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Nutritional and physicochemical changes of white cabbage (*Brassica oleracea*) after minimal processing and during storage

Alterações nutricionais e físico-químicas em repolho branco (*Brassica oleracea*) após o processamento mínimo e durante o armazenamento

Camila Faria Trivelato Batista[1]
Cassiano Oliveira da Silva[1]
Cláudia Maria Tomás Melo[2]
Erika Maria Marcondes Tassi[1]
Grazieli Benedetti Pascoal[1]

[1] Universidade Federal de Uberlândia, Faculdade de Medicina, Curso de Nutrição. Uberlândia-MG, Brasil.

[2] Instituto Federal do Triângulo Mineiro, Curso de Tecnologia em Alimentos. Uberlândia-MG, Brasil.

Correspondence
Grazieli Benedetti Pascoa
E-mail: grazi@famed.ufu.br

Abstract

Introduction: Fresh-cut vegetables are foods which are subjected to several preparation steps (sorting, peeling, cutting, washing, sanitation, centrifugation and packaging) which make them fully usable. Minimal processing causes injuries to vegetable tissues, leading to nutritional losses. White cabbage (*Brassica oleracea*) stands out among other minimally processed vegetables as being a source of vitamins, minerals and bioactive compounds. *Objective*: To evaluate changes in the nutritional quality and antioxidant activity of white cabbage after minimal processing and during storage under refrigeration. *Methodology*: Samples of fresh and minimally processed white cabbage were purchased in three lots and analyzed at three different times, at 1, 7 and 14 days after storage. Proximate composition, ascorbic acid, total phenolics and antioxidant activity were determined by methods from the Association of Official Analytical Chemists and Brazilian Instituto Adolfo Lutz. The unpaired t-test was performed to compare the data and shelf-life was analyzed by one-way variance analysis, with Tukey's test and 5% significance. *Results and discussion*: At t-1, moisture, protein, ash, "available" carbohydrates, ascorbic acid, total phenolics, antioxidant activity and the energy value of fresh and minimally processed white cabbage showed differences ($p<0.05$) while fat content and total dietary fiber did not show any difference ($p>0.05$). At t-7, the content of ascorbic acid and antioxidant activity was reduced ($p<0.05$) and the total phenolic content remained constant. Ascorbic acid content, antioxidant activity and total phenolics did not show any difference ($p>0.05$) between t-7 and t-14. *Conclusion*: In general, the nutritional quality and antioxidant activity of white cabbage after minimal processing and during storage under refrigeration were reduced.

Keywords: Cabbage. Minimal Food Processing. Nutritional Composition. Antioxidant Activity. Physicochemical Processes. Food Quality.

Resumo

Introdução: Hortaliças minimamente processadas (HMP) são alimentos que passam por etapas de pré-preparo, tornando-se totalmente aproveitáveis. O processamento mínimo causa injúrias no tecido vegetal, o que pode ocasionar perdas nutricionais. O repolho branco (*Brassica oleracea)* destaca-se entre as HMP por ser fonte de vitaminas, minerais e compostos bioativos. *Objetivo*: Avaliar alterações na qualidade nutricional e na atividade antioxidante de repolho branco após o processamento mínimo e durante o acondicionamento sob refrigeração. *Metodologia*: Foram analisados três lotes de repolho branco *in natura* e de minimamente processado, em triplicata e em 1, 7 e 14 dias após o armazenamento. A composição centesimal, o ácido ascórbico, os fenólicos totais e a atividade antioxidante foram determinados por métodos da Association of Official Analytical Chemists e do Instituto Adolfo Lutz. Foi utilizado o teste t não pareado para comparação dos tratamentos, e a vida de prateleira foi analisada pela análise de variância *one-way*, com teste de *Tukey,* e nível de significância de 5%. *Resultados e discussão*: No t-1, os teores de umidade, proteínas, cinzas, carboidratos "disponíveis", ácido ascórbico, fenólicos totais, atividade antioxidante e o valor energético do repolho branco *in natura* e do minimamente processado apresentaram diferença ($p<0,05$), não observada entre si nos teores de lipídios e de fibras alimentares totais ($p>0,05$). No t-7, os teores de ácido ascórbico e atividade antioxidante reduziram significativamente, e o teor de fenólicos totais se manteve constante. Os teores de ácido ascórbico, atividade antioxidante e fenólico totais não apresentaram diferença significativa entre o t-7 e t-14. *Conclusão:* De uma maneira geral, a qualidade nutricional e a atividade antioxidante do repolho branco após o processamento mínimo e durante o acondicionamento sob refrigeração foram reduzidas.

