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ScienceDirect
Food Chemistry 107 (2008) 55–59
Food Chemistry
www.elsevier.com/locate/foodchem

The antioxidant activity of selected cruciferous vegetables subjected to aquathermal processing

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Received 11 January 2007; received in revised form 17 May 2007; accepted 12 July 2007

Abstract

Kale (*Brassica oleracea var. Acephala*), broccoli (*Brassica oleracea var. botrytis italica*), Brussels sprouts (*Brassica oleracea L. var. gemmifera*) and green and white cauliflower (*Brassica oleracea var. botrytis*) were used to determine their contents of antioxidising agents: vitamin C, carotenoids and polyphenols. The examined vegetables were found to contain between 40.6 and 107 mg/100 g FW of vitamin C, from 0.04 to 2.7 mg/100 g FW of carotenoids, and from 144 to 773 mg/100 g FW of polyphenols. Cauliflower was found to contain the smallest amount of these compounds and kale the largest. The antioxidant activity of the vegetables was determined on the basis of their ability to extinguish the ABTS free radical. The aquathermal processes to which the vegetables were subsequently subjected reduced their antioxidant activity, mainly due to escape of vitamin C and polyphenols into the water environment. These losses were largest in the case of leafy or highly fragmented vegetables.

Keywords: *Brassica* vegetables; Vitamin C; Carotenoids; Polyphenols; Antioxidant activity

1. Introduction

The breathing process and various other reactions taking place in the human body cause the formation of free radicals. There is increasing evidence from scientific research that these reactive forms of oxygen cause damage to cells, leading to cancer, inflammation, or unfavourable changes in blood vessels. The damage caused by excessive production of free oxygen radicals contributes to many common illnesses, such as: cardiovascular disease, certain prenatal complications, malignant tumors, inflammations (e.g. rheumatic joint inflammation), cataracts, Parkinson's disease and Alzheimer's disease, as well as accelerating the ageing process. The body's antioxidant defence mechanism consists mostly of endogenously produced enzymes: catalase, glutathione peroxidase and superoxide dismutase, which suppress the formation of free radicals. In recent years, there has been growing interest in food substances, which are able to inhibit or decrease harmful effects of the free radicals in the human body. Dietary intake of these compounds provides effective support for the body's defensive systems (Ghiselli, Serafini, Natella, & Scaccini, 2000; Wasowicz & Gromadzińska, 2005).

Vitamin E and C, β-carotene and polyphenols are well known as the antioxidant compounds of plant-based foods. Polyphenols were recently considered to be unnecessary for human diets, but there is now substantial evidence indicating that their potential as antioxidants is actually greater than the above-mentioned vitamins (Bravo, 1998; Manach, Scalbert, Morand, Remesy, & Jimenez, 2004; Nijveldt, 2000).

The results of the recent research clearly indicate the importance of fruit and vegetables as the richest potential source of these substances and emphasise the need to increase the proportion of these products in the diet. A

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doi:10.1016/j.foodchem.2007.07.023

prominent role in this process is played by the popular cruciferous vegetables (*Cruciferae*), which contain several bioactive compounds and which not only act as antioxidants, but also have other health-promoting properties (Beecher, 1994; Borowski, Borowska, & Szajdek, 2005; Cao, Sofic, & Prior, 1996).

The aim of this research was to establish the content of compounds with antioxidant properties, i.e. vitamin C, carotenoids and polyphenols, in selected cruciferous vegetables, and the degree to which these substances are active as antioxidants. Because these vegetables are often eaten in processed form, the effect of common aquathermal processes on these parameters was investigated.

2. Materials and methods

The vegetables subjected to analysis were: kale (*Brassica oleracea var. Acephala*, cv. Winterbor), broccoli (*Brassica oleracea var. botrytis italica*, cv. Sebastian), Brussels sprouts (*Brassica oleracea* L. *var. gemmifera*, cv. Maczuga), and cauliflower (*Brassica oleracea var. botrytis*) – white cauliflower (cv. Rober) as well as green cauliflower (cv. Amphora). The vegetables were cultivated in the Poland Plant and Horticultural Seed Production Centre in Kraków in 2004.

A prepared average laboratory sample of vegetables was separated from inedible parts, and washed and dried at room temperature. One part of the vegetables was analysed without processing, while others were divided into portions which were subjected to:

- boiling for about 12–15 min, until ready for consumption, at a temperature of around 100 °C,
- blanching at a temperature of around 80 °C for about 3 min,
- freezing after blanching, at a temperature of −22 °C,
- boiling after freezing for about 10 min.

