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Antioxidant Capacity and Total Phenolics Changes of Minimally Processed Radish Stored in an Active Modified Atmosphere Under Refrigeration

BIGE INCEDAYI*, CANAN ECE TAMER, SIBEL PARSEKER YONEL and OMER UTKU COPUR
Department of Food Engineering, Faculty of Agriculture,
University of Uludag, 16059 Görükle-Bursa, Turkey
Fax: (90)(224)2941402; Tel: (90)(224)2941504; E-mail: bige@uludag.edu.tr

The radish in this research was treated with citric acid (1.5 %) and Ca-ascorbate (0.5 %) + citric acid (1 %) following pre-processes. After centrifugation, the samples were packed in 20 % atmospheric air + 80 % N_2 and 20 % atmospheric air + 70 % N_2 + 10 % CO_2 conditions with 42 μ bi-axially oriented polypropylene (BOPP) film. After 20 days of storage at 4 ± 2 °C, total phenolics, ascorbic acid, total carotenoids content and antioxidant activity of radishes had decreased by 22.65, 24.84, 30.91 and 20.52 %, respectively. More reductions occurred in the control samples that were not treated with any chemicals and they were also rejected by the panelists at the 95 % probability level because of their deleterious texture and appearance. Ca-ascorbate with citric acid treatment with the carbon dioxide enriched atmosphere was found to be more effective with regard to limiting the phenolics, antioxidant activity, weight and total dry matter losses, microbiological spoilage of packaged radishes and prevented organoleptic degradation.

Key Words: Minimally processing, Modified atmosphere packaging, Radish, Antioxidant activity, Total phenolics.

INTRODUCTION

The radish (*Raphanus sativus*) is an edible root vegetable of the *Brassicaceae* family that was domesticated in Europe in pre-Roman times. It is grown and consumed throughout the world and have been for over 1500 years. The consumption of radish has significantly increased in North America in recent years[1]. Radish is grown throughout the year under varying climate conditions, but especially warm and cold climatic conditions are more favourable for the growth of this vegetable[2]. The postharvest lifespan of radish is limited because of rapid water loss, softening and internal sponginess. This characteristic rapid water loss is mainly the result of the lack of wax and cutin in the protective cuticle[1].

The radish is an excellent source of calcium, phosphorus and manganese, contains vitamins B1 and B2, nicotinic acid and vitamin C, acts as a diuretic and as an anti-scorbutic agent and stimulates the digestive glandules and liver-promoting better digestion by increasing bile production[3]. In addition, this vegetable shows anti-microbial, antimutagenic, anticarcinogenic and atherosclerosis preventive effects[4].

The chemical composition of the radish is shown in Table-1[5]. The marketing of fresh-cut salads is limited by a short shelf life and the rapid deterioration of their components due to tissue damage caused by slicing and similar methods of preparation[6]. Slicing accelerates physiological changes, such as enzymatic browning and promotes the growth of spoilage microorganisms[7]. The increase in the microbial population and the browning of the cut surfaces causes a deterioration of quality during storage[8].

TABLE-1
CHEMICAL COMPOSITION OF FRESH RADISH*

Nutrient	Value	Nutrient	Value
Water	952.7 g kg^{-1}	Magnesium	100 mg kg^{-1}
Energy	160 kcal kg^{-1}	Phosphorus	200 mg kg^{-1}
Protein	6.8 g kg^{-1}	Potassium	2330 mg kg^{-1}
Ash	5.5 g kg^{-1}	Sodium	390 mg kg^{-1}
Carbohydrate	34 g kg^{-1}	Flor	60 μ kg^{-1}
Total dietary fiber	16 g kg^{-1}	Vitamin C	148.0 mg kg^{-1}
Total sugars	18.6 g kg^{-1}	Vitamin A	7 IU
Calcium	250 mg kg^{-1}	β-Carotene	40 μ kg^{-1}

*USDA National nutrient database for standard reference [22].

