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Research Article

The effects of blanching, and freezing on quality properties of frozen cabbage (*Brassica oleracea* var. capitata)

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Abstract

By changing lifestyle recently many consumers prefer to use processed and ready food like frozen vegetables because of the fastest and easiest way. A factorial experiment based on RCBD was designed with 3 replicates to investigate the effects of blanching and freezing methods during storage time on frozen cabbage. Treatments included 2 blanching methods boiling water (Bb) and steam (Bs) and freezing methods home frozen (Fh) at -18°C and semi-commercial frozen (Fs) at -40°C, and finally packed and kept in the freezer for 6 months. Phenolic, antioxidant, and vitamin C were measured after 0, 2, 4 and 6 months. Color, texture, and element content were measured after 0, 3, and 6 months. The results showed that the main effect of blanching exhibited that vitamin C decreased in Bs, phenolic compound and antioxidant increased in Bs. The main effect of blanching, freezing, and storage time showed that texture, decreased with Bs and Fs significantly and storage time did not affect the texture. Vitamin C, the phenolic compound, and antioxidant decreased in all storage time however freezing method did not affect them. The interactive effect revealed that cabbage quality in chemicals, antioxidant, texture, and nutrient value decreased over time, especially, after 2-months storage in all freezing and blanching method. This reduction can be prevented by proper blanching and freezing methods, but it plays different roles for various parameters. Conclusively, the steam blanching was more effective in keeping the antioxidant content of frozen cabbage and the semi-commercial freezer was more effective than home freezing in keeping the nutritional value of cabbage however the shorter storage time was more effective than all the treatments in keeping cabbage quality.

Keywords: Antioxidant, Nutritional value, Vitamin C, Texture, Phenolic compound
Abbreviation: Bb: Boil water; Bs: Steam water; Fh: Home frozen; Fs: Semi-commercial frozen; RCBD: Randomized Complete Block Design

Introduction

Fruits and vegetables represents an overall concentration of bioactive compounds including ascorbic acid, tocopherols, carotenoids, and phenolic compounds. Some of these antioxidant compounds are known to be pigmented and have a characteristic color on the other hand, visual perception plays a key role in the selection of nutritious and healthy foods. Color, as one of the most important senses of vision, can be used as an indicator of food quality/defects and grade. It is recommended that the consumers use various colors in their plate to obtain various vitamins and minerals (Dogan *et al.*, 2020). Cabbage (*Brassica oleracea* var. capitata) structurally consists of clusters of stiff leaves superimposed in compacted layers, allowing it to acquire round or globular shape vegetable. This vegetable-rich in phytonutrient anti-oxidants and also different types of cabbage (red, green, and Savoy) contain different patterns of glucosinolates (Funes-Collado *et al.*, 2015). The growth of vegetables is usually restricted by area and season, and fresh vegetables are perishable because of their high water content. Thus, an effective vegetable preservation technique is required (Wu *et al.*, 2004). On the other hand, changing lifestyle and needing stored vegetable in the freezer, necessitates introducing new methods for preserving vegetable quality during storage. Vegetables are perfectly suitable for freezing. They are characterized by high biological quality owing to their high content of antioxidative compounds, such as vitamin C, folic acid and beta-carotene is a rich source of basic mineral constituents as well. The impacts of freezing on food quality are directly related to the growth of ice crystals (Anzaldua-morales *et al.*, 1999). Ice crystal size and structure depend on the cooling method and solute concentration (Chevalier *et al.*, 2000). Frozen vegetables are convenient and after the original reduction caused by blanching and freezing, maintain nutritional quality levels at -20°C during storage for water-soluble antioxidant activity in peas and spinach (Hunter and Fletcher, 2002). Typically,