The prepared samples were assessed for the contents of vitamin C (ascorbic and dehydroascorbic acid) by the Tillmans method, as modified by Pijanowski (Rutkowska, 1981), and for contents of carotenoids (Lichtenthaler & Buschmann, 2001a, 2001b).

Additionally, methanol extracts were prepared (3 g of raw or 5 g of processed vegetables in 80 cm^3 of 70% methanol solution) which were used to establish the polyphenol content by the AOAC, 1995AOAC method (1995), using the Folin-Ciocalteau reagent, as well as antioxidant activity by determining ability to extinguish an ABTS free radical (Re et al., 1999).

3. Results and discussion

The content of vitamin C in the examined vegetables was in the range at 40.6–107 mg/100 g of fresh vegetables (Table 1). Cruciferous vegetables are generally considered to be a good source of vitamin C in the diet. Kale may be especially important in this regard as it contains the highest amount of this compound (107 mg/100 g). The amount of vitamin C in kale may vary greatly from 48 to 150 mg/100 g (Nowak, 2004). The only vegetable containing more vitamin C than kale is pepper (Kunachowicz, Nadolna, Przygoda, & Iwanow, 2005).

The average content of vitamin C in the Brussels sprouts was 90.3 mg/100 g. The vitamin C content in Brussels sprouts varies from 66 to 196 mg/100 g (Podsędek, Sosnowska, Redzynia, & Anders, 2006). According to Rutkowska (1994), Brussels sprouts may contain as much as 284 mg/100 g of this component, its amount showing inverse correlation with the size of head.

Broccoli contains 66.4 mg of vitamin C per 100 g of fresh vegetables average. This value lies within the range given in the reference material (Howard, Wong, Perry, & Klein, 1999; Kurilich et al., 1999; Lisiewska & Kmiecik, 1996). A lower value of this ingredient is found in cauliflower, green cauliflower containing a little more vitamin C than white cauliflower (52.4 and 40.6 mg/100 g, respectively). Lisiewska and Kmiecik (1996) examined the amount of vitamin C in cauliflower immediately after harvest and found it to be 60.6–64.7 mg/100 g. Lower values may be the result of varieties used or growing conditions. It is also possible that the content of this sensitive compound is decreased by storage or preliminary processing of the vegetables.

Applied technological processes reduced the vitamin C content in the vegetables (Fig. 1). The lowest loss was caused by blanching the vegetables, ranging from 7% in the case of white cauliflower to 20% for kale. Boiling causes the greatest decrease of vitamin C levels in the vegetables: vegetables

Table 1
Content of natural antioxidants and antioxidant activity of selected Brassica vegetables

Product	Vitamin C (mg/100 g of FW)	Carotenoids (mg/100 g of FW)	Total polyphenols[a] (mg/100 g of FW)	Antioxidant activity (μM trolox/g of FW)
Kale	107 ± 3.1	2.7 ± 0.20	773 ± 46.88	36.2 ± 1.05
Broccoli	66.4 ± 1.2	0.26 ± 0.046	289 ± 6.12	26.2 ± 1.37
White cauliflower	40.6 ± 3.4	nd	145 ± 3.73	20.9 ± 0.55
Green cauliflower	52.4 ± 1.16	0.04 ± 0.003	144 ± 3.31	24.9 ± 2.81
Brussels sprouts	90.3 ± 2.2	0.26 ± 0.036	331 ± 33.22	32.1 ± 1.71

nd – not determined.
[a] Total polyphenols value is expressed as chlorogenic acid.

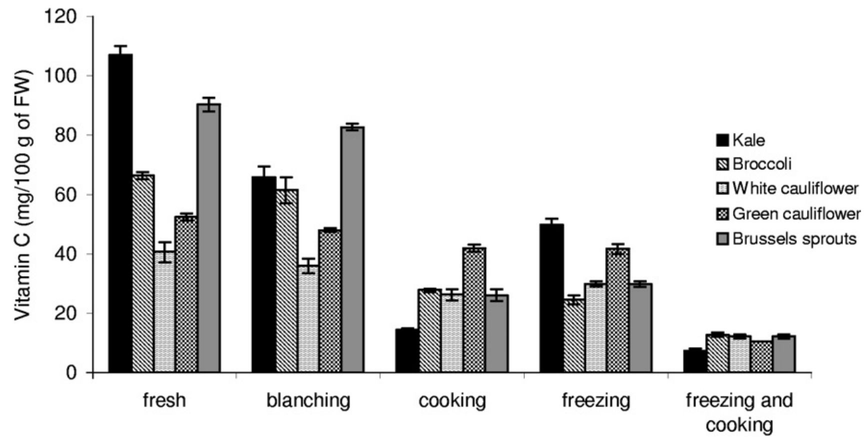

Fig. 1. Vitamin C content in fresh and processed cruciferous vegetables.

after boiling contained between 24% (green cauliflower) and 80% (kale) less than the original content. Vegetables being boiled after freezing showed still higher losses. The variation of vitamin C losses in some vegetable species depends on the degree of fragmentation. To a large extent, results are consistent with those given in reference material (Howard et al., 1999; Puupponen-Pimiä et al., 2003).