In addition, the radish is gaining a great market share with other minimally processed products, although its physiologic behaviour after packaging is still poorly understood[9]. Observations were made earlier that radish slices started to deteriorate and that anthocyanin leakage could occur after 5-7 days at 10 °C, a temperature commonly used in the produce display section of retail markets[8].

Aguila *et al.*[10] stored the fresh-cut radish at 5 ºC and 90 % relative humidity for 10 days and showed that the packaging materials did not have a significant effect on the total soluble solids, the total acidity and the ascorbic acid contents. Also, the lightness values (L) decreased as the storage time increased.

The present study is undertaken to determine the conditions required for extending the shelf life of minimally processed radish by applying a modified atmosphere packaging (MAP) technique with vacuum and with different gas combinations. 42 μ bi-axially oriented polypropylene (BOPP) film was also used to match the respiratory requirement of the radish. The chemical composition and the organoleptic characteristics of radishes during the 20 days of storage were then investigated in an attempt to determine the most effective treatment and the optimum processing parameters.

EXPERIMENTAL

In this study, mature red radishes without any damage were obtained from the local market in Bursa, Turkey. The radish was washed, peeled and, to inhibit enzymatic oxidation, was put into a 1500 ppm Na-metabisulphide + 1 % NaCl solution.

The radishes were divided into two groups and both of the groups were dip-treated with 150 ppm Na-hypochlorite (pH: 6.9) for 5 min. The radishes were then washed with tap water to eliminate the dipping solution to remove the typical chlorine odour. After the first group was dipped into the solution containing the citric acid (1.5 %) for 5 min, the second group was dipped into the solution of Ca-ascorbate (0.5 %) + citric acid (1 %) for 10 min. Centrifugation was used for the removal of excess solutions. The radishes were then packed (approximately 200 g) in polypropylene dishes (190 mm × 140 mm × 50 mm) with 42 μ bi-axially oriented polypropylene (BOPP) (top film) packages. At 24 °C, the oxygen and the carbon dioxide transmission rates of the film were 1775.40 and 6428.60 cc/m^2/day, respectively.

The packages were then separated into two groups. The first group was sealed with an 80 % vacuum with 80 % N_2 while the second group was sealed with an 80 % vacuum with 70 % N_2 + 10 % CO_2. The packaged radishes were coded as 1 (the samples packaged in the nitrogen gas, the control sample of the first group), 1A (the samples packaged in the nitrogen gas after the citric acid treatment), 1B (the samples packaged in the nitrogen gas after the Ca-ascorbate + citric acid treatment), 2 (the samples packaged in a nitrogen + carbondioxide gas, the control sample of the second group), 2A (the samples packaged in a nitrogen + carbon dioxide gas after the citric acid treatment) and 2B (the samples packaged in a nitrogen + carbondioxide gas after the Ca-ascorbate + citric acid treatment).

The ReeTray 25 TC model machine was used for the packaging process. The seal temperature was set at 160 °C and the seal time was 3 s. The minimally processed radishes were stored at 4 ± 2 °C for 20 days for analyzing.

Folin-Ciocalteau's reagent was acquired from Fluka (Buchs, Switzerland). Methanol, 2,2-diphenyl-2-picryhydrazyl radical (DPPH), gallic acid, petroleum ether (analytical grade), 2,6-dichlorophenol indophenol and acetone were purchased from Sigma Chemical Co. (St. Louis, MO). Oxalic acid, sodium carbonate and sodium hydroxide were obtained from Merck (Darmstadt, Germany).

The amount of the total dry matter was analyzed using the oven-dry method. The ascorbic acid was determined by direct spectrophotometrically using a 2,6-dichlorophenol indophenol dye[11]. The antioxidant activity was identified by using the 2,2-diphenylpicrylhydrazyl (DPPH) radical spectrophotometrically. The inhibition percentage of the DPPH free radical at 517 nm was calculated[12]. The method employed for the total phenolics was based on Folin-Ciocalteau's phenol reagent and spectrophotometric determination[13]. The spectrophotometric measurements were carried out at 452 nm using a Shimadzu UV 1208 model spectrophotometer and the results were calculated as the gallic acid equivalent. The total carotenoids were determined by using the spectrophotometric method[11].