Palavras-chave: Repolho. Processamento Mínimo dos Alimentos. Composição Centesimal. Atividade Antioxidante. Processos Físico-Químico. Qualidade dos Alimentos.

Introduction

Social, political and economic changes that have taken place in recent years and the search for a healthier lifestyle have increased consumer demand for fresh, ready-to-eat and convenient foods, especially vegetables and fruits.[1-3] In this sense, the food industry has been trying to develop new technologies for food processing, which would result in products that meet consumers' expectations, thus launching minimally processed foods in the market.[3,4]

Minimally processed foods (particularly potherbs and fruits) are products that have undergone minimal processing operations, such as washing, sanitizing, sorting, peeling, cutting, packaging and storage. It is important to inform that minimal processing affects the food original state but can keep them close to food in fresh (original) state.[3,5-7]

Minimally processed foods have gained much prominence among consumers as they are offered in some fashion that allows them to be immediately consumed. With this, a promising market has emerged to show and confirm the new trends of population's consumption.[3,6] In Brazil, such foods have been gaining increasing participation since the early 1990s. And vegetables are among the most commercialized and consumed by the Brazilian population. In particular, minimally processed white cabbage stands out because it is one of the most popular vegetables in Brazil and is consumed as an ingredient in several dishes that are typical of Brazilian food culture.[8]

Many studies have shown the benefits of healthy eating, rich in vegetables and fruits. These foods are very important, since they can reduce the risk of developing some chronic noncommunicable diseases (NCD), such as cancer, cardiovascular diseases, diabetes mellitus and obesity.[7,9] From a nutritional point of view, white cabbage has many compounds, such as: macronutrients ("available" carbohydrates, dietary fibers, proteins and lipids), micronutrients (vitamins C, B1, B2, E, K and minerals, principally calcium and phosphorus) and "non-nutrient bioactive compounds" (emphasis on glucosinolates and phenolic compounds).[10] "Non-nutrient bioactive compounds" and ascorbic acid (considered a "nutrient bioactive compound") appear to be the main responsible ones for vegetables high antioxidant capacity.[7,8,11]

In general, vegetables and fruits deteriorate after harvest due to physiological changes that may spontaneously occur. Physicochemical changes are also inevitable and more intense during minimal processing of food when compared to fresh food. Minimal processing operations damage plant tissues, leading to harms and metabolic alterations and thus activity of enzymes (mainly polyphenol oxidase) and respiratory rate increase in minimally processed foods. Therefore, biochemical modifications arising from minimal processing may result in loss of nutrients (vitamins and sugars) and bioactive compounds (emphasis on phenolic compounds).[12-14]

Therefore, it is very important to investigate whether minimal processing significantly results in macronutrients loss ("available" carbohydrates, dietary fibers, proteins and lipids), micronutrients (vitamins and minerals) and "non-nutrient bioactive compounds" (phenolic compounds, carotenoids and glucosinolates).[7, 10] Although some studies have been conducted to investigate changes in various quality parameters during storage under refrigeration of minimally processed foods, most of them have focused mainly on the evaluation of physicochemical parameters (soluble solids, pH and acidity) during the shelf life.[15] In addition, there are still few studies comparing nutritional differences between fresh vegetables and minimally processed vegetables.[7,13,15,16]

To date, no research has been found to evaluate changes in the composition of centesimal, bioactive compounds and antioxidant activity in white cabbage after minimal processing in order to verify its impact on this vegetable nutritional quality. No research has been found either to evaluate evolution and/or behavior of phenolic compounds, ascorbic acid and antioxidant activity during the shelf life of minimally processed white cabbage during storage under refrigeration.

Thus, the present study has aimed to investigate changes in centesimal composition (moisture, proteins, lipids, ashes, "available" carbohydrates and dietary fiber), phenolic compounds, ascorbic acid and antioxidant activity in white cabbage after minimal processing. Also to evaluate the behavior of ascorbic acid, phenolic compounds and antioxidant activity in minimally processed white cabbage during storage under refrigeration.