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blanching is carried out by treating the vegetables with steam or hot water for 1-10 min at 75-95°C, the time/temperature combination depending on the type of vegetables (Cano, 1996). Blanching of foods involves mild heating in water and serves. Blanching can have a negative effect on nutrients such as vitamins and phenolic compounds which are relatively unstable when subjected to heat treatments (Prochaska *et al*., 2000). When Brassica vegetables are chewed or cut, tissues will disrupt and the glucosinolates will come into contact with myrosinase (thioglucoside glucohydrolase EC 3.2.1.147), leading to the production of reactive compounds (Bones and Rossiter, 1996). The wet-thermal treatment causes denaturation of enzymes that can catalyze breakdown of nutrients and phytochemicals. On the other hand, processing can result in the reduction of constituents by leaching or due to thermal destruction (Rungapamestry *et al*., 2007). Furthermore, Rosa and Heaney (1993) investigated the levels of glucosinolates before and after boiling of cabbage and found a reduction of more than 50%. In chopped and stored cabbage the levels of indole glucosinolates have been reported to increase, apparently due to a stress response reaction in the plant tissue (Verkerk *et al*., 2001). This work was aimed to understand how an industry or home processing (regarding blanching and freezing) could affect the nutritional compounds and quality of frozen cabbage during the storage time.

Material and methods

Sample preparation and treatment application: The factorial experiment based on a RCBD was designed with three replicates. Treatments included 2 levels of blanching and 2 levels of freezing methods including 1) vegetable was added to boil water (95-98°C) for 3 min and immediately was cooling by cold water (Bb). 2) Vegetable sample reached the boil in a stainless steel pan in tunnel steam for 100s (Bs) and were cooled rapidly by cold water till 20°C. All samples were frozen by two methods, including, 1: home frozen (Fh) (-18°C) and semi-commercial frozen (Fc) (-40°C) and finally packed and kept in the freezer for 6 months. Fresh cabbage was purchased from local markets in Isfahan, Iran, and used as material research in 2018. Vegetables were washed with tap water after manually removing inedible parts with a sharp knife. Vegetables were on the paper towel and were cut into almost equal small pieces or slices (0.5×0.5 cm) divided into four portions and washed. Phenolic, antioxidant, vitamin C was measured after 0, 2, 4, and 6 months. Color, texture, and element content were measured after 0, 3, and 6 months.

Measurement of frozen cabbage quality, phenolic content: In order to determine the total phenol content, leaves of cabbage were mixed with 5 ml Folin-Ciocalteu and 4 ml and aqueous Na_2CO_3 separately. The phenols were determined by spectrophotometer at 765 nm as gallic acid equivalents per gr (mg GAE g^{-1} DW) (Kahkonen *et al*., 1999).

Antioxidant activity: The antioxidant activity of vegetables was determined by (Yu *et al*., 2002). 3 mg of sample was dissolved in 5 mL methanol stock and 1.4 ml of this solution was blended with 0.6 mL of DPPH solution. After 30 min the absorbance of the solution was recorded at 515 nm by the spectrophotometer (V-530, JASCO, Japan) against methanol as a blank. The 0.2 mM of DPPH solution in methanol was used as a stock of DPPH for the determination of the free radical scavenging activity of the samples (Yu *et al*., 2002).

Vitamin C measurements: The determination of the vitamin C content was carried out according to the method of Tillman. It was estimated from 5 g of finely chopped fruit and homogenized with 50 mL of oxalic acid, taking an aliquot of 10 mL. The concentration was expressed in mg/g fresh weight by a standard curve of ascorbic acid (Nweze *et al*., 2015).

Color measurements: Color measurement was conducted using a Texflash instrument (Datacolor, International). The device was standardized each time with a white and a black ceramic plate. The color values were expressed as L^* (whiteness or brightness / darkness), a^* (redness / greenness), and b^* (yellowness / blueness) at any time, respectively (Maskan, 2001).

Texture measurements: A relative change of texture was measured. Cutting force of row and thawed material in three replicates was established according to the method of Soto and Borquez (2001) using the following formula:

Change of maximal cutting force = (Cutting force of raw material- Cutting force of thawed material) / Cutting force of raw material.

Element measurements: The concentrations of Ca, Fe, Zn, and Mg were analyzed by Budrat and shotipruk (2009) method and their concentrations were determined by ICP emission spectrometry (Shield Torch System, Agilent 7500a).

All data were subjected to two-way ANOVA by using Statistix 8 software (Tallahassee FL, USA) and the means were compared for significance by the least significant difference (LSD) test at $P < 0.05$.

