, and malabsorption syndrome may influence the vitamin C requirements (Martí *et al.*, 2009; Rebouche, 1991). These health problems are connected to the vitamin C absorption and/or excessive ingestion and must be accounted for the accurate determination of the daily needs of vitamin C.

Certain physiological conditions or developmental states also require different vitamin C supplementation. For example, pregnancy and lactation are special physiological conditions with extra needs (as a result of a higher intensity of organic processes as well as liquid retention and body mass differences) entailing variations in vitamin C nutritional requirements. In this way, while the RDA of vitamin is increased during pregnancy (by 16%) over the non-pregnant women, additional requirements for dietary vitamin C are around 50-58% during lactation, to fulfill both the mother and the infant needs, depending on the lactation phase (Urgell *et al.*, 1998). Likewise, during childhood, the daily recommended intake for infants of 1-18 years of age is 30-40 mg per day and it must be gradually increased until reaching the necessities described for adulthood (Rees and Shaw, 2007). Interestingly, regarding elderly, despite the fact that the metabolic rate is decreased, higher doses are required since vitamin C plasma concentration of this population group is lower than in young adults, which has mainly been attributed to disturbances in the intestinal and renal function (Heseker and Schneider, 1994).

With respect to smoking, it has been suggested that smokers need a 50% higher intake of vitamin C than non-smokers to ensure an optimal physiological concentration of AA able to cope with the much higher oxidative reactions occurring in their bodies as a consequence of this toxic habit (Kallner, 1987).

These general considerations on the vitamin C requirements for distinct sub-population of humans are closely linked with the dietary habits of the different collectives considered. In this way, the requirements abovementioned convert the intake of fruits and vegetables in a necessary source of vitamin C, among which *Brassicaceae* is a highlighted vegetables family that guarantee a healthy status in human populations, conferring additional advantages (it constitutes a simultaneous source of fiber and other essential vitamins and minerals) in comparison with the use of synthetic forms on this nutrient. In addition, the extraction of vitamin C from natural products reduces, and almost makes it disappear, the risk of surpassing the upper limit.

This safe upper limit for vitamin C consumption has been established in around 1 g per day as higher intakes have been related to pathological signs. Supplementation with 2-3 g per day may cause diarrhea as a consequence of osmotic disturbances of the unabsorbed vitamin C (Hathcock *et al.*, 2005). Likewise, it has also been described the oxalate-stone formation in kidneys when vitamin C is ingested in the range of 5-10 g per day, although this has only been associated with high amounts of urinary calcium (Urivetzky *et al.*, 1992). Haemolysis has been pointed out as triggered by toxic doses of vitamin C as well (Delanghe *et al.*, 2007). Moreover, chronic doses of 500 mg per day or acute doses of 1-3 g may cause toxic effects expressed as vasoreactivity, with relevant considerations on cardiovascular and cerebrovascular diseases (Carr and Frei, 1999). However, clinical findings linked to excessive intake of vitamin C are very limited and linked to the administration of nutritional supplements and not to vegetable foods (including *Brassica* or any other natural foods).

Therapeutic potential of dietary vitamin C and *Brassica*

Vitamin C has been pointed out as an essential nutrient with an active role in the maintenance of body functions, displaying a wide range of therapeutic properties such as antioxidant, anticarcinogenic, co-factor in the collagen synthesis, and promoter of iron absorption (Arrigoni and De Tullio, 2002; Franceschi *et al.*, 1994; Hallberg *et al.*, 1987; Telang *et al.*, 2007; Yoshikawa *et al.*, 2001). In fact, a broad number of reports have been performed in order to demonstrate the health-promoting properties of vitamin C (Martí *et al.*, 2009). Nevertheless, only a few works have been focused on the role of dietary vitamin C on health, even though the well-established effect of other nutrients and the food matrix on the bioavailability of this vitamin is evident as reviewed above. Regarding this, long periods with an insufficient intake of fresh vegetable foods can produce a reduction in the serum levels of AA, with dramatic consequences, increasing the formation of reactive oxygen species (ROS), leading to a greater incidence of chronic diseases and aging (Benzie, 2003; Li and Schellhorn, 2007b). *Brassica* foods have been related to the prevention of degenerative diseases linked to oxidative processes (Jahangir *et al.*, 2009). In *Brassicas*, the 80% of their natural antioxidant activity comes from phenolic compounds and vitamin C, being vitamin C responsible of 10%-12% of the total antioxidant capacity of broccoli and cabbage (Podsedek, 2007).