Methodology

Fresh and minimally processed white cabbages were purchased in a vegetable minimal processing industry located in the Brazilian city of Uberlândia, MG, and randomly distributed. Samples of minimally processed white cabbage were obtained from the same lot of fresh white cabbage and minimal processing had been carried out on the day prior to the analysis. During minimal processing, white cabbage was subjected to stages of selection, washing, sorting, cutting (slicing), sanitization and centrifugation, being immediately stored in plastic packaging under passive atmosphere and stored under refrigeration.

Three lots of fresh and minimally processed white cabbage were analyzed in three different months. They have been purchased between June 2013 and May 2014 and transported in isothermal boxes to the Laboratory of Food Bromatology and Microbiology of the Faculty of Medicine at Brazilian university *Universidade Federal de Uberlândia*.

Fresh white cabbage was used as "control food," being analyzed only on the first day of acquisition (t-1). The objective of the analyses was to investigate the effect of minimal processing of white cabbage on nutritional parameters (moisture, proteins, lipids, ashes, dietary fibers, "available" carbohydrates, ascorbic acid and total phenolics) and antioxidant activity. Analyses in t-1 consisted of: 3 test pieces (lots 1, 2 and 3) x 2 treatments (fresh and minimally processed) x 1 sample unit (about 2 kilos) x 1 local x 3 analyses (triplicate).[15,17-19]

In relation to storage under refrigeration, samples of minimally processed white cabbage were subjected to ascorbic acid, total phenolics and antioxidant activity analyses for 14 days under refrigeration at 4 °C and at three different times, namely: t-1, t-7 and t-14. Thus, the study experimental design of the refrigerated storage consisted of: 3 test pieces (lots 1, 2 and 3) x 1 treatment (fresh and minimally processed) x 1 sample unit (about 2 kilos) x 1 local x 3 analyses (triplicate).[15,17-19]

Centesimal composition (moisture, proteins, ashes, dietary fibers and lipids), ascorbic acid ("nutrient" bioactive compound) and total phenolics ("non-nutrient" bioactive compounds) were determined by several methods proposed by the Association of Official Analytical Chemists[20] and by Brazilian institute *Instituto Adolfo Lutz*.[21] Moisture was established by the oven drying method at 65 ºC for 72 hours. Lipids were analyzed by the Goldfish Method.[22] Ashes were determined by quantifying the fixed mineral residue remaining after incineration in muffle at 550 ºC for six hours, according to the 018/IV methodology.[21] Proteins by the micro-Kjeldahl method[20] with the application of factor 5.75 (conversion factor for vegetables).[23] Total dietary fiber contents were determined by the enzymatic-gravimetric method.[20] The "available" carbohydrates by difference were calculated by the following formula: % CHO "available" = 100 – (moisture + proteins + lipids + ashes + dietary fibers), figures provided in percentage (g "available carbohydrates" per 100 g of food).[23] Ascorbic acid content has been stipulated by the 364/IV methodology.[21] Total phenolics have been analyzed by the Folin–Ciocalteu reagent (FCR) method,[24] using gallic acid as the standard (mg of equivalents of gallic acid per 100 g sample). Antioxidant activity was determined by the percentage (%) inhibition of oxidation of 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical.[25]

Total energy value (TEV) was shown in two units: kilocalories (kcal) and kilojoules (kJ). Kilocalories (kcal) were estimated by multiplying "available" carbohydrates (by difference), proteins and lipids by values 4.4 and 9 kcal/g, respectively. TEV in kilojoules (kJ) was determined by multiplying TEV in kilocalories (kcal) by factor 4.2.[26,27]

Moisture of fresh and minimally processed white cabbage was established and the remaining dry extract was used to determine the centesimal composition analyses. Ascorbic acid, total phenolics and antioxidant activity were determined by samples of cabbage in the wet basis.[26,27]

Centesimal composition (proteins, lipids, ashes, dietary fibers and "available" carbohydrates), energy value and bioactive compounds (ascorbic acid and total phenolics) of fresh and minimally processed cabbage were expressed in the wet basis and in the dry basis. Antioxidant activity value and shelf life variables under refrigeration (ascorbic acid, total phenolics and antioxidant activity) were expressed as wet basis.

For comparison between treatments (fresh and minimally processed), an unpaired t-test was used. In addition, shelf life results were evaluated by the one-way analysis of variance with the Tukey's test. Significance level of 5% was considered, and statistical analysis was carried out with the aid of SAEG software version 9.1.

