

# Effect of different blanching times on antioxidant properties in selected cruciferous vegetables

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**Abstract:** This study aimed to evaluate the effect of different blanching times on the antioxidant properties (antioxidant and free radical scavenging activities) and phenolic content of selected cruciferous vegetables. The study revealed that a 10-min blanching time had a significant effect ( $p < 0.05$ ) on the antioxidant properties and phenolic content of all the vegetables except for cabbage and mustard cabbage. The loss of antioxidant activity was highest in Chinese cabbage (40%) after 15 min of blanching, followed by cabbage (27%), Chinese white cabbage (19%), mustard cabbage (9%) and red cabbage (4%). Red cabbage had lost a total of 40% scavenging activity after 15 min of blanching followed by Chinese cabbage (38%), cabbage (36%), mustard cabbage (23%) and Chinese white cabbage (11%). Only Chinese cabbage showed an increase ( $p < 0.05$ ) in total phenolic content after 15 min of blanching compared with other vegetables. Minimal heat treatment through blanching process is recommended to prevent the major loss of antioxidant properties and phenolic content in selected cruciferous vegetables.

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**Keywords:** cruciferous vegetables; blanching; antioxidant properties; phenolic content

## INTRODUCTION

Vegetables act as a source of natural antioxidants; they help in defense mechanisms by removing potentially damaging free radicals that cause various human diseases. Studies have found that vegetables have high antioxidant activities.<sup>1,2</sup> There is a considerable amount of epidemiological evidence indicating an association between diets rich in fresh fruits and vegetables and a decreased risk of cardiovascular disease and certain cancers. It is generally assumed that the responsible dietary constituents contributing to these protective effects are vitamins, minerals, dietary fiber and polyphenols.<sup>3,4</sup>

Cruciferous vegetables such as cabbage are among the most important dietary vegetables consumed in Malaysia owing to their availability in local markets, cheapness and consumer preference. Most cruciferous vegetables undergo cooking processes rather than being eaten raw. This process involves heat and exposure to oxidation.<sup>5</sup> Blanching by immersion in boiling water or by treatment with steam is one of the cooking practices often used. Blanching results in inactivation of enzymes, softening of the structure of vegetables and also changes in mechanical properties such as flexibility and strength during the first 12 min of blanching.<sup>6</sup> Gil *et al*<sup>7</sup> have shown that household cooking results in the

decrease in total antioxidant activity in fresh-cut spinach.

The antioxidant status of fruits and vegetables is potentially affected by changes that occur during food processing (harvesting, preparation and handling).<sup>8</sup> Several groups have carried out studies on the loss of antioxidant activity and responsible components during processing and storage.<sup>7,9–12</sup>

The study aimed to investigate the effect of different blanching times on the antioxidant activity and total polyphenol content in selected fresh cruciferous vegetables, commonly consumed in Malaysia as prepared in boiling water using either fresh or refrigerated produce, with the hope that the findings would guide future practice on suitable blanching times in order to minimize the degradation of antioxidant activity in fresh vegetables.

## MATERIALS AND METHODS

### Vegetables

Samples of vegetables, namely red cabbage (heading cabbage) (*Brassica oleracea* var *capitata rubra*), Chinese cabbage (Cantonese name: Wong baak) (non-heading cabbage) (*Brassica rapa pekinensis* var *cylindrica*), green cabbage (heading cabbage) (*Brassica oleracea* var *capitata*), mustard cabbage (non-heading cabbage)

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(*Brassica juncea* var *rugosa*) and Chinese white cabbage (Cantonese name: Pak choi) (non-heading cabbage) (*Brassica rapa* var *chinensis*) were purchased from a wet market at Sri Serdang, Selangor, Malaysia.

### Chemicals

Tween 20, linoleic acid, DPPH (2,2-diphenyl-1-picrylhydrazyl), gallic acid and  $\beta$ -carotene were purchased from Sigma Chemical (St Louis, MO, USA), Folin–Ciocalteu reagent and methanol from Merck (Darmstadt, Germany), chloroform from BDH Chemicals (Poole, UK) and sodium bicarbonate from May and Baker (Dagenham, UK). Other chemicals used were of analytical grade.