In general, despite the complete range of reactions in which vitamin C may be involved, as well as the sense of its contribution, that is not fully understood, its antioxidant properties, the protection against free radicals, cytoprotective functions such as prevention of DNA mutation, protection against lipid peroxidative damage, and repairing amino acid residues to save the protein integrity have all been suggested (Barja *et al.*, 1994; Hoey and Butler, 1984; Lutsenko *et al.*, 2002). Moreover, the consumption of *Brassica* foods as source of vitamin C has additional advantages in comparison with other dietary sources of vitamin C. In fact, joined to the rich-in-phytochemicals *Brassica* food matrix, these health-promoting properties attributed to vitamin C could be interestingly boosted. Actually, a wide range of positive effects on some cardiovascular diseases has been displayed by *Brassicas* in several assays (Akhlaghi and Bandy, 2010; Kataya and Hamza, 2008) and prospective studies. Kim *et al*. has shown that the incorporation of dark green leafy cruciferous foods to the diet can prevent coronary artery disease in hypercholesterolemic men by decreasing risk factors (Kim *et al.*, 2008). In accordance to this, the regular supplementation of kale juice reduces the intestinal lipid absorption, modulating the lipid profile and thereby decreasing serum lipid substrates available for peroxidation. So, the efficiency of the antioxidant system was increased and, thus, the oxidative disturbances and related conditions were eased (Kim *et al.*, 2008).

Oxidative reactions are also in the basis of cancer initiation and, hence, vitamin C may play an essential role in its prevention (Lutsenko *et al.*, 2002). Mechanism of action of AA in the prevention of the deleterious activity of free radicals has been connected to the generation of hydrogen peroxide (H_2O_2) from O_2 and to the induction of apoptosis in cancer cells since normal cells are significantly more resistant to H_2O_2 than cancerous ones (Q. Chen *et al.*, 2005; Frei and Lawson, 2008). Healthy levels of vitamin C in the organism can prevent DNA mutation induced by oxidative stress as well (Lutsenko *et al.*, 2002). Likewise, vitamin C has carried out functions related to cancer risk reduction through diet, as it has been pointed out in epidemiological trials, and the correlation between vitamin C intake and cancer prevention has shown higher significance when consuming fruits and vegetables as source of vitamin C instead of the synthetic form (Q. Chen *et al.*, 2005; Dennison *et al.*, 1998; Frei and Lawson, 2008; Moreno *et al.*, 2006). These contributive effects have been also attributed to the role of other phytochemicals with anticarcinogenic properties in *Brassica* (Jahangir *et al.*, 2009; Kusznierewicz *et al.*, 2010; Tiku *et al.*, 2008). In this sense, glucosinolates, isothiocyanates, phenolic compounds, and vitamin C may act synergistically in therapeutic functions. Clinical trials supplementing single vitamins and minerals have indicated the dependence or pharmacological benefits of vitamin C owed to synergistic effects of food components in fruits and vegetables (Bjelakovic *et al.*, 2007; Blot *et al.*, 1993; Loria *et al.*, 2000). Therefore, therapeutic features associated with *Brassica* consumption are generated from the influence of

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multiple bioactives acting in a cooperative action better than the sole biological action of a single agent and more developments on this area are expected.

As conclusive remarks, in spite of the many experimental approaches existing so far, on the biological activity derived of *Brassica* consumption, further comprehensive studies are required and should be conducted to ascertain the *in vivo* prospects of such products, as the majority of the experimental procedures have been carried out with *in vitro* models. Likewise, experimental animal and human interventions focused on the elucidation of the multiple therapeutic properties of vitamin C in *Brassica* vegetables and aiming to improve the real dimension of the connections between food, nutrition and health are needed.

Acknowledgements

Authors would like to express their gratitude to the Spanish Ministery of Science and Innovation (MICINN) for the funding through the projects CICYT (AGL2007-61694). Part of this work was also funded by the project “Group of excellence” (04486/GERM/06) from the Regional Agency for Science and Technology of Murcia (Fundación Séneca) and the Consolider-Ingenio 2010 Fun-*C*-Food project (CSD2007-00063).

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Figure captions:

Figure 1. Vernacular and scientific names of some examples of commercial *Brassicaceae*

Figure 1.

