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Effects of Thermal Treatment on the Phenolic Content and Antioxidant Activity of Some Vegetables

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Abstract: Vegetables are valuable sources of nutrients and they are also being recognised for their antioxidant properties. To assess the benefits and value of phenolic compounds in extracts, it is imperative to evaluate the effects of different processing methods applied to foods on the ultimate quantities/activities of the phenolics. In this study, the effects of thermal treatment on some vegetables is reviewed.

Key words: Antioxidant activity, phenolics, thermal treatment, nutrients

INTRODUCTION

Phenolic compounds are widely distributed in fruits and vegetables. Epidemiological studies have indicated that regular consumption of foods rich in phenolic compounds such as fruits, vegetables, whole grain cereals, red wine and tea, is associated with reduced risk of cardiovascular diseases, neuro-degenerative diseases and certain cancers (Amin *et al*., 2006; Huang *et al*., 2007; Hunter and Fletcher, 2002; Nilsson *et al*., 2004; Parr and Bolwell, 2000). The beneficial effects derived from phenolic compounds have been attributed to their antioxidant activity, protection and regeneration of other dietary antioxidants (i.e., vitamin E) and chelating of pro-oxidant metal ions. The amount and species of phenolic compounds vary dramatically among vegetables. Therefore, it is important to analyse the composition of phenolic compounds in different vegetables before their health promoting properties can be claimed. According to Ismail *et al*. (2004) each type of vegetable has a different antioxidant activity contributed by different antioxidant components. Some of present studies Muchuweti *et al*. (2007a, b) and Chitindingu *et al*. (2007) showed that some vegetables are rich sources of phenolic compounds that might contribute to their antioxidant activities. These components are affected differently when exposed to different processing techniques.

Vegetable processing such as blanching, canning, sterilising and freezing, as well as cooking is expected to affect the yield, composition and bioavailability of antioxidants (Amin *et al*., 2006; Chu *et al*., 2000; Hunter and Fletcher, 2002) and some nutritional antioxidants such as the heat labile vitamin C. During vegetable processing, qualitative changes, antioxidant breakdown and their leaching into surrounding water may influence the antioxidant activity of the vegetables (Podsedek, 2007). Some antioxidant compounds like ascorbic acid and carotenoids are very sensitive to heat and storage and are lost during

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different vegetable processing steps (Zhang and Hamauzu, 2004). Hence the present review focuses on the effects of processing vegetables on their phenolic contents and antioxidant activities.

ANALYTICAL METHODS FOR TOTAL PHENOLICS CONTENT AND ANTIOXIDANT ACTIVITY

One of the methods that have been developed for quantification of phenolic compounds is the Folin Ciocalteu (Folin C.) method, which is based on the reduction of phosphomolybdic acid in acid by phenols in aqueous alkali. The method is used to determine the total free phenolic groups. We found this method to be fast and simple in most of our studies on the phenolic contents of some fruits (Ndhlala *et al*., 2007, 2008a, b). The method does not differentiate between tannins and many other phenolics that are not tannins. Interfering substances such as ascorbic acid, tyrosine and glucose are also measured (Singleton and Jr. Rossi, 1965; Makkar, 1999). Commercial tannic acid which used to be the common standard for the Folin C method comprises a mixture of gallotannins. Tannic acid has been replaced by gallic acid in its use as a standard because of its heterogeneous structure which consists of a mixture of galloyl esters (Hagerman, 2002).

The radical scavenging assays involve direct measurement of hydrogen atom donation or electron transfer from the potential antioxidant to free radical molecules in lipid free systems. Such assays are available as commercial kits and or a laboratory can prepare their own reagents (Becker *et al*., 2004). The assays for detection of antioxidant activity, scavenging of stable radicals and scavenging of short lived radicals include; the Ferric Reducing Antioxidant Power (FRAP) assay, Trolox Equivalent Antioxidant Capacity (TEAC) assay, 1, 1-diphenyl-2-picrylhydrazyl radical (DPPHÿ) assay, the Oxygen Radical Absorbance Capacity (ORAC) assay and model systems. The evaluation of antioxidants in model systems is based on measuring changes in the concentration of compounds being oxidized, on depletion of oxygen or on the formation of oxidation products (Becker *et al*., 2004; Kumazawa *et al*., 2004).

