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# The effect of cooking on *Brassica* vegetables

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**Abstract**

Assessing antioxidant intake requires a food antioxidant database. However, cooking may affect antioxidant content due to antioxidant release, destruction or creation of redox-active metabolites. Here, effects of boiling, steaming and microwaving of broccoli, cauliflower, cabbage and choy-sum (Chinese cabbage) were explored by measuring antioxidant contents of raw and cooked vegetables. Cooking water was also tested. For all cooked vegetables, antioxidant content was highest in steamed > boiled > microwaved, and decreased with longer cooking time, regardless of method. All steamed vegetables had higher antioxidant contents than had matching raw vegetables. Effects were variable for boiling and microwaving. Microwaving caused greater antioxidant loss into cooking water than did boiling. Marked losses of anitoxidants occurred in microwaved cabbage and spinach. To assess food antioxidant content/intake accurately, cooking effects need detailed study. Steaming may be the cooking method of choice to release/conserve antioxidants. The cooking water is a potentially rich source of dietary antioxidants.


*Keywords:* Vegetables; Antioxidants; FRAP; Cooking

## 1. Introduction

Diets rich in fruits and vegetables are protective against disease and populations that consume such diets have higher plasma antioxidant status and exhibit lower risk of cancer and cardiovascular disease (Kaliora, Dedoussis, & Schmidt, 2006; Lampe, 1999; Szeto, Kwok, & Benzie, 2004; WCRF & American Institute for Cancer Research, 2007). Whether the health benefits of antioxidant-rich diets are due wholly or in part to their antioxidant capacity is controversial, but increased intake of antioxidants from food is promoted globally as a simple and potentially highly effective means of health promotion (WCRF, 2007). There are many different kinds of antioxidants in foods, and it is impossible to measure all (Benzie & Strain, 2005). Therefore, measurement of 'total' antioxidant capacity of foods, herbs and beverages, and the collation of data into a food antioxidant index is an area of intense research interest (Benzie & Szeto, 1999; Serafini et al., 2003; Szeto, Tomlinson, & Benzie, 2002). Antioxidant capacity of a wide range of foods, from cocoa beans and chocolate, to herbs, spices, fruits, vegetables, beverages and different diets, has been assessed in a range of studies (Othman, Ismail, Ghani, & Adenan, 2007; Pulido, Hernandez-Garcia, & Saura-Calixto, 2003; Saura-Calixto & Goni, 2006; Wong, Leong, & Koh, 2006; Zhou & Yu, 2006). Many dietary agents are cooked, but, to date, the effects of cooking and comparison of cooking methods on antioxidant capacity of foods have not been well studied. In this study, we explored the effects of three cooking methods (boiling, steaming and microwaving) and two cooking times (5 and 10 min), performed under controlled laboratory conditions, on the total antioxidant capacity (as the FRAP value) and total phenolics content of four commonly consumed vegetables: broccoli, cabbage, cauliflower and choy-sum (a dark green Chinese cabbage). These are all members of the genus *Brassica* which belong to the Cruciferous family and are reported to posses both antioxidant and health-promoting properties (Podsedek, 2007; Singh, Upadhyay, Prasad, Bahadur, & Rai, 2007; Verhoeven, Verhagen, Goldbohm, van den Brandt, & Poppel, 1997).

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Cruciferous vegetables, such as those tested in this small study, can be eaten uncooked, but are most commonly eaten after cooking by steaming, boiling or microwaving.

There are different methods for measuring antioxidant capacity of foods. In this study, the FRAP assay, which is a widely used, well validated and highly precise method, was used (Benzie & Strain, 1996; Serafini et al., 2003). In addition, total phenolics were measured using the Folin–Ciocalteu method (Spanos & Wrolstad, 1990). Increased intake of plant-derived phenolics is thought to help lower risk of age-related diseases, such as cardiovascular disease and cancer (Fresco, Borges, Diniz, & Marques, 2006; Kaliora et al., 2006). Therefore, the effect of cooking on both the total antioxidant capacity and the total phenolics content of foods is of interest.