### Preparation of samples

After purchase, all the vegetables were brought to the laboratory to be washed and weighed. One kilogram of each type of vegetable was used for this study. Each sample was chopped into small pieces and divided into two portions, 600 g for blanching treatment and 400 g for fresh sample without any treatment. The blanched and fresh vegetables were then freeze-dried in a freeze-dryer (Virtis, Gardiner, New York, USA). The samples were ground into small particles in a blender (MX-291N, National, Selangor, Malaysia) and then kept at  $-20^{\circ}\text{C}$  for further analysis. Extraction of each ground sample (fresh, 5, 10 and 15 min blanched) was carried out by mixing with deionized water in a ratio of 1:10 (w/w). The mixture was shaken using a Unimax 1010 orbital shaker (Heidolph Instruments, Schwabach, Germany) at 200 rpm for 1 h at room temperature ( $28^{\circ}\text{C}$ ). The extracts were then filtered through a Whatman No 4 filter-paper (Whatman, Maidstone, UK) to obtain a clear solution.

### Blanching

For blanching treatment, the vegetables were then randomly divided into three homogeneous groups (200 g for each group). Samples were blanched for three different times, 5, 10 and 15 min. Blanching was done by simmering the sample in 1000 ml of hot water ( $98^{\circ}\text{C}$ ). The ratio of sample to water was 1:5 (w/w). After blanching, the samples were cooled to room temperature under running tap water.

### Determination of antioxidant activity

The total antioxidant activity of the sample extracts and control (deionized water) were determined according to the  $\beta$ -carotene bleaching assay following the procedure described by Velioglu *et al*<sup>13</sup> with slight modifications. In these modifications, non-oxygenated distilled water was used and the absorbance was read at 15- instead of 10-min intervals to monitor the rate of bleaching of  $\beta$ -carotene. For a typical assay, 1 ml of  $\beta$ -carotene ( $0.2 \text{ mg ml}^{-1}$  in chloroform) was added to a round-bottomed flask (500 ml) containing 0.02 ml of linoleic acid and 0.2 ml of Tween 20. The mixture was evaporated to dryness under vacuum at  $40^{\circ}\text{C}$  using a Laborata 4000 rotary evaporator

(Heidolph Instruments) at 90 rpm for 10 min. Then, 100 ml of distilled water were added to the residue and the mixture was shaken to form a liposome solution. A 5-ml aliquot of the liposome solution was then added to 0.2 ml of distilled water (as a control) or corresponding vegetable extracts at  $10 \text{ mg ml}^{-1}$ . The samples were then subjected to thermal autoxidation in a Model 810 water-bath (Protech, Kuala Lumpur, Malaysia) at  $45^{\circ}\text{C}$  for 2 h. The absorbance of the mixture was monitored using a UV1601 UV-visible spectrophotometer (Shimadzu, Rydalmere, New South Wales, Australia) at 470 nm. The absorbance was read every 15 min against a blank which consisted of emulsion without  $\beta$ -carotene. All samples were measured in duplicate.

The antioxidant activity (*AA*) was calculated according to the following equation:

$$AA (\%) = [1 - (A_0 - A_t)/(A_0^0 - A_t^0)] \times 100$$

where  $A_0$  and  $A_0^0$  = absorbance values measured at zero time of incubation for test sample and control, respectively, and  $A_t$  and  $A_t^0$  = absorbance measured in the test sample and control, respectively, after incubation for 120 min.

### Determination of free radical scavenging activity

The free radical scavenging activity of vegetable extracts and the standard (ascorbic acid) was determined according to the DPPH free radical scavenging assay procedure described by Tang *et al*.<sup>14</sup> An aliquot of 200  $\mu\text{l}$  of sample extract ( $10 \text{ mg ml}^{-1}$ ) or ascorbic acid was added to 1 ml of 0.2 mM DPPH in anhydrous methanol. The mixture was shaken vigorously and left to stand for 30 min at room temperature in the dark. The absorbance at 517 nm with deionized water as the blank was measured using a spectrophotometer (Shimadzu, Rydalmere, New South Wales, Australia). A 20  $\mu\text{l}$  volume of deionized water was mixed with 1 ml of DPPH serving as the control. Triplicate samples were analyzed. The radical scavenging activity was calculated as follows:

$$\text{Scavenging activity (\%)} =$$

$$= \left( 1 - \frac{\text{absorbance of sample at } 517 \text{ nm}}{\text{absorbance of control at } 517 \text{ nm}} \right) \times 100$$