THERMAL TREATMENT

Vegetables are usually processed by the application of dry or moist heat to improve their organoleptic properties or extend their shelf life. This technique has been known from time immemorial to reduce the quantity of nutrients in foods, especially the heat labile vitamins. Hence, consumer demand for nutritious foods, which are minimally and naturally processed, has led to interest in some non thermal technologies. These non thermal technologies are not commonly used by industries in developing countries. Therefore, in most of the processing unit operations heat is applied. When subjected to heat treatment vegetables are affected differently.

EFFECTS ON TOTAL PHENOLIC CONTENT

In most studies on the effects of heat treatment on the total phenolic content, the results are contradicting. Some researchers reported an increase in the phenolic content whilst others observed a decrease. In some researches an attempt was made to simulate the actual cooking conditions and as a result in some papers the cooking conditions were not explicitly specified. The data generated using the actual cooking conditions is beneficial when

Table 1: Effects of different heat treatments on the total phenolic content of some vegetables

Vegetables	Treatments	Effects	Percentage of increase/ decrease/no change	Source
Red kidney bean	Conventional cooking after soaking in sodium bicarbonate	Decrease	78.70	Yasmin *et al.* (2008)
Broad beans	Steam cooking fresh material	Decrease	16	Wolosiak *et al.* (2009)
	Steam cooking frozen material	Decrease	2-8	
Chinese cabbage	Convectional cooking	Decrease	2	Lima *et al.* (2009)
Green asparagus	Convectional cooking	Increase	23	Fanasca *et al.* (2009)
Red cabbage	Convectional cooking	Decrease	45.7-66.9	Podsedek *et al.* (2008)
	Convectional cooking+decreasing cooking water by 50%	Decrease	2.7-14.5	
	Convectional cooking +shortening cooking time by 50%	Decrease	0-2.2	
	Steam cooking	Decrease	10	
Broccoli florets	Convectional cooking and microwaving	Decrease	71.6-71.9	Zhang and Hamauzu (2004)
Broccoli stems	Convectional cooking and microwaving	Decrease	42.2-44.4	
Broccoli	Convectional cooking	Decrease	41.30	Gawlik-Dziki (2008)

included in food composition databases as it will enable the users to evaluate the actual amounts of bioactive compounds consumed. Effects of different heat treatments on the total phenolic content of some vegetables are shown in Table 1.

Lima *et al.* (2009) observed a dramatic loss of phenolic content on convectional and organic grown food as a result of thermal treatment. Significant differences between foods obtained by the two cultivation procedures were not observed. Organic and minimally processed foods are mostly preferred because of the nominal changes to the nutrients and non-nutrient components of foods. Hence, the consumption of organically grown and minimally processed foods will entail food that is free from toxicants and nutritious.

Cooking asparagus was found to increase total phenols by 23% (Fanasca *et al.*, 2009). The results also indicate that the effect of cooking process was significant and more pronounced than the effect of cultivars. The study was in agreement with that by Lima *et al.* (2009) in which the type of food did not have a profound effect on the phenolic content. Ascorbic acid of asparagus was greatly reduced by the cooking process (Fanasca *et al.*, 2009). The vitamin contributes to the total phenols as it is capable of reducing the active reagent used in the analysis of phenols. Hence processes that affect ascorbic acid will ultimately reduce the total phenolic content.

Decreasing temperature of processing was also found to preserve 80-100% of phenolic content in some vegetables (Roy *et al.*, 2007). Convectional and steam cooking caused significant reduction in total phenol content of red cabbage and decreasing cooking water and time by half led to better retention (Podsedek *et al.*, 2008). The short cooking time used in steam cooking preserves the antioxidant components of the vegetables than convectional cooking.

Total phenolic content of selected vegetables (peas, carrot, spinach, cabbage, cauliflower, yellow turnip and white turnip) was found to be generally decreased by boiling, frying and microwave cooking (Sultana *et al.*, 2008). Microwave cooking was found to cause more significant changes than the other methods of processing. Thus an appropriate method might be sought for the processing of such vegetables to retain their antioxidant components at maximum level.