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Brassica spp. plants

Brassica oleracea

Broccoli
(*B. oleracea* var. *italica*)

Brussels sprouts
(*B. oleracea* var. *gemmifera*)

Cauliflower
(*B. oleracea* var. *botrytis*)

Collards
(*B. oleracea* var. *viridis*)

Curly kale
(*B. oleracea* var. *acephala*)

White, Red, and Savoy cabbage
(*B. oleracea* var. *capitata*)

Brassica rapa

Broccoli raab
(*B. rapa* var. *ruvo*)

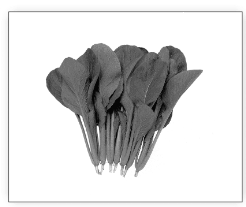
Chinese cabbage (Pak-choi)
(*B. rapa* var. *chinensis*)

Chinese cabbage (Pe-tsai)
(*B. rapa* var. *pekinensis*)

Turnip greens
(*B. rapa* var. rapa)

Chinese flowering cabbage (Choi sum)
(*B. rapa* var. *parachinensis*)

Turnip tops
(*B. rapa* var. *rapiferaa*)



Mustard spinach or tender greens
(*B. rapa* var. *perviridis*)

Brassica juncea

Mustard cabbage or Indian mustard
(*B. juncea* var. *rugosa*)

Brassica albogabra

Chinese broccoli (Kai lan)

Table 1. Content in vitamin C (mg 100 g^{-1} fw) of fresh edible parts of *Brassica* plants.

Comodity	**AA**	**Vitamin C**	**Extraction/Analysis method**	**Source (reference)**
Broccoli (*Brassica oleracea* var. *italica*)		93.2	Total ascorbic acid	(USDA, 2010)
		83.0	Trichloroacetic acid/HPLC	(Puupponen-Pimiä *et al.*, 2003)
		66.4	Till-mans method	(Sikora *et al.*, 2008)
		72.2-122.6 37.7-124.9 ~200 ~115 (leaves) ~150	MeOH:H2O/HPLC	(Vallejo *et al.*, 2003b) (Vallejo *et al.*, 2003a) (López-Berenguer, 2007) (López-Berenguer *et al.*, 2009) (López-Berenguer *et al.*, 2009)
	106.9	117.7 130	MeOH:H2O/HPLC	(Vallejo *et al.*, 2002a) (Moreno *et al.*, 2007)
		25.5-82.3	Non available	(Jagdish *et al.*, 2006)
	84		Citric acid/HPLC	(Hrncirik *et al.*, 2001)
	 96.79 32	77-93 74.8	Methaphosphoric acid/2,6-Dichloroindophenol	(Favell, 1998) (Bahorun *et al.*, 2004) (Schonhof *et al.*, 2007) (Ansorena *et al.*, 2011)
		2.34-5.77*	Metaphosphoric acid/microfluorometric method	(Borowski *et al.*, 2008)
	112 (78 stems)		Metaphosphoric acid/spectophotometry	(Murcia *et al.*, 2000)
	89.0-148.2 74.7 103 (124 stems) 374.1	97.0-163 121.1 ~152 75 43.2-146.3 41-64 87.19	Methaphosphoric acid/HPLC	(Vanderslice *et al.*, 1990) (Mangels *et al.*, 1993) (Kurilich *et al.*, 1999) (Howard *et al.*, 1999) (Hussein *et al.*, 2000) (Vallejo *et al.*, 2002b) (Zhang and Hamauzu, 2004) (Franke *et al.*, 2004) (Koh *et al.*, 2009) (Patras *et al.*, 2011)
	 35-65	113 93	Not available	(Davey *et al.*, 2000) (Chu *et al.*, 2002) (Lemoine *et al.*, 2010)
Broccoli raab (*Brassica rapa* var. *ruvo*)		20.1	Total ascorbic acid	(USDA, 2010)
		26.6	MeOH:H2O/HPLC	(Cefola *et al.*)
Brussels sprouts (*Brassica oleracea* var. *gemmifera*)		85	Total ascorbic acid	(USDA, 2010)
		90.3	Till-mans method	(Sikora *et al.*, 2008)
	27.4 76		Methaphosphoric	(Kurilich *et al.*, 1999) (Pfendt *et al.*, 2003)