### Determination of total phenolic content

The total phenolic content of vegetable extracts in deionized water was determined by the Folin–Ciocalteu assay following the procedure described by Velioglu *et al*<sup>13</sup> with some modifications. In this study, vegetable extracts were filtered through a Whatman No 4 filter-paper instead of using centrifugation to obtain a clear solution. The volumes of the reagents used in this study were double those in the previous method. The sample was prepared at a concentration of 5 rather than  $1 \text{ mg ml}^{-1}$ . For a

typical assay, 0.1 mg of sample was extracted with 20 ml of deionized water by placing the mixture on an orbital shaker at 200 rpm for 2 h. The extract was filtered through a Whatman No 4 filter-paper to obtain a clear solution. A 200  $\mu$ l volume of clear extract was mixed with 1.5 ml of Folin-Ciocalteu reagent (previously diluted 10-fold with distilled water) and then left to stand for 5 min at room temperature. Then, 1.5 ml of sodium bicarbonate (60 g l<sup>-1</sup>) was added to the mixture containing vegetable extract and Folin-Ciocalteu reagent and left to stand for 90 min at room temperature before the absorbance was measured at 725 nm. All assays were performed in duplicate.

Gallic acid was used as the standard for estimating the total phenolic content of the vegetables studied. A calibration curve (0.001–0.007 mg ml<sup>-1</sup>) was plotted using gallic acid. The total phenolic contents of the vegetable extracts were expressed as gallic acid equivalents in g kg<sup>-1</sup> fresh weight.

### Statistical analysis

Results obtained were expressed as mean  $\pm$  standard deviation. One-way ANOVA was used to analyze the mean differences between samples with different times of blanching treatments at a significance level of  $p < 0.05$ . The Social Package for Social Science version 10.0 (SPSS Inc, Chicago, IL, USA) was used for statistical analysis.

## RESULTS

### Effect of different blanching times on the antioxidant activity

The blanching effect of cruciferous vegetables on the  $\beta$ -carotene bleaching rates is shown in Fig 1a–e. The results indicate that not all fresh cruciferous vegetables possessed a higher antioxidant capacity than blanched vegetables. Except for red cabbage, cabbage and mustard cabbage, the other samples studied, when blanched for 15 min, showed a higher bleaching rate compared with the samples blanched for 5 and 10 min. A lower bleaching rate was observed with fresh Chinese cabbage than with the other cruciferous vegetables studied (Fig 1b). A more stable trend could be observed in the decrease in antioxidant activity

for Chinese cabbage (fresh and blanched). Figure 1e shows a higher bleaching rate for fresh and blanched (5, 10 and 15 min) Chinese white cabbage than for the other samples. This shows that Chinese white cabbage had a low antioxidant activity.

The antioxidant activity of red cabbage decreased to 41% after blanching for 5 min (Table 1). A further decrease in antioxidant activity could be observed after red cabbage was blanched for 10 min, but after 15 min of blanching the antioxidant activity was slightly increased to 39%. No significant difference could be found in the LSD test for the means of antioxidant activity between red cabbage blanched for 5, 10 and 15 min. There was a significant difference ( $p < 0.05$ ) in the means of antioxidant activity of fresh and blanched red cabbage.

No significant difference was observed for Chinese cabbage that was blanched for 5 and 10 min. However, the antioxidant activity of Chinese cabbage was decreased significantly ( $p < 0.05$ ) after 15 min of blanching (Table 1). The results of the one-way ANOVA showed a significant difference ( $p < 0.05$ ) in the mean antioxidant activity between fresh and Chinese cabbage that was blanched for 5, 10 and 15 min. Furthermore, a significant difference ( $p < 0.05$ ) was found in the mean antioxidant activity of Chinese cabbage blanched for 15 min and the samples blanched for 5 and 10 min. However, no significant difference was found between Chinese cabbage that was blanched for 5 and 10 min.