Normal cooking temperatures were found to detrimentally affect phenolic content of spinach, *komatsuna*, *haruna*, *chingensai*, cabbage and Chinese cabbage (Roy *et al.*, 2007). The same authors noted that the degree of thermal processing affects not only the content of phenolic compounds in vegetables but also beneficial biological effects associated with these compounds. Soaking, boiling and steaming processes caused significant ($p<0.05$) decreases in total phenolic content of commonly consumed Cool Season Food Legumes (CSFL's), including green pea, yellow pea, chickpea and lentil. However steaming treatments resulted in a greater retention of TPC values in all tested CSFL's as compared to boiling treatments (Xu and Chang, 2008).

Turkmen *et al.* (2005) observed that cooking affected total phenolics content of some vegetables significantly ($p<0.05$). After cooking, total activity increased or remained unchanged depending on the type of vegetable but not type of cooking. The results of the study contradicts some studies (Lima *et al.*, 2009; Fanasca *et al.*, 2009) were the type of vegetable did not have any effect on the phenolic content.

Blanching up to 15 min was found to cause losses of phenolic content, depending on the species of spinach (Amin *et al.*, 2006). Semi-drying of tomatoes was found to lower the phenolic content by 30% but drying of pepper gave contradicting results (Toor and Savage, 2006). Vega-Galvez *et al.* (2009) observed that the total phenolic content of red pepper content decreased as air-drying temperature decreased.

EFFECTS ON ANTIOXIDANT ACTIVITY

Phenolic compounds and other reductones in vegetables contribute to their antioxidant activities; hence processes that affect the total phenolic content will also affect antioxidant activity. Effects of different heat treatments on the antioxidant activity of some vegetables are shown in Table 2.

Canning is a common industrial process for preserving vegetables and was shown to cause a more pronounced loss of antioxidant activity on frozen vegetables than fresh vegetables (Murcia *et al.*, 2009). The reduction in antioxidant activity as a result of canning might be caused by the high temperatures used during sterilisation and the degradation of phenolic compounds as a result of storage.

Faller and Fialho (2009) evaluated the effect of boiling, microwaving and steaming on fresh conventional and organic retail vegetables (potato, carrot, onion, broccoli and white cabbage). Organic vegetables showed higher sensitivity to heat processing than did conventionally grown vegetables. In contrast significant differences between foods obtained by the two cultivation procedures were not observed by Lima *et al.* (2009). In general, cooking was found to lead to reductions in the antioxidant capacity for most vegetables, with small differences between the cooking methods applied (Faller and Fialho, 2009). In his

Table 2: Effects of different heat treatments on the antioxidant activities of some vegetables

Vegetables	Treatments	Method of analysis	Effects	Percentage of increase/decrease/ no change	Reference
Broad beans	Steam cooking fresh material	[1]ABTS·+	Decrease	11	Wolosiak *et al.* (2009)
	Steam cooking frozen beans	ABTS·+	Decrease	10-17	Wolosiak *et al.* (2009)
Green asparagus	Convectional cooking	[2]TEAC	Increase	16	Fanasca *et al.* (2009)
Red cabbage	Steam cooking	TEAC	Decrease	5-20	Podsedek *et al.* (2008)
Spinach, *komatsuna, haruna, chingensai* and white cabbage	Mild heating (50°C, (10-30 min)	[3]DPPH· Deoxyribose assay	Decrease	0-20	Roy *et al.* (2007)
Tomatoes	Semi-drying	TEAC	Decrease	53	Toor *et al.* (2006)
Broccoli	Convectional cooking	[4]β-CLAMS	Decrease	4.80	Gawlik-Dziki (2008)
Broccoli	Steam cooking	[5]ORAC	Increase	230	Roy *et al.* (2009)

[1]ABTS.+-2,2'-azino-bis [3-ethylbenzothiazoline-6-sulphonic acid] ,[2]TEAC: Trolox equivalent antioxidant capacity, [3]DPPH.-1,1-diphenyl-2-picrylhydrazyl, [4]ß-CLAMS-ß- carotene linoleic acid model system, [5]ORAC: Oxygen radical absorbance capacity

studies, Sultana *et al.* (2008) reported that different cooking methods affected the antioxidant properties of vegetables differently, with microwave treatment exhibiting more deleterious effects when compared with those of other treatments.