Physiological losses in weight: The initial weight of the packaged samples was noted and periodical observations on the losses in weight were made by weighing the samples. So the results were expressed as a cumulative percentage loss.

Sensory evaluation: The modified atmosphere packaged radishes were organoleptically evaluated for their quality attributes, such as colour, appearance, odor and texture, by a panel consisting of 8 trained members using a ranking test[14]. According to this test, the panelists would order the samples from their most favourite one to their least favourite by giving a point between 1 and 6. As a result of this statistical test, the samples that ranked below 11 (the mean of all of the panelist's point values) were preferred and samples ranked above 31 were rejected at the 95 % probability level.

Statistical analysis: The experiment was conducted in a completely randomized design with three replications. The results were statistically evaluated using a one way analysis of variance (ANOVA) in the JMP software package version 8.0 (SAS Institute Inc. NC, 27513). The means were compared using the LSD (least significant difference) test ($p < 0.05$).

RESULTS AND DISCUSSION

The preparation of the radishes resulted in a 26 % wastage and the fruit flesh/peel ratio was 2.80/1. The average width and the height of the vegetable was 6.57 and 5.79 cm, respectively. The results of the analyses of raw material were shown in Table-2.

TABLE-2
RAW-MATERIAL ANALYSES RESULTS

Total dry-matter (g 100 g^{-1})	6.52 ± 0.05
Total acidity* (g 100 g^{-1})	0.03 ± 0.00
Ascorbic acid (mg 100 g^{-1})	8.50 ± 0.12
Total carotenoids (mg kg^{-1})	56.51 ± 2.45
Total phenolics (mg GAE** 100 g^{-1})	616.00 ± 34.07
Antioxidant activity (%)	56.31 ± 3.58
Total aerobic mesophilic bacteria count (cfu*** g^{-1})	9.5×10^3
Total psychrophilic bacteria count (cfu g^{-1})	1.3×10^3
Total coliform count (mpn**** g^{-1})	< 3

*Citric acid, **GAE: gallic acid equivalent, ***cfu: colony forming unit, ****mpn: most probable number.

Weight losses in the packaged radishes through respiration during the storage period were changed between 17.71-21.12% (Fig. 1). More losses were not seen because of medium respiration rate of the radish[15]. Except for the sample 1A, weight losses of the control samples (1 and 2) were found to be higher than the other groups because the pre-processing stage did not include any respiration reducing application. On the contrary, the samples packaged under the nitrogen conditions with carbondioxide gas (especially in 2A and in 2B) showed the minimum losses because of the metabolism restricting effects of CO_2. Chu *et al.*[1] reported that daily weight losses from 0.02-0.03 % occurred in Taibai radishes that were stored at 5 ºC and packaged with a film that transmitted 4192 mL m^{-2} h^{-1} CO_2 and 570 mL m^{-2} h^{-1} O_2.