For cabbage, after blanching for 5 and 10 min, the antioxidant activity remained fairly stable (Table 1). However, a significant decrease ( $p < 0.05$ ) in the antioxidant activity of cabbage after blanching for 15 min was observed. No significant difference was found between fresh cabbage and cabbage that was blanched for 5 and 10 min. The mean antioxidant activity of cabbage blanched for 15 min was significantly different ( $p < 0.05$ ) to that of the other blanched samples.

A negligible reduction in antioxidant activity was observed in mustard cabbage after blanching for 5, 10 and 15 min compared with the fresh sample. After blanching for 10 and 15 min, the antioxidant activity had dropped to 64 and 63%, respectively (Table 1). ANOVA showed that there was no significant difference in the means of antioxidant

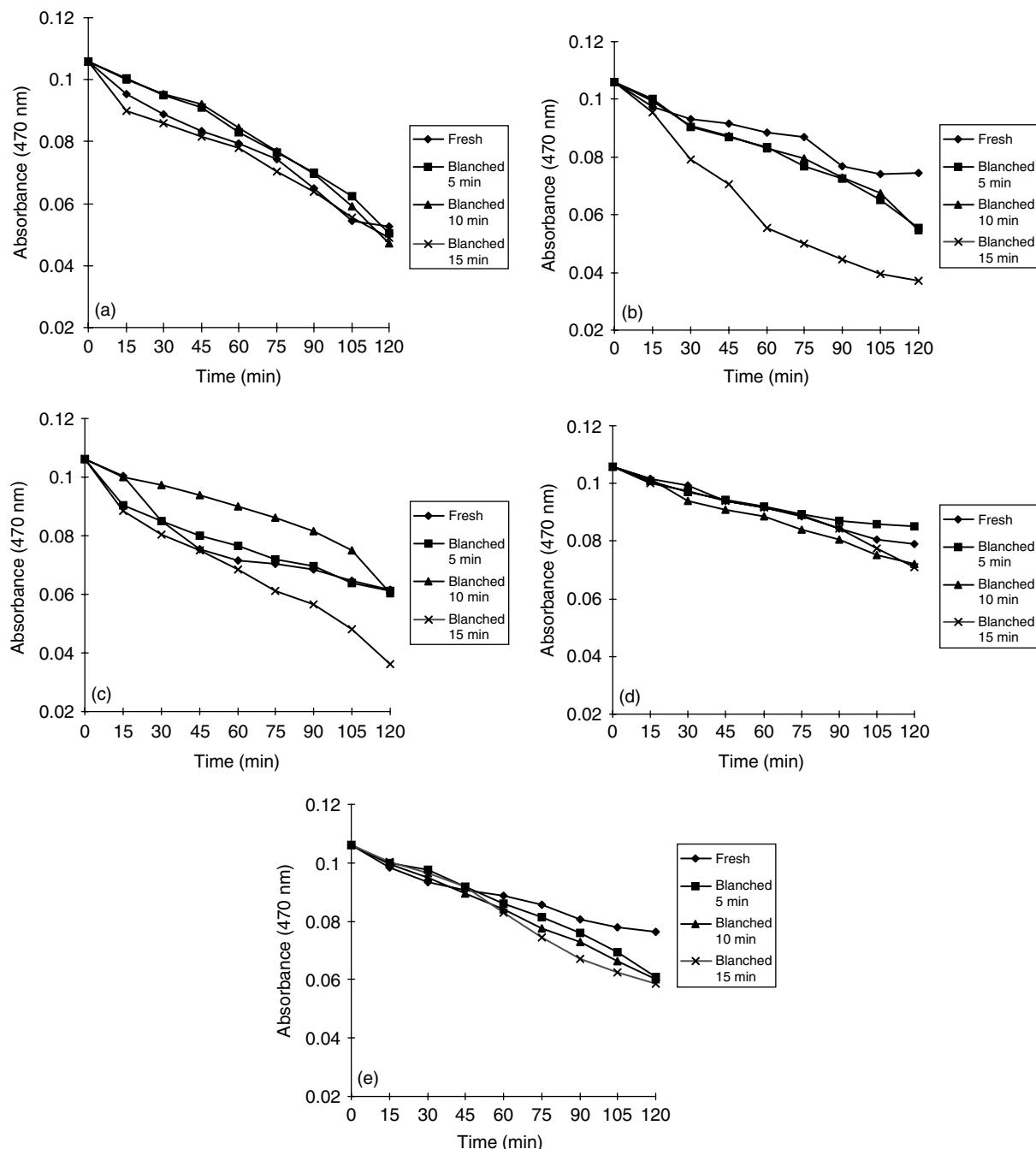
Table 1. Total antioxidant activity of fresh and blanched vegetables extracts at 10 mg ml<sup>-1</sup> using  $\beta$ -carotene bleaching assay