Results

The main effect of blanching showed that vitamin C decreased in Bs, whereas phenolic compounds and antioxidants increased in Bs (Table 1). Antioxidant increased at the phenolic compound and vitamin c did not change significantly with the freezing method (Table 1). Vitamin C, phenolic compound and antioxidant decreased significantly after 2 months of storage. Vitamin C decreased 3 times in 2 months and did not change after 2 months significantly. Phenolic compound decreased 56, 68, 75% after 2, 4, and 6 months. Similarly, antioxidants decreased 56, 60, 64% after 2, 4, and 6 months significantly (Table 1).

The interaction effects of blanching and freezing showed that Bs decreased vitamin C in all freezing treatment but increased phenolic compound. Antioxidants were higher in Bs treatment and reached

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Table 1. The main effect of blanching, freezing and storage time on vitamin C, phenolic compound and antioxidant

Treatment	Vitamin C (mg/100gDW)	Phenolic compound (mg/100gDW)	Antioxidant (%)
(Blanching)		Blanching	
Bb	3.3402 ^{a}	84.24 ^{b}	39.454 ^{b}
Bs	2.5346 ^{b}	120.57 ^{a}	46.506 ^{a}
(Frozen)		Freezing	
Fh	2.8966 ^{a}	99.93 ^{a}	41.628 ^{b}
Fs	2.9783 ^{a}	104.88 ^{a}	44.333 ^{a}
(Storage time)		Storage time	
0	6.2500 ^{a}	204.72 ^{a}	78.778 ^{a}
2	1.9155 ^{b}	89.35 ^{b}	34.314 ^{b}
4	1.8129 ^{b}	65.03 ^{c}	31.180 ^{c}
6	1.7712 ^{b}	50.53 ^{d}	27.649 ^{d}

Within each column in each treatment, means with different letters are significantly different at P< 0.05.
cold water (Bb), steam water (Bs), home frozen (Fh), and semi-commercial frozen (Fc), 0, 2, 4, 6 month storage

Table 2. The interactive effect of treatments on vitamin C, phenolic compound and antioxidant

Treatments		Vitamin C (mg/100gDW)	Phenolic compound (mg/100gDW)	Antioxidant (%)
			Blanching×freezing	
Bb	Fh	3.28 ^{a}	81.78 ^{b}	38.88 ^{c}
	Fs	3.39 ^{a}	86.71 ^{b}	40.02 ^{c}
Bs	Fh	2.50 ^{b}	118.09 ^{a}	44.37 ^{b}
	Fs	2.56 ^{b}	123.04 ^{a}	48.64 ^{a}
			Blanching×storage time	
Bb	0	7.25 ^{a}	129.73 ^{b}	69.31 ^{b}
	2	2.14 ^{c}	76.73 ^{d}	31.08 ^{de}
	4	2.00 ^{c}	74.99 ^{d}	30.91 ^{de}
	6	1.96 ^{cd}	55.53 ^{e}	26.51 ^{f}
Bs	0	5.25 ^{b}	279.70 ^{a}	88.24 ^{a}
	2	1.684 ^{de}	101.96 ^{c}	37.54 ^{c}
	4	1.62 ^{e}	55.06 ^{e}	31.44 ^{d}
	6	1.58 ^{e}	45.54 ^{e}	28.78 ^{ef}
			Freezing×storage time	
Fh	0	6.25 ^{a}	204.72 ^{a}	78.77 ^{a}
	2	1.85 ^{b}	85.60 ^{b}	34.57 ^{b}
	4	1.74 ^{b}	59.40 ^{d}	28.35 ^{c}
	6	1.73 ^{b}	50.02 ^{d}	24.79 ^{d}
Fs	0	6.25 ^{a}	204.72 ^{a}	78.77 ^{a}
	2	1.97 ^{b}	93.09 ^{b}	34.05 ^{b}
	4	1.87 ^{b}	70.66 ^{c}	34.00 ^{b}
	6	1.80 ^{b}	51.04 ^{d}	30.49 ^{c}