Results and Discussion

In relation to results obtained from white cabbage analyses at the time of acquisition (t-1), it was possible to observe that there was a significant increase ($p < 0.05$) in moisture content in minimally processed white cabbage (94.9% ± 0.34%) when compared to fresh one (92.8% ± 0.85%). Corroborating this study, Verzeletti et al.[28] have found increased moisture in minimally processed carrot samples when compared to fresh ones. Physical damage caused to plant tissue during minimal processing can cause respiratory rate acceleration and ethylene production, which contributes to water increase in the vegetable intracellular environment.[29]

Due to the increase in moisture content ($p < 0.05$) of minimally processed cabbage when compared to fresh cabbage, data of centesimal composition (proteins, lipids, ashes, "available" carbohydrates and dietary fiber), energy value, ascorbic acid and total phenolics were expressed in the wet basis and the dry basis (Table 1).

Table 1. Nutritional parameters (% or mg/100 g) and energy value (kcal/100 g and kJ/100 g) in white cabbage (*Brassica oleracea*) fresh and minimally processed in initial time (t-1), expressed in wet basis and dry basis.[1-2]. Uberlândia, MG, 2014.

Nutritional parameters	Fresh white cabbage		Minimally processed white cabbage	
	Wet basis	Dry basis	Wet basis	Dry basis
Moisture (%)	92.8 ± 0.85^{a}	–	94.9 ± 0.34^{b}	–
Proteins (%)	1.1 ± 0.07^{a}	16.2 ± 2.63^{A}	0.7 ± 0.06^{b}	13.8 ± 2.44^{A}
Lipids (%)	0.1 ± 0.00^{a}	1.1 ± 0.16^{A}	0.1 ± 0.00^{a}	1.5 ± 0.10^{B}
Ashes (%)	0.5 ± 0.04^{a}	7.5 ± 0.92^{A}	0.4 ± 0.02^{b}	7.3 ± 0.61^{A}
Dietary fibers (%)	2.1 ± 0.51^{a}	29.5 ± 4.78^{A}	2.0 ± 0.46^{a}	38.7 ± 8.21^{A}
"Available" carbohydrates (%)	3.3 ± 0.61^{a}	36.5 ± 6.60^{A}	2.0 ± 0.38^{b}	39.0 ± 7.63^{A}
Energy value (kcal/100 g)	18.4 ± 2.22^{a}	221.1 ± 28.82^{A}	11.3 ± 1.42^{b}	223.1 ± 30.43^{A}
Energy value (kJ/100 g)	77.4 ± 9.33^{a}	928.6 ± 121.06^{A}	47.5 ± 5.94^{b}	936.9 ± 127.7^{A}
Ascorbic acid (mg/100 g)	17.3 ± 0.57^{a}	244.8 ± 30.55^{A}	15.2 ± 0.89^{b}	304.8 ± 33.46^{A}
Total phenolics (mg EAG/100 g)	387.6 ± 5.00^{a}	5478.3 ± 721.62^{A}	367.3 ± 5.02^{b}	7353.9 ± 628.11^{B}

[1]Analyses in three lots (n = 3) in triplicate (n = 3); [2]Mean values ± standard deviation; Different lowercase letters in the same row mean that there was a statistical difference ($p < 0.05$, unpaired t-test) in the wet basis. Different uppercase letters in the same row mean that there was a statistical difference ($p < 0.05$, unpaired t-test) in the dry basis.

With respect to other centesimal composition parameters in the wet basis, there was a significant reduction in levels of proteins, ashes and "available" carbohydrates and energy of minimally processed white cabbage when compared to fresh white cabbage ($p < 0.05$). However, lipid and dietary fiber contents in fresh and minimally processed white cabbage presented no significant differences between them ($p > 0.05$). Comparative results of centesimal composition (fresh versus minimally processed) showed that harm caused in plant tissue during white cabbage minimal processing can cause different losses of some components of the centesimal composition.

Also in the wet basis it was possible to observe significant reduction ($p < 0.05$) in ascorbic acid and phenolic compounds contents in white cabbage after minimal processing. Reduction in ascorbic acid content may be related to cellular disorganization and consequent ascorbic acid oxidation due to tissue harm in white cabbage during cutting – one of the minimal processing stages.[30] Such results differ from those presented by Maia et al.,[31] which found no significant difference in ascorbic acid content between fresh and minimally processed broccoli. Alarcón-Flores et al.,[7] when studying vegetables behavior after minimal processing, have also noticed a significant reduction in total phenolics content in minimally processed carrots and broccoli when compared to the same fresh vegetables. Such reduction can be justified by phenolic compounds oxidation by oxidoreductase (peroxidases and polyphenol oxidase), which are directly related to plant tissues darkening.[32]

However, when data were presented on the dry basis, nutrient behavior after minimal processing was different since the moisture had a significant difference ($p < 0.05$) between treatments, that is, moisture content of minimally processed cabbage was higher ($p < 0.05$) than of fresh one. Thus, moisture content of the present study can be considered an interfering variable since the data were modified when we removed it from the analysis.