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		127.7-129.3	acid/HPLC	(Podsedek *et al.*, 2006)
		87-109	No available	(Davey *et al.*, 2000)
Cauliflower (*Brassica oleracea* var. *botrytis*)		48.2	Total ascorbic acid	(USDA, 2010)
	81		Trichloroacetic acid/HPLC	(Puupponen-Pimiä *et al.*, 2003)
		40.6-52.4	Till-mans method	(Sikora *et al.*, 2008)
		50	Metaphosphoric acid/2,6-dichlorophenol	(Bahorun *et al.*, 2004)
	17.2		HCl/2,6-dichlorophenol	(Pfendt *et al.*, 2003)
	64		Citric acid/HPLC-UV	(Hrncirik *et al.*, 2001)
	54.0 42.0	63.1	Methaphosphoric acid/HPLC	(Vanderslice *et al.*, 1990) (Kurilich *et al.*, 1999)
		64-78	No available	(Davey *et al.*, 2000)
Chinese broccoli (Kai lan) (*Brassica alboglabra*)		28.2	Total ascorbic acid	(USDA, 2010)
Chinese cabbage (Pak choi) (*Brassica rapa* var. *chinesis*)		45.0	Total ascorbic acid	(USDA, 2010)
		25.3	Metaphosphoric acid/2,6-dichlorophenol-indophenol	(Bahorun *et al.*, 2004)
		29	Methaphosphoric acid /HPLC	(Wills *et al.*, 1984)
Chinese cabbage (Pe tsai) (*Brassica rapa* var. *pekinensis*)		27.0	Total ascorbic acid	(USDA, 2010)
	11		Citric acid/HPLC-UV	(Hrncirik *et al.*, 2001)
		20	Methaphosphoric acid /HPLC	(Wills *et al.*, 1984)
Chinese flowering cabbage (Choi sum) (*Brassica rapa* var. *parachinensis*)		46	Methaphosphoric acid /HPLC	(Wills *et al.*, 1984)
Collards (*Brassica oleracea* var. *viridis*)		35.3	Total ascorbic acid	(USDA, 2010)
	92.7	93.3	Methaphosphoric acid/HPLC	(Vanderslice *et al.*, 1990)
Curly kale (*Brassica oleracea* var. *acephala*)		120	Total ascorbic acid	(USDA, 2010)
		107	Till-mans method	(Sikora *et al.*, 2008)
		51.3	Methaphosphoric acid/ Dinitrophenylhydrazine method	(Fonseca *et al.*, 2005)
	92.6		HCl/2,6-dichlorophenol-indophenol	(Pfendt *et al.*, 2003)
	 730*	55.52 969*	Methaphosphoric acid/HPLC-UV	(Martínez *et al.*, 2009) (Hagen *et al.*, 2009)
		186	Not available	(Davey *et al.*, 2000)
Mustard cabbage (Indian mustard)		70.0	Total ascorbic acid	(USDA, 2010)
	36.2	36.2	Methaphosphoric	(Vanderslice *et al.*, 1990)

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(*Brassica juncea* var. *juncea*)		100	acid/HPLC	(Wills *et al.*, 1984)
Mustard spinach (Tender greens) (*Brassica rapa* var. *perviridis*)		130.0	Total ascorbic acid	(USDA, 2010)
Red cabbage (*Brassica oleracea* var. *capitata*)		57.0	Total ascorbic acid	(USDA, 2010)
		62.0-72.5	Methaphosphoric acid/HPLC-UV	(Podsedek *et al.*, 2006)
Savoy cabbage (*Brassica oleracea* var. *capitata*)		31.0	Total ascorbic acid	(USDA, 2010)
		49.8-65.7 33.3	Methaphosphoric acid/HPLC-UV	(Podsedek *et al.*, 2006) (Martínez *et al.*, 2009)
White cabbage (*Brassica oleracea* var. *capitata*)		36.6	Total ascorbic acid	(USDA, 2010)
	5.5	25.6	Manufactured kit/HPLC	(Gökmen *et al.*, 2000)
	44		Citric acid/HPLC-UV	(Hrncirik *et al.*, 2001)
	28.2		HCl/2,6-dichlorophenol	(Pfendt *et al.*, 2003)
	18.8		Metaphosphoric acid/2,6-dichlorophenol-indophenol	(Bahorun *et al.*, 2004)
		18.0-35.6	Methaphosphoric acid/HPLC	(Podsedek *et al.*, 2006)
	42.3-67.0 17.0-24.0	44.3-74 46-47 32 43 34.1	Not available	(Vanderslice *et al.*, 1990) (Kurilich *et al.*, 1999) (Davey *et al.*, 2000) (Chu *et al.*, 2002) (Puupponen-Pimiä *et al.*, 2003) (Martínez *et al.*, 2009)
White or yellow mustard (*Brassica alba*)		3	Total ascorbic acid	(USDA, 2010)
Turnip tops (*Brassica rapa* var. *Rapiferaa*)		21.0	Total ascorbic acid	(USDA, 2010)
		46	MeOH:H2O/HPLC	(Francisco *et al.*, 2010)
		89.39	Methaphosphoric acid/HPLC	(Martínez *et al.*, 2009)
Turnip greens (*Brassica rapa* var. *Rapa*)		60.0		(USDA, 2010)
		62	MeOH:H2O/HPLC	(Francisco *et al.*, 2010)
		67.5	Methaphosphoric acid/HPLC	(Martínez *et al.*, 2009)
		~70	Not available	(Mondragón-Portocarrero, 2006)