Within each column in each treatment, means with different letters are significantly different at P< 0.05.
cold water (Bb), steam water (Bs), home frozen (Fh), and semi-commercial frozen (Fc), 0, 2, 4, 6 month storage

the highest in Bs×Fs (Table 2). Vitamin C, phenolic compound and antioxidant was highest in the control and decreased over time and the highest ones at Bb, Bs and Bs at the control respectively (Table 2). Vitamin C, phenolic compound and antioxidant decreased highly after 6 months in both blanching methods. Vitamin C, phenolic compound and antioxidant activity decreased in all storage time and freezing method did not affect it so the highest was in the control in Fs and Fh (Table 2). Reducing in vitamin C, phenolic compound and antioxidant after 2 months are much higher than 4, 6 months, on the other hand, decreasing in vitamin C, phenolic compound and antioxidant were 69, 56 and 56% after 2 months so it can be concluded that vitamin

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C decreased much more than antioxidant and phenolic compound by the first 2 months (Table 2).

Table 3. The main and two interaction effect of blanching, freezing, and storage time on texture and color parameters

Treatment		Texture (N/cm^2)	L^*	a^*	b^*	h
				Blanching		
Bb		0.35 ^{a}	59.88 ^{a}	-4.72 ^{b}	14.50 ^{a}	105.36 ^{a}
Bs		0.16 ^{b}	61.90 ^{a}	-3.93 ^{a}	13.47 ^{a}	102.07 ^{b}
				Freezing		
Fh		0.28 ^{a}	60.73 ^{a}	-4.42 ^{a}	14.22 ^{a}	104.27 ^{a}
Fs		0.22 ^{b}	61.05 ^{a}	-4.22 ^{a}	13.75 ^{a}	103.15 ^{a}
				Storage time		
0		0.27 ^{a}	36.00 ^{c}	-10.71 ^{c}	17.95 ^{a}	120.87 ^{a}
3		0.25 ^{a}	75.77 ^{a}	-1.47 ^{b}	13.83 ^{b}	95.89 ^{b}
6		0.24 ^{a}	70.89 ^{b}	-0.79 ^{a}	10.18 ^{c}	94.38 ^{b}
				Blanching×freezing		
Bb	Fh	0.35 ^{a}	59.885 ^{a}	-4.72 ^{b}	14.50 ^{a}	105.36 ^{a}
	Fs	0.162 ^{b}	61.90 ^{a}	-3.93 ^{a}	13.47 ^{a}	102.07 ^{b}
Bs	Fh	0.28 ^{a}	60.73 ^{a}	-4.428 ^{a}	14.22 ^{a}	104.27 ^{a}
	Fs	0.22 ^{b}	61.05 ^{a}	-4.22 ^{a}	13.75 ^{a}	103.15 ^{a}
				Blanching × storage time		
Bb	0	0.29 ^{a}	59.84 ^{a}	-4.70 ^{a}	14.64 ^{a}	105.26 ^{a}
	3	0.124 ^{c}	59.92 ^{a}	-4.73 ^{a}	14.36 ^{a}	105.45 ^{a}
	6	0.25 ^{b}	61.62 ^{a}	-4.15 ^{b}	13.79 ^{a}	103.28 ^{ab}
Bs	0	0.45 ^{a}	62.17 ^{a}	-3.72 ^{a}	13.14 ^{a}	100.86 ^{b}
	3	0.173 ^{b}	35.15 ^{d}	-10.88 ^{d}	17.94 ^{a}	121.25 ^{a}
	6	0.18 ^{b}	74.53 ^{ab}	-2.13 ^{c}	15.91 ^{a}	97.74 ^{b}
				Freezing× storage time		
Fh	0	0.378 ^{a}	69.96 ^{c}	-1.14 ^{b}	9.65 ^{b}	97.08 ^{bc}
	3	0.33 ^{a}	36.84 ^{d}	-10.54 ^{d}	17.95 ^{a}	120.48 ^{a}
	6	0.12 ^{b}	77.02 ^{a}	-0.80 ^{ab}	11.75 ^{b}	94.05 ^{cd}
Fs	0	0.35 ^{a}	71.83 ^{bc}	-0.45 ^{a}	10.70 ^{b}	91.68 ^{d}
	3	0.27 ^{ab}	36.00 ^{c}	-10.71 ^{c}	17.95 ^{a}	120.87 ^{a}
	6	0.20 ^{b}	74.79 ^{ab}	-1.53 ^{b}	13.97 ^{b}	95.96 ^{b}