Normal cooking temperatures detrimentally affected the antiradical and anti-proliferative activities of spinach, *komatsuna*, *haruna*, *chingensai*, cabbage and Chinese cabbage. However, mild heating of vegetable juices (50°C, 10-30 min) preserved the antioxidant activity and cell proliferation inhibition activities (Roy *et al.*, 2007). The results showed that foods should be minimally processed so as to preserve the compounds that contribute to their antioxidant and cell proliferation inhibition activities. Hence consumer demand for safe and nutritious food has led to the development of a number of non thermal food preservation techniques.

Xu and Chang (2008) reported the effects of soaking, boiling and steaming processes on the antioxidant activity in commonly consumed Cool Season Food Legumes (CSFL's), including green pea, yellow pea, chickpea and lentil. As compared to original unprocessed legumes, all processing steps caused significant ($p<0.05$) decreases in DPPH free radical scavenging activity in all tested CSFL's. All soaking and atmospheric boiling treatments caused significant ($p<0.05$) decreases in oxygen radical absorbing capacity (ORAC). However, pressure boiling and pressure steaming caused significant ($p<0.05$) increases in ORAC values. Steaming treatments resulted in a greater retention of DPPH and ORAC values in all tested CSFL's as compared to boiling treatments. Steam cooking was also reported to increase the antioxidant activity of broccoli by 230% (Roy *et al.*, 2007). Therefore, steam cooking should be used instead of boiling the vegetables for prolonged periods. When cooking, time and temperature combinations should be closely monitored, as prolonged exposure of vegetables to cooking conditions may lead to deleterious effects.

A study by Turkmen *et al.* (2005) on pepper, peas and broccoli gave interesting results, were after cooking total antioxidant activity increased or remained unchanged depending on the type of vegetable but not type of cooking. Amin *et al.* (2006) also reported that blanching up to 15 min may affect losses of antioxidant activity, depending on the species of spinach (Amin *et al.*, 2006). The type of vegetable or species differences might be due to the easy of extraction of phenolic compounds from different plant matrices. Processes, such as freezing plant material prior to cooking were found to reduce antioxidant activities to some greater extent. Processes applied on fresh material reduced the activity against $ABTS^{\bullet+}$ to a smaller extent (cooking by 11% and freezing by around 20%), while cooking frozen beans caused a further decrease by 10-17% (Wolosiak *et al.*, 2009).

In most studies on effects of heat treatment on vegetables, the antioxidant activity decreased as a result of processing, in contrast Fanasca *et al.* (2009) reported an increase in antioxidant activity. In his study on antioxidant properties of raw and cooked spears of green asparagus cultivars, the cooking process increased the antioxidant activity by 16%. Podsedek *et al.* (2008) reported that steam-cooking is recommended to prevent the major loss of scavenging activity, because under these conditions, the corresponding TEAC (Trolox Equivalent Antioxidant Capacity) values were reduced only by 5-20%. Roy *et al.* (2007) and Xu and Chang (2008) also reported an increase in antioxidant activity as a result of steam cooking.

The effects of different cooking methods (boiling, frying and microwave cooking) on the antioxidant activity of some selected vegetables (peas, carrot, spinach, cabbage, cauliflower, yellow turnip and white turnip) were assessed by measuring the reducing power and percentage inhibition in linoleic acid system (Sultana *et al.*, 2008). The author reported contradicting results found by most researchers as there was a significant ($p<0.05$) increase in reducing power as a result of frying. However, boiling and microwave cooking did not affect reducing power. Inhibition of peroxidation was also increased by boiling and frying, whereas, in contrast it was decreased by microwave cooking.

CONCLUSION

The results of the present investigations showed that all the thermal treatment methods affected the total content of phenolics and antioxidant properties of the vegetables; however, other treatments such as microwave treatment exhibited more deleterious effects than the other methods. Thus appropriate methods might be sought for the processing of such vegetables to retain their antioxidant components at maximum level. Most losses are due to the leaching of antioxidant compounds from the vegetables into the cooking water during the prolonged exposure to water and heat. Therefore, it is vital to use less water and cooking time and also to consume the water used for boiling so as to obtain the optimum benefits of bioactive compounds present in vegetables.

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