The values expressed in dry basis are adequate to compare foods with statistically different moisture contents. Therefore, in these cases moisture is an interfering variable. In the present study, the values expressed in dry basis clearly showed that nutrient behavior after minimal processing (fresh cabbage versus minimally processed cabbage) was totally influenced by the food moisture content. In the dry basis, lipids and total phenolics contents increased ($p < 0.05$) in minimally processed cabbage when compared to fresh cabbage. Whereas proteins, ashes, dietary fibers, “available” carbohydrates, energy and ascorbic acid did not change ($p > 0.05$) after minimal processing.

Analyzing and comparing nutritional value through the dry basis is an interesting tool to see the influence of moisture on the variables. It is noteworthy that consumers buy and ingest food with moisture. Thus, data presented on a wet basis showed how the cabbage food matrix behaved after minimal processing and the dry basis data showed the influence of moisture on nutrient behavior after processing.

Antioxidant activity of the present study was 61.1% (± 1.20%) for fresh cabbage and 52.0% (± 2.10%) for minimally processed cabbage. There was a significant decrease ($p < 0.05$) of this activity after minimal processing. Results by Gil et al.[33] have corroborated the present research and verified that fresh spinach presented a significant reduction of antioxidant capacity after minimal processing. Vegetable hygiene and slicing during minimal processing disrupt plant tissue structures and expose nutrients to production of certain enzymes naturally present in plants and may reduce antioxidant capacity.[34]

With respect to results obtained during storage under refrigeration (t-1, t-7, t-14), it was possible to observe significant reduction ($p < 0.05$) in ascorbic acid content and antioxidant activity of minimally processed white cabbage after seven days of storage under refrigeration. There was no difference ($p < 0.05$) in ascorbic acid content and antioxidant activity between the seventh and fourteenth day of storage under refrigeration (Table 2).

Table 2. Ascorbic acid (mg/100 g), total phenolics (mg EAG/100 g) and antioxidant activity (%) in white cabbage (*Brassica oleracea)* minimally processed during storage under refrigeration (t-1, t-7, t-14), expressed in the wet basis.[1,2] Uberlândia, MG, 2014.

Variables	MP white cabbage (t-1)	MP white cabbage (t-7)	MP white cabbage (t-14)
Ascorbic acid (mg/100 g)	15.2 ± 0.84^a	13.6 ± 0.69^b	12.8 ± 1.47^b
Total phenolics (mg EAG/100 g)	367.6 ± 4.72^a	363.8 ± 4.67^a	363.2 ± 5.49^a
Antioxidant activity (%)	52.1 ± 2.00^a	42.0 ± 1.61^b	40.1 ± 1.43^b

[1]Analyses in three lots (n = 3) in triplicate (n = 3); [2]Mean values ± standard deviation; Different lowercase letters in the same row mean that there was a statistical difference ($p < 0.05$, one-way analysis of variance, Tukey's test). T-1 = 1 day of storage; t-7 = 7 days of storage; t-14 = 14 days of storage.

Observing Table 2, it was noted that antioxidant activity and ascorbic acid decreased during storage under refrigeration. Therefore, it can be inferred that such antioxidant activity reduction was due to the ascorbic acid. To ascertain that the variables ascorbic acid and antioxidant activity had an association, a Pearson correlation coefficient (PCC) was applied (Figure 1) and it was found that ascorbic acid and antioxidant activity had a strong and positive correlation with each other ($r = +0.98$), that is, as the ascorbic acid content decayed, antioxidant activity also accompanied this trend over the shelf life.