The content of carotenoids in the examined vegetables varies from 0.04 mg/100 g in green cauliflower to 2.7 mg/100 g in kale (Table 1). In white cauliflower, these compounds were absent. The results confirm that cruciferous vegetables are not a major dietary source of carotenoids except for kale, which is mainly a source of β-carotene (approx. 3.5–10.0 mg/100 g), and lutein (4.8–13.4 mg/100 g) (Kopsell, Kopsell, Lefsrud, Curran-Celentano, & Dukach, 2004; Kurilich et al., 1999) and contains more carotenoids than other vegetables, e.g. carrots, tomatoes or spinach (Kalt, 2005). For practical reasons, changes in the content of carotenoids in processed vegetables were not examined. However, reference literature indicates that the remaining contents of these substances in boiled, blanched and frozen vegetables is generally around 70–80% (Kalt, 2005; Puupponen-Pimiä et al., 2003; Zhang & Hamauzu, 2004).

Total polyphenols were measured with the FC reagent and expressed as mg of chlorogenic acid per 100 g of fresh product. The greatest quantity of these compounds (773 mg/100 g) was found in kale (Table 1). Similar amounts of polyphenols (300–600 mg/100 g of fresh kale) were found by Manach et al. (2004). Amin, Marjan, and Foong (2004) ranked kale in second place, behind spinach for polyphenol content.

The quantity of polyphenols found in kale was twice more than that in Brussels sprouts and broccoli, containing 331 and 289 mg/per 100 g, respectively. Brussels sprouts and broccoli are also rich in polyphenol compounds, which was confirmed by results of other authors (Cieślik, Gręda, & Adamus, 2006; Kaur & Kapoor, 2002; Podsedek et al., 2006; Vinson, Hao, Su, & Zubik, 1998). Lower polyphenol levels were confirmed by Vinson et al. (1998), who found the content of cauliflower to be about 50% lower than that in broccoli.

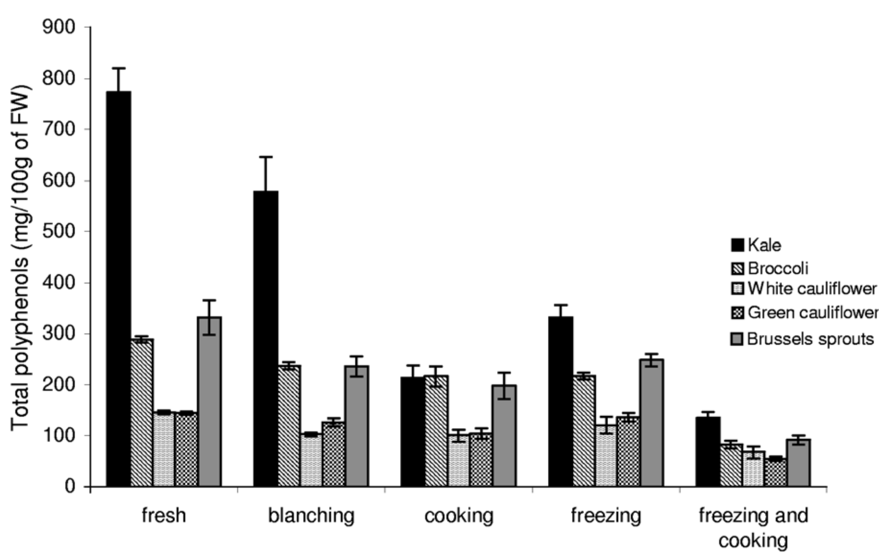

Fig. 2. Total polyphenols content in fresh and processed cruciferous vegetables.