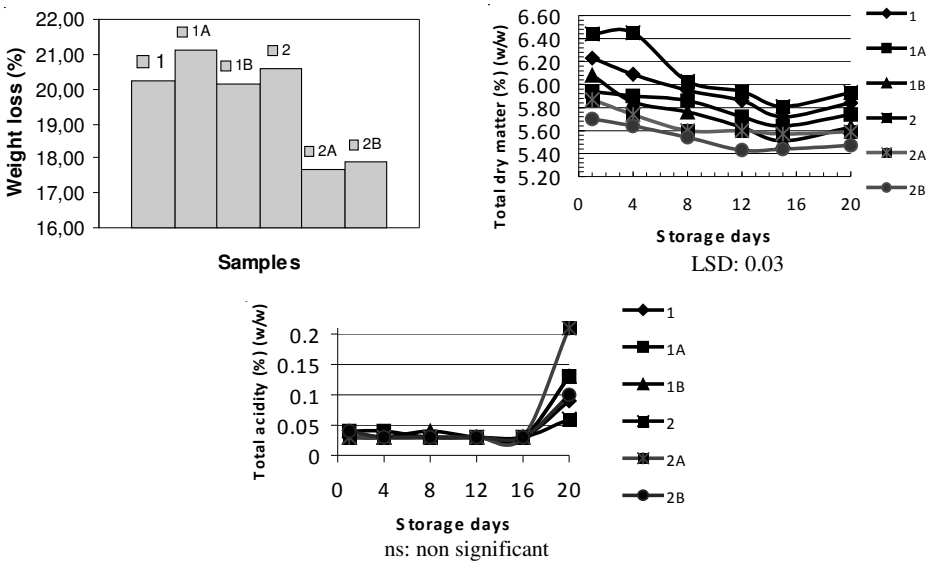


Fig. 1. Weight losses, total dry matter and total acidity contents of packaged radishes

Aguila *et al.*[16] determined that the unprocessed radishes presented a lower respiratory rate (40.61 mL CO_2 kg^{-1} h^{-1}) compared to the shredded radishes (93.90 mL CO_2 kg^{-1} h^{-1}) 4 h after processing. The whole and fresh cut radishes showed the highest respiratory rate on the 2nd day of storage, with 99.27 and 170.32 mL CO_2 kg^{-1} h^{-1}, respectively. On the 10th day of storage, the fresh cut radishes showed a respiratory rate that was 149 % higher than that of intact radishes. The minimal processing operations, mainly the cutting process, enhanced the respiratory rate of the radish.

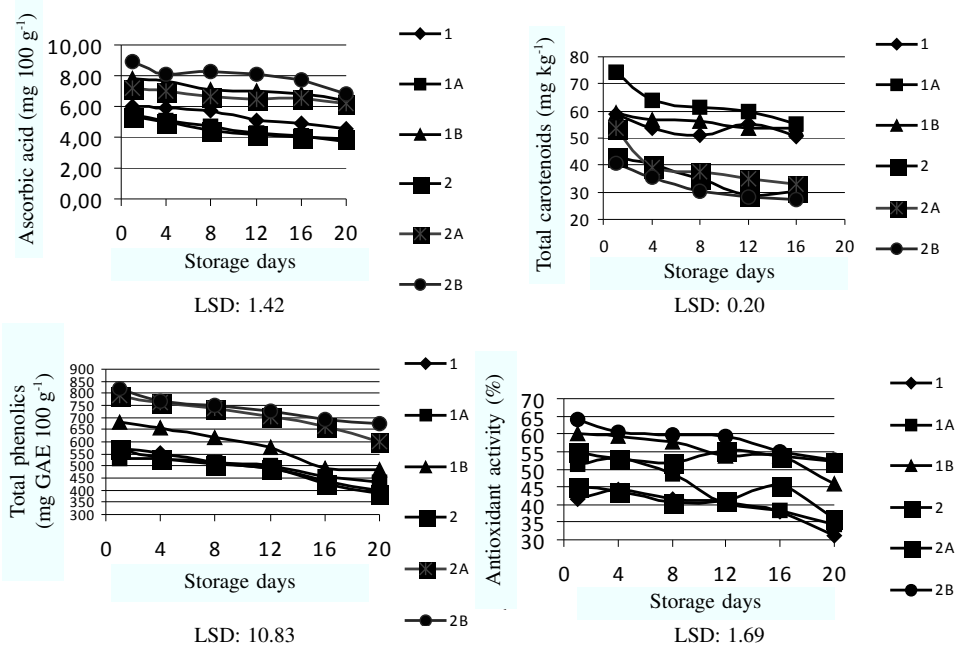
Total dry matter was reduced by the catabolic metabolism of the radishes along with storage time. The differences between the treatments and the storage times were found to be statistically significant ($p < 0.05$). As seen in Fig. 1, the total dry matter contents of the control samples were higher than the other samples. This could be due to a lack of chemical application, as some water-soluble components were lost during the dipping of the vegetables in the treatment solutions. Using the same interpretation, treatment 2B had the lowest dry matter content because of dipping in the Ca-ascorbate (0.5 %) + citric acid (1 %) solution for 10 min. The loss ratio of this sample (2B) was lower (5.97 %) than any of the others over 20 days of storage. The total dry matter content of the radish was reported as 4.73 g 100^{-1} g and 4 % according to previous reports[5,17]. The differences between the results could be affected by the variety of the vegetable, the harvest conditions (time, maturity, *etc*.) and the storage conditions.