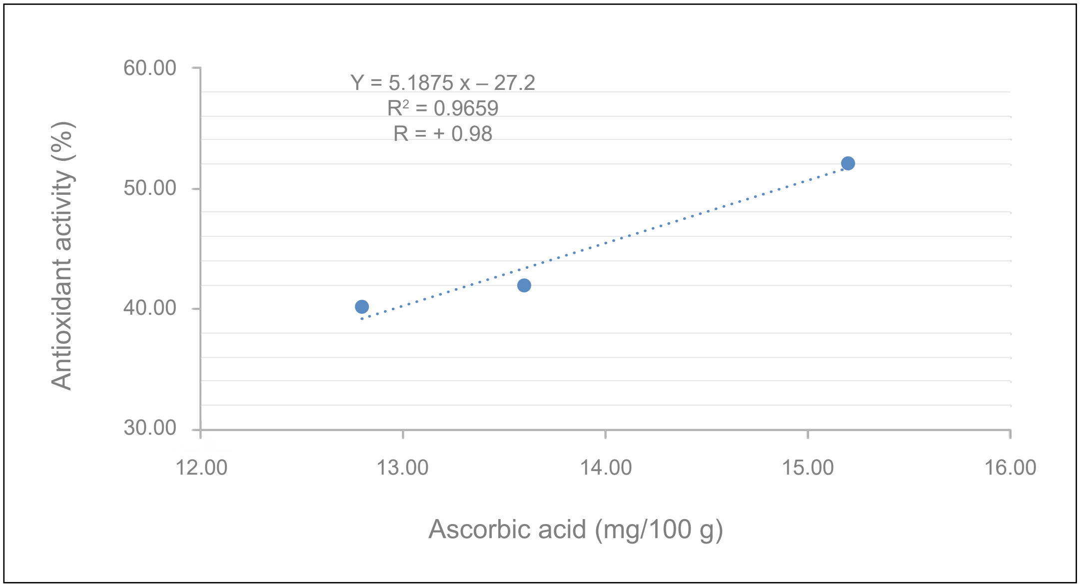

Figure 1. Pearson correlation coefficient (PCC) between ascorbic acid content (mg/100g) and antioxidant activity (%) during storage under refrigeration in white cabbage (*Brassica oleracea*) minimally processed during storage under refrigeration (t-1, t-7, t-14).[1, 2] Uberlândia, MG, 2014.

Along the storage of vegetables, there is a tendency to reduce the ascorbic acid content, mainly due to the action of the enzyme ascorbic acid oxidase (ascorbinase) or other oxidizing enzymes (for example, peroxidases).[35] Results from this study have corroborate those by Alves et al.,[30] which have verified a significant reduction of ascorbic acid in minimally processed mixed salad (chayote, carrot, arracacha and squash) after eight days of storage under refrigeration. Hussein et al.,[36] in a study with fresh and minimally processed broccoli, have also observed a significant reduction in ascorbic acid content during ten days of storage under refrigeration.

Antioxidant activity behavior in the present study differs from that found by Russo et al.,[37] who, when analyzing minimally processed pumpkin, have observed an increase in antioxidant activity until the ninth day of storage and a considerable reduction from the 12th day of storage under refrigeration.

Total phenolics content in minimally processed white cabbage presented no relevant difference during the three times of shelf life analyzed (t-1, t-7, t-14), with an average value of 364.9 mg EAG/100 g.

There is some strong divergence among authors about the correlation between phenolic content and antioxidant activity. Some studies have shown that the higher the phenolic content in some food, the greater its antioxidant activity, such as the one carried out by Kaur and Kapoor,[38] who have found a significant relationship between total phenolics and antioxidant activity in vegetables.[39,40] However, other surveys, such as that carried out by Ismail et al.,[41] have not shown this correlation, since they argue that the antioxidant activity depends on the food physicochemical composition as a whole and therefore is not based solely on its content of phenolic compounds.[42, 43]

Conclusion

In general, nutritional quality and antioxidant activity of minimally processed white cabbage were not fully preserved when compared to fresh white cabbage. Thus, it was concluded that fresh cabbage presented better nutritional quality than minimally processed cabbage. However, the minimally processed one meets the expectations and needs of other types of contemporary consumers, who increasingly seek convenience and/or practicality in food products.

In conclusion, new scientific studies should be carried out regarding nutritional and physicochemical changes after minimal processing of vegetables, particularly white cabbage. In addition, research involving the investigation of enzymatic activities and postharvest physiological changes during storage of minimally processed cabbage would be of great value and provide more in-depth data on vegetables physicochemical behavior after minimal processing.

Contributors

The authors have participated in all stages, from the design of the study to the article final version revision.

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