Within each column in each treatment, means with different letters are significantly different at $P< 0.05$.
cold water (Bb), steam water (Bs), home frozen (Fh), and semi-commercial frozen (Fc), 0, 2, 4, 6 month storage

The main effect of blanching, freezing and storage time showed that texture decreased significantly with Bs and Fs, but storage time did not affect texture (Table 3). The main effect of color index L^* and b^* did not change significantly by blanching and freezing and blanching treatments. The *-index of color increased Bs whereas the h-value decreased (Table 3). Storage time did not effect of texture and decreased b^*-index and L-index over time significantly. a^*-index increased over time and the highest L^*-index was seen after 3 months (Table 3). The interaction effect of blanching and freezing showed that texture and h-index decreased and a^*-index increased at Bb×Fs. Texture decreased at Bs×Fs too (Table3). The interaction effects of blanching and storage time showed that texture and a-index decreased by the time, b^*-index did not change significantly. L^*-index, a^*-index and h-index decreased in Bs by the time (Table3). The interaction effects of freezing and storage time showed that texture decreased after 3 and 6 months. There was not a specific trend in the color index during the time (Table 3).

The main effect of blanching and freezing on cabbages nutrient content was shown that Zn, Mg, K increased at Bs and Fe and Ca decreased. Fs decreased Mg and increased Fe. The interactive effect of blanching and freezing showed that Bs increased Zn, Mg, K and Bb increased Cu and Ca in all freezing methods. The blanching and storage time showed that both blanching methods decreased all nutrients after 3 and 6 months significantly the same result was seen in

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the freezing over time. Freezing treatments decreased all nutrients after 3 months too. There was not any difference between the blanching and freezing method (Table 4).

Table 4. The main and interactive effect of blanching, freezing and storage time on nutrient elements (mg mg/g100DW)

Treatment		Zn	Mg	Mn	Fe	Cu	Ca	K
Blanching								
Bb		0.22^{b}	7.61^{b}	0.073^{a}	0.46^{a}	0.09^{a}	17.29^{a}	189.61^{b}
Bs		0.25^{a}	8.44^{a}	0.073^{a}	0.42^{b}	0.08^{a}	14.96^{b}	228.92^{a}
Freezing								
Fh		0.23^{a}	8.24^{a}	0.073^{a}	0.41^{b}	0.09^{a}	16.51^{a}	206.16^{a}
Fs		0.24^{a}	7.81^{b}	0.073^{a}	0.48^{a}	0.08^{a}	15.75^{a}	212.37^{a}
Storage time								
0		0.51^{a}	11.76^{a}	0.09^{a}	0.81^{a}	0.17^{a}	22.13^{a}	252.49^{a}
3		0.09^{b}	6.69^{b}	0.06^{b}	0.27^{b}	0.05^{b}	13.10^{b}	201.18^{b}
6		0.10^{b}	5.62^{c}	0.05^{b}	0.24^{c}	0.03^{c}	13.15^{b}	174.12^{c}
Blanching×freezing								
Bb	Fh	0.22^{b}	7.825^{bc}	0.07^{a}	0.41^{c}	0.09^{a}	18.47^{a}	186.21^{b}
	Fs	0.22^{b}	7.41^{c}	0.07^{a}	0.51^{a}	0.08^{ab}	16.126^{a}	193.01^{b}
Bs	Fh	0.24^{ab}	8.66^{a}	0.07^{a}	0.40^{c}	0.08^{b}	14.55^{b}	226.11^{a}
	Fs	0.25^{a}	8.22^{ab}	0.07^{a}	0.44^{b}	0.085^{b}	15.37^{b}	231.74^{a}
Blanching × storage time								
Bb	0	0.51^{a}	11.76^{a}	0.09^{a}	0.81^{a}	0.17^{a}	22.1^{a}	227.73^{b}
	3	0.0^{cd}	6.29^{c}	0.07^{b}	0.29^{b}	0.05^{b}	14.69^{b}	185.77^{c}
	6	0.07^{d}	4.79^{d}	0.05^{c}	0.28^{bc}	0.04^{c}	15.06^{b}	155.32^{d}
Bs	0	0.51^{a}	11.76^{a}	0.09^{a}	0.81^{a}	0.17^{a}	22.13^{a}	277.26^{a}
	3	0.11^{bc}	7.10^{b}	0.06^{bc}	0.25^{c}	0.04^{bc}	11.51^{c}	216.58^{b}
	6	0.131^{b}	6.465^{bc}	0.06^{bc}	0.21^{d}	0.03^{c}	11.24^{c}	192.93^{c}
Freezing× storage time								
Fh	0	0.51^{a}	11.76^{a}	0.09^{a}	0.81^{a}	0.17^{a}	22.13^{a}	252.49^{a}
	3	0.09^{b}	7.27^{b}	0.06^{b}	0.23^{c}	0.05^{b}	13.55^{b}	194.49^{bc}
	6	0.10^{b}	5.69^{c}	0.06^{b}	0.18^{d}	0.04^{cd}	13.84^{b}	171.49^{d}
Fs	0	0.51^{a}	11.76^{a}	0.09^{a}	0.81^{a}	0.17^{a}	22.13^{a}	252.49^{a}
	3	0.10^{b}	6.12^{c}	0.06^{b}	0.31^{b}	0.04^{bc}	12.65^{b}	207.86^{b}
	6	0.10^{b}	5.56^{c}	0.05^{b}	0.31^{b}	0.03^{d}	12.46^{b}	176.75^{cd}