Few acidity changes occurred in the packaged samples during the 15 days of storage, but at the end of the storage period, the acidity increased depending on the microbial spoilage (Fig. 1). The differences between the treatments were determined to

be non significant ($p < 0.05$). Basay and Eris[2] reported that the total acidity values of four different varieties of radishes ranged from 0.10-0.37 g 100 g^{-1} (as oxalic acid). According to Aguila *et al.*[10], there were no differences in the acidity among the cut types (whole, shred, slice) and among the storage temperatures (1, 5 and 10 °C) of the radishes and the amount of malic acid varied from 0.05-0.06 %.

The content of ascorbic acid in most vegetables decreases when bruising, trimming and cutting occurs[18]. Ascorbate is affected by both biosynthesis and degradation reactions in fresh-cut products during storage[10].

The mean ascorbic acid loss rate was 22.65 % in the packaged samples (Fig. 2). The ratios for the 1, 1A, 1B, 2, 2A and 2B coded samples were 25.33, 30.70, 18.73, 26.72, 14.36 and 23.03 %, respectively. The ascorbic acid content differences in the raw material and in the packaged vegetables could be due to the applications and the treatments used in this study. However, the loss ratios were moderately eventuated, Ca-ascorbate + citric acid treatedsamples (1B, 2B) had the highest values as expected. Significant differences were determined between the ascorbic acid values as evaluated by the treatment and the storage time parameters of radishes ($p < 0.05$).



*Extracts for antioxidant activity of radishes were tested at concentration of 3 mg/mL on dry weight basis

Fig. 2. Ascorbic acid, total carotenoids, total phenolic matter and antioxidant activity contents of packaged radishes

According to the research results of Aguila *et al.*[10], the ascorbic acid content decreased in shredded radishes stored at 10 ºC from 220.45 to 30.01 mg kg^{-1} after 10 days of storage. Whole and sliced radishes showed essentially no reduction in their ascorbic acid content during storage. The USDA also reported[5] the ascorbic acid

content of raw radishes as 14.8 mg 100 g^{-1}. The differences of our results with those presented in the literature could be explained by the variety, the harvest technique and the storage conditions of the vegetable.

Carotenes are decomposed into polyene intermediates, or are oxidized to produce epoxy and carbonyl compounds, by free radical chain reaction during heating and storage[19]. Contrary to this, Kalt[20] found that carotenoids are stable components; which can be concentrated at suitable storage conditions. At the end of the 20 days of storage, a 30.91 % carotenoid loss occurred in the packaged radishes (Fig. 2). This significant loss in the 1, 1A, 1B, 2, 2A and 2B coded packages were 23.2, 25.61, 21.16, 40.67, 42.77 and 39.99 %, respectively. Because of the different initial carotenoid content of the radishes, the packaged forms showed varying concentrations. Generally, it could be said that the CO_2 enriched atmosphere conditions do not contribute to the preservation of this nutrient, however the results showed a statistically significant difference ($p < 0.05$).

Total phenolics decreased through the storage period of the MAP radishes (Fig. 2). Stresses such as light, temperature, water and wounding affect the physiology of fresh produce by triggering responses that could induce the accumulation of phenolic compounds or other secondary metabolites[21]. In general, the wound response was dependent on the type of tissue and was influenced by the initial levels of the reduced ascorbic acid and the phenolic compounds. Reyes *et al.*[17] reported a decrease in the phenolic content of the wounded radish by 7% after 2 days of storage at 15 °C.