Treatment	Antioxidant activity (%)				
	Red	Chi	Cab	Mus	Whi
Fresh	43.68 $\pm$ 3.76 <sup>b</sup>	66.49 $\pm$ 0.75 <sup>c</sup>	52.66 $\pm$ 0.75 <sup>b</sup>	71.28 $\pm$ 4.51 <sup>b</sup>	68.62 $\pm$ 3.76 <sup>b</sup>
Blanched 5 min	40.96 $\pm$ 2.26 <sup>a</sup>	46.28 $\pm$ 5.27 <sup>b</sup>	52.13 $\pm$ 1.51 <sup>b</sup>	67.66 $\pm$ 2.40 <sup>a,b</sup>	52.13 $\pm$ 4.51 <sup>a</sup>
Blanched 10 min	37.23 $\pm$ 0.00 <sup>a</sup>	45.21 $\pm$ 0.75 <sup>b</sup>	51.60 $\pm$ 2.26 <sup>b</sup>	63.83 $\pm$ 0.00 <sup>a,b</sup>	51.07 $\pm$ 6.02 <sup>a</sup>
Blanched 15 min	39.36 $\pm$ 0.00 <sup>a</sup>	26.60 $\pm$ 0.00 <sup>a</sup>	25.53 $\pm$ 3.01 <sup>a</sup>	62.77 $\pm$ 3.01 <sup>a</sup>	49.47 $\pm$ 0.75 <sup>a</sup>

Red = red cabbage, Chi = Chinese Cabbage, Cab = cabbage, Mus = mustard cabbage, Whi = Chinese white cabbage.

The antioxidant activity was calculated based on the equation in the section 'Determination of antioxidant activity'. Values are expressed as mean  $\pm$  standard deviation of three replicate measurements.

a,b,c Values with different superscripts were significantly different by the LSD test at the level of  $p < 0.05$ .



**Figure 1.** Antioxidant activity of fresh and blanched (a) red cabbage, (b) Chinese cabbage, (c) cabbage, (d) mustard cabbage and (e) Chinese white cabbage extracts at  $10 \text{ mg ml}^{-1}$  using a  $\beta$ -carotene bleaching assay.

activity between all the different mustard cabbage extracts tested. There was a significant difference ( $p < 0.05$ ) in the means of antioxidant activity of fresh mustard cabbage and mustard cabbage blanched for 15 min. However, there was no significant difference in the means of antioxidant activity between mustard cabbage that was blanched for 5 and 10 min.

After blanching for 5 min, the antioxidant activity of fresh Chinese white cabbage had decreased to 52% (Table 1). No significant difference in antioxidant activity was observed when the vegetable was blanched for 10 and 15 min. One-way ANOVA showed a significant difference ( $p < 0.05$ ) between fresh and

Chinese white cabbage that was blanched for 5, 10 and 15 min. However, no significant difference was found between samples that were blanched for 5, 10 and 15 min.

#### Effect of different blanching times on the free radical scavenging activity

Table 2 summarizes the means of free radical scavenging activity of the fresh and blanched cruciferous vegetables. The results clearly show a decrease in radical scavenging activity of all samples after blanching for up to 15 min. Fresh red cabbage showed a reduction in radical scavenging activity from 72 to 61% after blanching for 5 min. Red cabbage that was blanched

**Table 2.** Free radical scavenging activity of fresh and blanched vegetables extracts at 10 mg ml<sup>-1</sup> using DPPH free radical scavenging assay