## 2. Materials and methods

Fresh broccoli, cauliflower, choy-sum and cabbage were purchased from a local market. Vegetables were washed under cold running tap water and inedible parts and stems removed. Washed vegetables were blotted, and two 5 g portions of each vegetable were cooked by each of three methods (microwaving, steaming and boiling). Two uncooked portions of each vegetable were also tested. For microwaving, 100 ml (room temperature) of distilled water were added to a 5 g portion of vegetable in a glass beaker and microwaved (750 W) for 5 or 10 min. The vegetable was then drained, cooled for a few minutes at room temperature and homogenized. For steaming, a 5 g portion of vegetable was placed on a steaming rack over 95 °C water in a closed water bath for 5 or 10 min, after which the vegetable was removed, cooled and homogenized as above. For boiling, 100 ml of boiling distilled water were added to a 5 g portion of vegetable in a glass bottle (loosely sealed) and placed in water maintained at 95 °C for 5 or 10 min. After cooking, the vegetable was drained, cooled and homogenized. For homogenization, cooked and uncooked vegetables were placed in a commercial food blender, along with 100 ml distilled water, and homogenized for 1 min. Ten ml portions of mixed homogenate were removed, immediately centrifuged (3000*g*, 15 min), the supernatant filtered (Whatman paper #2) and measured immediately for total antioxidant capacity using the ferric reducing/antioxidant power (FRAP) assay following our established procedure (Benzie & Strain, 1996). Results are presented as μmol/kg of fresh wet weight of vegetable and μmol/l of cooking water (liquor).

The total phenolic content of filtrates and cooking liquors was measured manually using the Folin–Ciocalteau method (Spanos & Wrolstad, 1990). Results were expressed as μmol of gallic acid equivalents (GAE). Samples were stored for no longer than two weeks at −80 °C before measurement.

## 3. Results

In uncooked vegetables, the antioxidant capacity ranking was choy-sum > broccoli > cabbage > cauliflower, with FRAP values of 5634, 3911, 3480 and 2768 μmol/kg, respectively. Cooking style and duration affected antioxidant capacity and ranking, sometimes dramatically. Steaming showed increases for all vegetables, but boiling and microwaving had more variable effects. For example, homogenates made from cabbage and choy-sum after 5 min microwaving had <50% and <70%, respectively, of the antioxidant capacity of matching homogenates of the raw vegetables, while homogenates of 5 min-microwaved cauliflower and broccoli had 75% and 40% higher antioxidant capacity, respectively, than had their uncooked counterparts (Table 1).

Steaming led to an increase in antioxidant capacity of all vegetables. The effect was modest for cabbage (13%) but in cauliflower, broccoli and choy-sum, the FRAP values more than doubled after 5 min of steaming, compared with the uncooked vegetable. Overall, the ranking of antioxidant capacity of 5 min-cooked vegetables was steamed > boiled > microwaved. Vegetables cooked for 10 min had lower antioxidant capacities than had those cooked for 5 min, but the effect of longer cooking time was smaller in steamed vegetables (Table 1).

Results of the total phenolics content of the four vegetables for the uncooked and three cooking methods after 5 min of cooking are presented in Fig. 1. When comparing the effect of the three cooking methods (microwaving, boiling and steaming), steaming showed the highest total phenolics value, followed by boiling and microwave showed the lowest value.