Within each column in each treatment, means with different letters are significantly different at $P< 0.05$.
cold water (Bb), steam water (Bs), home frozen (Fh), and semi-commercial frozen (Fc), 0, 2, 4, 6 month storage

Vitamin C, phenolic compound and antioxidant decreased with storage. This decreased was 94, 71 and 63% for vitamin C, phenolic compound and antioxidant after three months and was 95, 78 and 65% for vitamin C, phenolic compound and antioxidant after six months. It seems that the most decrease was seen in vitamin C and the lowest was at antioxidant. There was not any significant difference between three and six months in all parameters (Table 5).

Discussion

Vitamin C, has many biological activities in the human body. More than 85% of vitamin C in human diets is supplied by fruits and vegetables (Davey *et al*., 2000; Lee and Kader, 2000). The content of vitamin C among Brassica vegetables varies significantly between and within their subspecies. Generally, among Brassica vegetables, white cabbage is the poorest source of vitamin C (Lisiewska and Kmiecik, 1996). However, it is a very popular species of Brassica vegetables in Iran. According to our results, freezing of cabbage for more than 2 months decreased vitamin C drastically. Loss of vitamin C after 7 and 14 days' storage at 20°C decreased to 44% and to 28% in broccoli. However, when broccoli was stored at 4°C, its vitamin C did not decrease after 7 days and 20% loss after 21 days (Favell, 1998). Vitamin C content in broccoli was reduced by 26% after 3 days of storage at room temperature; reducing the storage temperature to 5°C increased (25%) of vitamin C content in broccoli (Leja *et al*., 2001). Before vegetables freezing, they were washed and blanched to inactivate enzyme systems, especially oxidative enzymes (e.g. polyphenoloxidase, ascorbic oxidase, peroxidase) (Podsedek, 2007). Pre-storage treatments can affect vitamin C and antioxidant content of vegetable and fruit during storage and help them to reduce and destroy of the vitamin C in storage time (El-Wahab *et al.*, 2020).