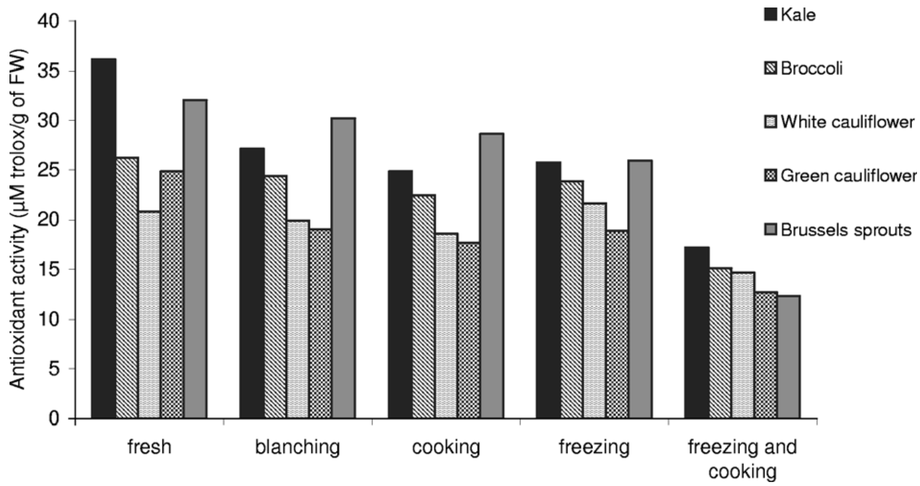

Fig. 3. Antioxidant activity of fresh and processed cruciferous vegetables.

In vegetables subjected to aquathermal processes, a decrease in the content of polyphenols was found compared to raw vegetables (Fig. 2). Generally, the largest changes in the polyphenol content was caused by boiling fresh or previously frozen vegetables. In the case of broccoli, cauliflower and Brussels sprouts, similar changes occurred, with losses reaching 30–40%. Similar results were obtained by Puupponen-Pimiä et al. (2003). After boiling, fresh kale polyphenol, losses were 70% compared to raw kale, while in kale boiled after freezing, losses were around 80%. Blanching of vegetables caused a smaller loss of polyphenols than did boiling, with the exception of kale. The concentration of polyphenols in blanched kale was lower than in other vegetables. Great losses of polyphenols in vegetables during aquathermal processing are due to the dilution of these compounds in water. The dissolution of polyphenols into water depends on time of processing and size of vegetables. Blanching therefore usually causes less loss of polyphenols than does boiling, while losses are usually greatest in leafy vegetables. According to Amin, Norazaidah, and Hainida (2006), less intensive aquathermal processing of leafly vegetables, such as blanching, causes a decrease of 50% in antioxidant activity, while boiling for 15 min causes as much as 82% of antioxidant compounds, including polyphenols, to escape into the water.

Antioxidant losses resulting from aquathermal processing brought about a decrease of antioxidant activity in the vegetables, as measured by the ability to extinguish the ABTS free radical. Antioxidant activity of fresh vegetables ranged from 20.9 μM trolox/g in the case of cauliflower to 36.2 μM trolox/g for kale (Table 1). These values are a little higher than those given in reference literature (Bahorun, Luximon-Ramma, Crozier, & Aruoma, 2004; Cao et al., 1996), which may be a result of different measurement methods. After blanching and boiling, there was a reduction in the antioxidising activity of the vegetables, the largest changes occurring in kale, and smaller changes occurring in Brussels sprouts, broccoli and white cauliflower (Fig. 3). This may be a result of the fact that kale's antioxidant activity results from its high vitamin C content, which shows considerably greater sensitivity to aquathermal processes than the polyphenols and is subjected to greater losses (Kalt, 2005). Other authors observed similar changes of antioxidant activity of the processed vegetables (Amin & Lee, 2005; Borowski et al., 2005; Ninfali & Bacchiocca, 2003; Zhang & Hamauzu, 2004).

In the case of all examined vegetables, except Brussels sprouts, the freezing process does not cause a decrease in antioxidising activity compared to the blanched product. In fact, there was even an increase in antioxidising activity. This may be the result of an increase in the content of phenol compounds, a common response to infection, damage or other stress-inducing factors in plants.

4. Conclusion

Brassica vegetables, such as kale, broccoli, cabbage, Brussels sprouts and cauliflower, are characterised by considerable antioxidant activity, due to their high contents of polyphenol compounds and vitamin C. The greatest activity is shown by kale which, additionally to a particularly high content of these compounds, also contains a substantial quantity of carotenoids.

Technological processes to which these vegetable are usually subjected give rise to changes in antioxidising activity. Boiling of vegetables causes a large decrease in antioxidising activity due to the loss of vitamin C and polyphenols, which dissolve in water. These losses are greatest in the case of leafy or highly fragmented vegetables. The blanching process, due to its short duration, has a smaller effect. Freezing of vegetables leads to greater retention of examined compounds, especially polyphenols, which may even increase during this process as part of the plants' response to stress. Due to their beneficial chemical composition, the examined vegetables should be consumed with as little processing as often as possible.

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