Boiling and microwaving had strong effects on cabbage, broccoli and choy-sum with a decrease of more than 60% in total phenolics whereas, for cauliflower, a loss of 39% was

Table 1
Total antioxidant power (as the FRAP value in μmol/kg fresh wet weight) of raw and cooked vegetables; results are means (SD) of duplicate samples, each tested in duplicate

| Vegetable | Uncooked | Microwaved | | Boiled | | Steamed | |
|---|---|---|---|---|---|---|---|
| | | 5 min cooking | 10 min cooking | 5 min cooking | 10 min cooking | 5 min cooking | 10 min cooking |
| Cauliflower | 2768 (846) | 4851 (465) | 3448 (177) | 6768 (713) | 5200 (873) | 8664 (1013) | 7205 (283) |
| Cabbage | 3480 (385) | 1522 (41) | 880 (57) | 2546 (400) | 1269 (141) | 3920 (167) | 3780 (226) |
| Broccoli | 3911 (671) | 5378 (665) | 4835 (447) | 7176 (854) | 6479 (1342) | 13138 (446) | 12174 (746) |
| Choy Sum | 5634 (86) | 3837 (414) | 2237 (492) | 5743 (1465) | 4850 (480) | 13795 (1793) | 14127 (898) |

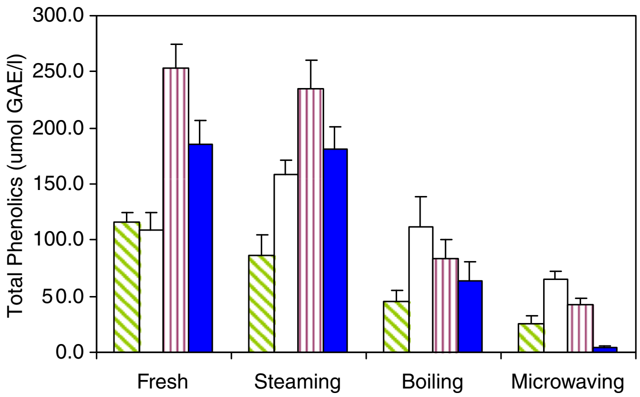


Fig. 1. Total phenolics of the four vegetables uncooked and in three different cooking methods after 5 min of cooking (mean ± SD). Cabbage (diagonal), cauliflower (open), choy-sum (horizontal), broccoli (filled).

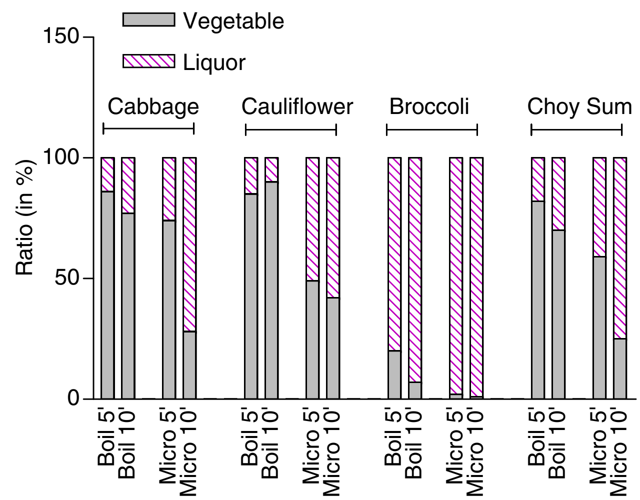


Fig. 3. Total phenolics in the vegetable and cooking water in cabbage, cauliflower, broccoli and Choy-sum after 5 and 10 min of cooking using boiling (written as boil) and microwave (written as micro). The results are presented as ratio (in %) between the total phenolics presented in the vegetable extract and the cooking water.

noticed after microwaving, 4% after boiling and an increase of 45% was noticed after steaming.

The antioxidant capacity and total phenolic content of the liquor from microwaved and boiled vegetables were tested, and relative (%) amounts of antioxidant capacity and phenolics in the homogenates and liquors were calculated. To do this, FRAP values (Fig. 2) or total phenolic content (Fig. 3) of liquor and vegetable homogenate were summed and taken as 100%. Microwaving led to a greater loss of antioxidants into the liquor than did boiling, and longer cooking time enhanced loss of antioxidant and phenolic compounds from the vegetables into the surrounding water.