Treatment	Radical scavenging activity (%)				
	Red	Chi	Cab	Mus	Whi
Fresh	72.23 ± 0.77 <sup>c</sup>	50.32 ± 0.17 <sup>d</sup>	49.68 ± 6.63 <sup>c</sup>	36.99 ± 0.52 <sup>c</sup>	21.15 ± 1.01 <sup>c</sup>
Blanched 5 min	61.11 ± 4.72 <sup>b</sup>	32.68 ± 3.64 <sup>c</sup>	42.88 ± 0.25 <sup>c</sup>	26.05 ± 0.87 <sup>b</sup>	20.54 ± 0.15 <sup>b,c</sup>
Blanched 10 min	28.84 ± 2.56 <sup>a</sup>	22.44 ± 5.82 <sup>b</sup>	29.05 ± 0.27 <sup>b</sup>	12.98 ± 0.32 <sup>a</sup>	18.48 ± 1.05 <sup>b</sup>
Blanched 15 min	32.01 ± 1.19 <sup>a</sup>	12.29 ± 1.50 <sup>a</sup>	13.74 ± 4.02 <sup>a</sup>	13.59 ± 1.70 <sup>a</sup>	10.08 ± 1.89 <sup>a</sup>

Red = red cabbage, Chi = Chinese Cabbage, Cab = cabbage, Mus = mustard cabbage, Whi = Chinese white cabbage.

Values are expressed as mean ± standard deviation of three replicate measurements.

a,b,c,d Values with different superscripts were significantly different by the LSD test at the level of  $p < 0.05$ .

for 10 and 15 min yielded radical scavenging activities of 29 and 32%, respectively (Table 2). ANOVA indicated that there was a significant difference ( $p < 0.05$ ) in the means of radical scavenging activity between fresh and other samples of red cabbage. However, no significant difference was found between red cabbage that was blanched for 10 and 15 min.

The radical scavenging activity Chinese cabbage dropped from 50 to 33% after 5 min of blanching and further decreased to 22 and 12% after 10 and 15 min of blanching, respectively (Table 2). ANOVA showed a significant difference ( $p < 0.05$ ) in the means of radical scavenging activity between fresh Chinese cabbage before and after blanching.

Cabbage showed a decrease in radical scavenging activity after blanching for 5 min (43%), 10 min (29%) and 15 min (14%) (Table 2). One-way ANOVA indicated a significant difference ( $p < 0.05$ ) in the means of radical scavenging activity between the fresh cabbage and samples blanched for 10 and 15 min. However, no significant difference was found between fresh cabbage and cabbage blanched for 5 min.

After 5, 10 and 15 min of blanching, the radical scavenging activity of mustard cabbage had decreased to 26, 13 and 14%, respectively (Table 2). ANOVA showed a significant difference ( $p < 0.05$ ) in the means of radical scavenging activity of the fresh vegetable and mustard cabbage blanched for 5, 10 and 15 min. No significant difference was observed between mustard cabbage that was blanched for 10 and 15 min.

For Chinese white cabbage, 5 min of blanching did not result in much difference in radical scavenging activity compared with fresh Chinese white cabbage. Blanching for 10 and 15 min decreased the radical

scavenging activity to 18 and 10%, respectively (Table 2). Based on ANOVA, the means of the radical scavenging activity of fresh and blanched Chinese white cabbage were significantly different ( $p < 0.05$ ). No significant difference was found between 5- and 10-min blanched, fresh and 5-min blanched Chinese white cabbage.

### Effect of different blanching times on the total phenolic content

Table 3 shows the total phenolic contents of fresh and blanched cruciferous vegetables. Fresh red cabbage had a very high phenolic content, 6.79 g gallic acid equivalents (GAE) kg<sup>-1</sup> fresh sample. A reduction in total phenolic content of red cabbage was detected after blanching for 5 min. Furthermore, a decrease in total phenolic content occurred after 10 and 15 min of blanching, to 4.35 and 4.29 g GAE kg<sup>-1</sup>, respectively. ANOVA showed a significant difference ( $p < 0.05$ ) in the means of total phenolic content between fresh and blanched red cabbage.