The effect of blanching in the retention time of vitamin C in different Brassica was investigated, although it depends on temperature and time of the blanching method. Vitamin C after blanching was 84% for cauliflower, 70% of cabbage, (Puupponen-Pimia *et al.*, 2003), loss of vitamin C was 28–32% in cauliflower, 41–42% in broccoli, 34% in broccoli (Czarniecka-Skubina, 2002). There was a different report shown that freezing decreased vitamin C in different Brassica. After blanching and freezing, about 30% in broccoli (Howard *et al.*, 1999). The freezing did not change vitamin C in broccoli and cauliflower during 12-month storage but decreased by 3–18% for broccoli and 6–13% for cauliflower and 30% for cabbage (Favell, 1998; Lisiewska and Kmiecik, 1996; Puupponen-Pimia *et al.*, 2003).

Table 5. The effect of storage time on the quality of cabbage compared with raw cabbage after 3 and 6 months

Treatment	Vitamin C (mg/100 gDW)	Phenolic compound (mg/100 gDW)	Antioxidant (%)
Raw	38.00 [a]	302.23 [a]	90.11 [a]
3 (month)	1.99 [b]	85.36 [b]	33.00 [b]
6 (month)	1.82 [b]	65.49 [b]	31.02 [b]

Within each column, means with different letters are significantly different at P< 0.05.

Generally, among Brassica brussels sprouts, broccoli, and red cabbage had high antioxidants compared to common cabbage (Prochaska *et al.*, 2000). Although, in some research revealed the antioxidant activities of cabbage comparable to broccoli (Wu *et al.*, 2004).

Blanching affects the antioxidant activity of vegetables and decreased it compared with raw vegetables; DPPH index of cauliflower decreased by 23%, broccoli retained about 35% of the total (Zhang and Hamauzu, 2004). Conversely, increased by 9% cabbage (Puupponen-Pimia *et al.*, 2003), red cabbage was significantly higher (40%) in ORAC value compared to the raw form. Their antioxidant effectiveness depends on the stability in different systems, as well as the number and location of hydroxyl groups (Cook and Samman, 1996; Czeczot, 2000). The content of polyphenols in vegetables can be influenced by various factors such as varieties, climatic conditions and cultural practices, maturity at harvest, and storage conditions. Phenolic compounds have antioxidant activity. Phenolic compounds demonstrated higher antioxidant activity than antioxidant vitamins and carotenoids (Re *et al.*, 1999; Vinson *et al.*, 1995).

Phenolic content of cabbage did not change with blanching and freezing method but decreased with storage time. On the other hand, the decreasing of the phenolic compound was lower than vitamin C over time concluding that frozen cabbage after 2 months is good enough in phenolic compound compared with vitamin C. In contrast, there are some reports was shown that phenolic compounds in broccoli, which are stored 7 days at 1°C, showed more decrease than ascorbic acid (Vallejo *et al.*, 2003). Storage time effect on phenolic compounds in different Brassica. Phenolic compounds in broccoli, which are stored 7 days decreased 2–3 times (Vallejo *et al.*, 2003). On the contrary, total polyphenols did not significantly change in broccoli during 7 days' storage (Leja *et al.*, 2001).

Among color spaces, the CIELAB color scale is commonly used in the food industry to express the color of foods. It consists of L^*, a^*, b^* coordinates, where L^* value indicates lightness, a^* indicates redness or greenness, and b^* indicates yellowness or blueness. Hue angle (h^*) is considered the qualitative attribute of color and is related to the traditional color expressions reddish, yellowish etc. It is used to define color difference with reference to grey color with the same lightness. Many studies have used hue angle as a color attribute to correlate with pigments in fruits and vegetables. For example, the hue value was correlated with extracted chlorophyll a and b content of dried parsley leaves. The freezing can keep the color indices in good condition but blanching and time of storage decrease it (Dogan *et al.*, 2020).

Conclusion

Conclusively, it was observed that cabbage quality decreased over time, especially after two-month storage and these parameters did not change as sharply as the first two months. Between qualitative characteristics, the most reduction was seen in vitamin C although cabbage is not rich in vitamin C compared with other brassicas. The steam blanching was more effective in keeping the antioxidant content of frozen cabbage and the semi-commercial freezer was more effective than home freezing in keeping the nutritional value of cabbage however the shorter storage time was more effective than all the treatments in keeping cabbage quality. The effect of blanching and freezing varied and it seems that was not as important as storage time in cabbage quality
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