## 4. Discussion

Many plant-based foods can be eaten raw or after cooking. Cooking can be performed in various ways but, for vegetables, most common are steaming, boiling and, increasingly in modern times, microwaving. Therefore, while there is a growing database of antioxidant capacity of foods from carefully performed work, the effect on antioxidant capacity of the various styles of cooking is an area that has yet to be addressed in detail. The aim of this study was to explore and highlight cooking-related effects on antioxidant capacity of four commonly consumed Brassicca vegetables, cabbage, cauliflower, broccoli and choy-sum, all of which can be eaten raw but are usually cooked by means of boiling, steaming or microwaving.

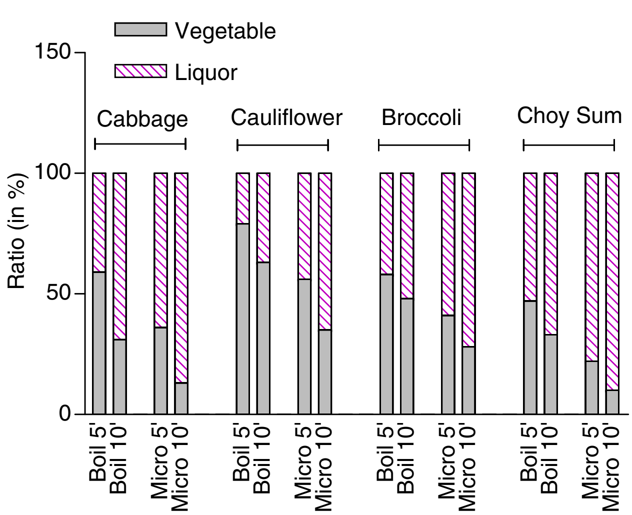


Fig. 2. Relative amounts of total antioxidant capacity in the vegetable homogenates (shaded) and in the associated cooking water (liquor; diagonal lines) after 5 and 10 min of boiling or microwaving.

There are many hundreds of different antioxidants in food, and an index of the total antioxidant capacity of food items would be a useful tool for epidemiological and intervention studies in relation to dietary antioxidants and health. Halvorsen et al. (2006) have published a very comprehensive study of antioxidant capacity (as the FRAP value) of >1000 commonly consumed foods, and this has added greatly to current knowledge to help guide dietary planning for enhanced antioxidant intake through food choices. However, processing of food, such as by thermal treatment, has an effect on a range of characteristics of the plant and includes texture, colour, structure as well as nutritional value (Rechkemmer, 2007).

This study shows that effects of cooking on antioxidant capacity of different vegetables may be different. The antioxidant capacity of choy-sum was unchanged or slightly decreased, while boiling markedly decreased that of the cabbage. On the other hand, steaming led to an apparent increase in vegetable antioxidant capacity. This was modest in cabbage, but 2–3 fold increases were seen in the other vegetables. Boiling of broccoli and cauliflower also led to apparent increases in antioxidant capacity. This effect is perhaps due to production of redox-active secondary plant metabolites or breakdown products, but is highly likely to be related to release of antioxidants from intracellular proteins, changes in plant cell wall structure, matrix modifications and more efficient release of antioxidants during homogenization (Rechkemmer, 2007). For all four vegetable types, when cooked by microwaving, the antioxidant capacity was ~30% lower than when cooked by boiling, and was only ~30–50% that of steamed vegetables.

The effect of thermal treatment was investigated in other studies as well. Turkmen, Sari, and Velioglu (2005) examined the effect of cooking on broccoli antioxidant activity and reported an increase (as shown in this current study) after boiling, microwaving and steaming. In another study, the effects of boiling (16 min), stewing (8 min) and steaming (10 min) were examined on β-carotene and α-tocopherol contents with the different cooking methods leading to a significant release of all-*trans*-β-carotene and α-tocopherol in fresh broccoli (Bernhardt & Schlich, 2006). On the other hand, Zhang and Hamauzu (2004) found that antioxidants and phenolics in broccoli floret and stem decreased with duration of thermal processing, no matter whether the cooking was with conventional methods or microwave heating. Ismail, Marjan, and Foong (2004) reported a decrease in antioxidant capacity of shallots, spinach, cabbage and kale after 1 min of cooking using the β-carotene-linoleate system. These results are similar to the results presented here for cabbage, in which the antioxidant capacity decreased after 5 min of cooking.