The total phenolic content in Chinese cabbage decreased to 0.75 g GAE kg<sup>-1</sup> after 5 min of blanching, but increased to 1.17 g GAE kg<sup>-1</sup> after 10 min of blanching (Table 3). Furthermore, it exhibited an increment of total phenolic content from 1.58 to 1.94 g GAE kg<sup>-1</sup> after 15 min of blanching. This result suggests that heat treatment might have released phenolic compounds. One-way ANOVA indicated a significant difference ( $p < 0.05$ ) in the means of total phenolic content between fresh and blanched Chinese cabbage.

A significant decline in total phenolic content of fresh and blanched cabbage was clearly observed.

**Table 3.** Total phenolic content of fresh and blanched vegetables extracts at 5 mg ml<sup>-1</sup> using the Folin–Ciocalteu assay

Treatment	Total phenolic content (GAE) (g kg <sup>-1</sup> fresh weight)				
	Red	Chi	Cab	Mus	Whi
Fresh	6.79 ± 0.00 <sup>d</sup>	1.58 ± 0.01 <sup>c</sup>	2.24 ± 0.01 <sup>d</sup>	1.83 ± 0.03 <sup>c</sup>	2.68 ± 0.01 <sup>d</sup>
Blanched 5 min	6.48 ± 0.01 <sup>c</sup>	0.75 ± 0.03 <sup>a</sup>	1.79 ± 0.00 <sup>c</sup>	1.39 ± 0.00 <sup>b</sup>	1.14 ± 0.01 <sup>c</sup>
Blanched 10 min	4.35 ± 0.03 <sup>b</sup>	1.17 ± 0.02 <sup>b</sup>	1.13 ± 0.00 <sup>b</sup>	0.89 ± 0.03 <sup>a</sup>	0.99 ± 0.00 <sup>b</sup>
Blanched 15 min	4.29 ± 0.00 <sup>a</sup>	1.94 ± 0.01 <sup>d</sup>	1.01 ± 0.03 <sup>a</sup>	0.84 ± 0.04 <sup>a</sup>	0.49 ± 0.03 <sup>a</sup>

Red = red cabbage, Chi = Chinese Cabbage, Cab = cabbage, Mus = mustard cabbage, Whi = Chinese white cabbage.

Values are expressed as mean ± standard deviation of three replicate measurements. Total phenolic contents of all samples are expressed as gallic acid equivalents (GAE).

a,b,c,d Values with different superscripts were significantly different by the LSD test at the level of  $p < 0.05$ .

Fresh cabbage had a total phenolic content of 2.24 g GAE kg<sup>-1</sup> fresh weight. The loss of phenolic compounds in fresh cabbage after blanching for 5, 10 and 15 min was 20, 50 and 55%, respectively (Table 3). There was a significant difference ( $p < 0.05$ ) in the means of total phenolic content between fresh and blanched cabbage extracts.

Mustard cabbage showed a steady trend in the loss of phenolic contents. Fresh unblanched mustard cabbage had a total phenolic content of 1.83 g GAE kg<sup>-1</sup> fresh weight, followed by 1.39 g GAE kg<sup>-1</sup> after blanching for 5 min. In addition, about 51 and 54% of the total phenolic content were lost after blanching for 10 and 15 min, respectively (Table 3). ANOVA found a significant difference ( $p < 0.05$ ) in the means of total phenolic content in mustard cabbage between fresh and blanched samples. However, no significant difference was found between mustard cabbage that was blanched for 10 and 15 min.

Fresh Chinese white cabbage extract had a total phenolic content of 2.68 g GAE kg<sup>-1</sup> fresh weight. After 5 min of blanching, its total phenolic content had decreased by about 58% to 1.14 g GAE kg<sup>-1</sup>. About 63 and 82% reductions in total phenolic content were observed after Chinese white cabbage was blanched for 10 and 15 min, respectively (Table 3). Among all the cruciferous vegetables studied, Chinese white cabbage exhibited the greatest loss of total phenolic content after blanching. There was a significant difference ( $p < 0.05$ ) in the means of total phenolic content between fresh and blanched Chinese white cabbage.