NDB = USDA nutrient databank identifier, *mg g^{-1} dw; **mg Kg^{-1} pf

Table 2. Content in vitamin C (mg 100 g^{-1} fw) of stored and cooked edible parts of *Brassica* plants

Comodity	Frozen	Refrigerated	Cooked (cooking method)	Source (reference)
Broccoli			40.1	(USDA, 2010)

	56.0 (frozen); 23.1 (boilied/frozen)	106-134	40.1 (boiled); 116.2 (microwaved	(Vanderslice *et al.*, 1990)
	56.4		71.7-62.2/2	(Mangels *et al.*, 1993)
	64.3-73.7			(Favell, 1998)
	77-89 (frozen); 77-86 (blanched/frozen); 69-80 (microwaved/frozen)	115-116	~90-~135 (blanched); 112-117 (Microwaved)	(Howard *et al.*, 1999)
			84 (pillow packed)	(Hussein *et al.*, 2000)
	55-56 (florets blanched/frozen); 35-36 (stems blanched/frozen)			(Murcia *et al.*, 2000)
				(Murcia *et al.*, 2000)
			90 (boiled)	(Davey *et al.*, 2000)
			73 (boiled); 75 (high pressure boiled); 106 (steamed); 54.9 (microwaved)	(Vallejo *et al.*, 2002a)
			18-21	(Franke *et al.*, 2004)
			35.2-83.5 (floret boiled); 36.0-100.0 (stem boiled); 35.5-85.1 (floret microwaved); 36.5-103 (leaves microwaved)	(Zhang and Hamauzu, 2004)
			110-170	(López-Berenguer, 2007)
			65-120 (stir fried)	(Moreno *et al.*, 2007)
	~20 (frozen)		~60 (blanched); ~25 (boiled)	(Sikora *et al.*, 2008)
	62.7 (frozen); 373.2 (Blanched/frozen)			(Patras *et al.*, 2011)
			40 (CMC coated); 52 (chitosan coated)	(Ansorena *et al.*, 2011)
Brussels sprouts	74.1		62.0	(USDA, 2010)
	~30-~50 (frozen)		~15-~40 (boiled); ~35-~80 (blanched)	(Sikora *et al.*, 2008)
Cauliflower			55	(Davey *et al.*, 2000)
	66-73		14.4 (boiled); 73 (Blanched)	(Puupponen-Pimiä *et al.*, 2003)
	~35		~35 (blanching); ~25 (boiled)	(Sikora *et al.*, 2008)
Chinese cabbage (Pak-choi)			26.0	(USDA, 2010)
			14-15	(Franke *et al.*, 2004)
Chinese cabbage (Pe-tsai)			15.8	(USDA, 2010)
			68-10	(Franke *et al.*, 2004)
Collards			18.2	(USDA, 2010)
			41 (boiled)	(Vanderslice *et al.*, 1990)
Curly Kale				(USDA, 2010)
			62	(Davey *et al.*, 2000)
	~45		~15 (boiling); ~65(blanching)	(Sikora *et al.*, 2008)
		~465-~828*		(Hagen *et al.*, 2009)
Mustard			25.3	(USDA, 2010)

cabbage (Indian mustard)		4.8 (boiled)	(Vanderslice *et al.*, 1990)
Mustard spinach (Tender greens)		65.0	(USDA, 2010)
Red cabbage		10.8	(USDA, 2010)
Savoy cabbage		17.0	(USDA, 2010)
White cabbage		37.5	(USDA, 2010)
		24.4 (boiled)	(Vanderslice *et al.*, 1990)
Turnip tops	26.8	18.2	(USDA, 2010)
		29.4 (steamed); 0 (boiled/high pressure boiled)	(Francisco *et al.*, 2010)
Turnip greens	4.4	3.9	(USDA, 2010)
	20-30 (frozen); 25-35 (dried, blanched, frozen)		(Mondragón-Portocarrero, 2006)
		39.7 (steamed); 0 (boiled/high pressure boiled)	(Francisco *et al.*, 2010)

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* mg $100g^{-1}$ dw

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