It is important to remember, when comparing different studies, that the effect of cooking is likely to depend on several factors, such as the cooking procedure, degree of heating, leaching into the cooking medium, solvent used for extraction, pH and surface area exposed to water and oxygen. For example, increasing water temperature from 50 to 100 °C, and longer cooking time (10, 30, 75 min) had an effect on antioxidant activity measured by the DPPH assay and phenolics content on cabbage, with decreasing antioxidant activity and phenolic content seen as temperature and cooking duration increased (Roy, Takenaka, Isobe, & Tsushida, 2007). In addition, different plants contain various compounds some of which are thermally labile and some are not and therefore, the same cooking method may have different effects on different types of plants (Bernhardt & Schlich, 2006).

Results of this study on total phenolics showed that cooking had a negative effect on phenolics content after 5 and 10 min compared with the raw vegetable. Steaming was the only method that retained the total phenolics content in the vegetables cooked, with an enhancement found in cauliflower. The depletion of total phenolics content after boiling or microwaving could be due to phenolics breakdown during cooking (Lo Scalzo, Genna, Branca, Chedin, & Chassaigne, 2007). During steaming, however, it may be that the temperature were lower than in the other two methods and therefore did not effect the phenolic content as much. It can also be concluded that the phenolic compounds did not contribute to the total increase shown in some cases after boiling or microwaving.

When examining the antioxidant capacity and phenolic content of the water in which the vegetables were cooked, a leakage from the vegetables to the cooking water was noticed. With time (from 5 to 10 min) the total antioxidant capacity and phenolics content decreased in the vegetable and increased in the cooking water. This effect was especially noticed when using microwaving as the cooking method. This effect may be due to the capacity of the microwave, which is higher than those of steaming or boiling, to affect the cell walls of the vegetables and result in more total phenolics content leaching from the vegetable to the cooking water. Price, Casuscelli, Colquhoun, and Rhodes (1998) found that only 18% of total phenolics content was retained inside broccoli after 15 min of boiling, the remainder being largely leached into the cooking water. The results support the data shown here, and indicate that microwave cooking and boiling cause losses of antioxidants and phenolics in the vegetables, and that the phenolics are largely leached into the cooking water.

In this study, cooking conditions were tightly controlled so that comparisons could be made. However, the thermal energy at the cellular level across the three different cooking methods cannot be either measured or standardized. It may be that the lower antioxidant capacity of microwaved vegetables was due to a greater thermal effect, rather than the microwaving *per se*. It must be acknowledged that the samples of the vegetables were small (5 g), and cooking times were standardized to 5 and 10 min for all cooking methods. In the home, a few hundred grammes of vegetable may be steamed or boiled or microwaved for 20–30 min or longer. Furthermore, the effects may be different for different foods.

In conclusion, knowing the antioxidant capacity of foods can help in dietary surveys assessing intake, and in dietary planning for enhanced antioxidant intake. However, such work and the databases generated must consider the effects of processing, storage and cooking on antioxidant capacity. The results presented here clearly demonstrate that cooking can make the antioxidant capacity of cooked food quite different from that of uncooked food. This is most probably caused by a variety of effects, including destruction, release, and transformation of food components. In this study, steaming was shown to retain and/or enhance the vegetable antioxidant capacity and phenolic content best, followed by boiling and then microwaving. Cooking in water seems to cause a leakage of vegetable antioxidants into the cooking water and this effect increases with cooking time. From the results of this study, steaming is the preferred method to enhance the potential to obtain antioxidants from vegetables. In addition, using the cooking water for soups and gravies should be considered for increasing antioxidant intake from vegetables. The effect of cooking on nutrient availability or loss, especially the antioxidant capacity, should be investigated in other vegetables and foods in order to better guide food preparation methods that do not deplete food of their rich antioxidant capacity.

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