## DISCUSSION

The antioxidant activities of cruciferous vegetables decreased in the order fresh > 5-min blanched > 10-min blanched > 15-min blanched, except for red cabbage, for which the order was fresh > 5-min blanched > 15-min blanched > 10-min blanched. In addition, only mustard cabbage had a similar order of free radical scavenging activity as red cabbage after blanching. Vegetables are known to be rich in antioxidant components such as vitamin C,  $\beta$ -carotene, carotenoids, polyphenols and other phytochemicals. These components are reported to contribute high antioxidant activities. Previous studies have indicated the influence of different cooking practices on the content of antioxidant components in selected vegetables.<sup>15–18</sup> Up to 75% of the vitamin C present in green vegetables might be lost during cooking.<sup>19</sup> Blanching of broccoli, carrots and green beans resulted in the loss of ascorbic acid.<sup>10</sup> Gil *et al*<sup>7</sup> reported that cooking spinach in boiling water extracted 60% of vitamin C and 50% of total flavonoids. Tomatoes and onions showed a lowered quercetin content due to flavonoid breakdown during cooking.<sup>15</sup> Papetti *et al*<sup>20</sup> reported that *Cichorium* vegetable juices exhibited anti- and pro-oxidant activity after undergoing thermal treatments.

In addition, blanching can result in loss of antioxidant activity due to the large surface area of the vegetables in contact with the water during blanching.<sup>10</sup> Hence the low antioxidant activities of the blanched vegetables studied might be due to the loss of activity of some antioxidant components during blanching. Furthermore, there was also the probability that most components with high antioxidant activity had high solubility in boiling water.

In this study, blanching for more than 5 min resulted in a significant loss of antioxidant activity, which was supported by the results for total phenolic content. This might have resulted in a decreased ability of the studied vegetables to scavenge free radicals. The results obtained in this study were in agreement with those of Sánchez-Moreno *et al*,<sup>3</sup> Gil *et al*<sup>9</sup> and Kurilich *et al*.<sup>21</sup> However, Chu *et al*<sup>22</sup> found that blanching for 30–60 s increased free radical scavenging activity in sweet potato leaves.

Different blanching times might have resulted in some loss of antioxidants such as ascorbic acid,  $\alpha$ -tocopherol and phenolic compounds such as flavonoids. On the other hand, heat also tends to degrade certain compounds with antioxidant properties. In addition, the amount of heat and time needed to cause any loss or degradation of the associated components may differ for each vegetable.

As seen for antioxidant activity, the free radical scavenging activity increased in red cabbage after longer blanching times. This might have been due to the presence of heat-stable antioxidant components during blanching. This finding is in agreement with Papetti *et al*.<sup>20</sup> On the other hand, the free radical scavenging activity of all other vegetables decreased with longer blanching times.

The total phenolic content of red cabbage, cabbage, mustard cabbage and Chinese white cabbage decreased in the order of fresh > 5-min blanched > 10-min blanched > 15-min blanched, whereas the order for Chinese cabbage was 15-min blanched > fresh > 10-min blanched > 5-min blanched. The low phenolic content of red cabbage, cabbage and Chinese white cabbage after blanching might have been due to the degradation of phenolic compounds or their release from vegetable tissues into the boiling water. In this study, heat treatment through blanching might have resulted in a greater loss of red cabbage pigments. It has been reported that anthocyanin pigments are sensitive to heat and partly degrade into other products.<sup>9</sup> According to Gil *et al*,<sup>7</sup> the flavonoid content in fresh-cut spinach decreased significantly after cooking. However, Chu *et al*<sup>22</sup> reported that a blanching time of not more than 1 min retained more flavonoid content.

Moore *et al*<sup>23</sup> reported that apolar solvents were found to be the most suitable extraction medium for extracting phenolic compounds from water. However, a study found that a water extract of dittany (*Origanum dictamnus*) exhibited an unexpectedly high concentration of phenolic compounds compared with

the organic solvents.<sup>24</sup> Along with ethanol, water is the most widely employed extraction medium owing to their hygienic characteristics.<sup>23</sup>

Further studies are under way to evaluate the distribution of the polyphenol composition in the remaining water and cooked vegetables after blanching.

## CONCLUSION

Major losses of antioxidant properties and total phenolic content of the fresh cruciferous vegetables studied were observed after blanching for more than 5 min. However, this depended on the type of cruciferous vegetable. Minimal heat treatment in cooking practices, for example blanching for not more than 5 min at 98 °C, is recommended to prevent the major loss of antioxidant activity and also to reduce the pro-oxidant activity of vegetable components.

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