The general reduction in the ratio of the total phenolics in the packaged samples was 24.84 %. The values of the control samples (1 and 2) were found to be lower than the chemically treated samples. Additionally, the loss ratios were higher (29.88 and 32.62 % respectively) in radish. Therefore it could be stated that chemical treatments (especially the Ca-ascorbate + citric acid treatment) contributed to the preservation of the phenolics. Furthermore, the CO_2 enriched modified atmosphere could be used for minimally processed radish production because of the higher total phenolic contents of these samples (2A, 2B). The differences between the storage times and the treatments resulted in the total phenolic matter content changes were found to be statistically significant ($p < 0.05$).

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Fruits and vegetables are good sources of natural antioxidants such as vitamins, carotenoids, flavonoids and other phenolic compounds[12]. There has been increasing interest in the characterization of antioxidant phytochemicals due to their distinct bioactive properties. Antioxidants scavenge reactive oxygen species that can cause cell damage in plant tissues[17].

Antioxidant activity of the minimally processed radishes was reduced by 20.52 % (Fig. 2) with the reduction of the antioxidative compounds, such as vitamins, carotenoids

and phenolics. The reason for the higher values seen in some of the samples compared to the raw material was that there was an increase of the antioxidant activity in some of the analysis periods (such as 8th and 12th storage days of 2A sample) that was associated with biotic and abiotic stress factors such as wounding, low temperature and the attack of pathogens[22]. Similarly, recent research has shown that wounding increases the antioxidant capacity of carrots[23], lettuce[24] and purple-flesh potatoes[25]. This increase might be related with the observed increment of the total phenolic content after wounding[17].

The antioxidant activity reduction ratios of the packaged samples were 24.37, 33.15, 23.98, 20.14, 5.40 and 17.83 % for the 1, 1A, 1B, 2, 2A and 2B coded samples, respectively and the differences were determined to be significant ($p < 0.05$). The highest antioxidant activity was seen in the samples packaged after being treated with the Ca-ascorbate + citric acid solution (1B and 2B) and the lowest values were shown in the control samples (1 and 2).

Antioxidative vitamin C values were higher in the 1B and the 2B samples (Fig. 2). The maximum total phenolic content and the antioxidant activity of the 2B samples were found to be positively correlated with each of these parameters. Velioglu *et al.*[26] emphasized this positive correlation in research on some fruits, vegetables and cereals.

On the first day of storage, the aerobic mesophilic bacteria count was determined as < 10 in the 1A and the 2B samples (Table-3). The highest count (3.3×10^7 cfu g^{-1}) was found in the nitrogen enriched atmosphere packaged control samples (1) on the final day of storage. The psychrophilic bacteria count was similarly lower in the 1A, the 1B and the 2B coded samples (< 10), but it became higher (8.5×10^8 cfu g^{-1}) at the end of 20 days of storage in the samples packaged with nitrogen gas after being treated with Ca-ascorbate + citric acid (1B). Ready to eat vegetables harbor large and diverse populations of microorganisms and counts of 10^5-10^7 cfu g^{-1} are frequently present. Between 80-90 % of the bacteria were gram negative rods, predominantly *Pseudomonas*, *Enterobacter* and *Erwinia* species[27].

The final step in minimal processing is the removal of the excess water added during washing and is usually achieved by centrifuging[28]. Water above the surface of the vegetable causes the growth of microorganisms due to the water activity. This could be the result of a cross contamination, as the aerobic mesophilic bacteria counts of the control samples on the first day of storage were found to be higher than those of the raw material, as seen in Tables 2 and 3. The other samples presented an opposite conclusion. It could therefore be stated that the application of chlorine at the pre-processes stage showed a microbiologically limiting effect. This was especially true in the group 2 control sample, which had an increase in the total coliform by the 12th day of storage and in the group 1 control sample by the 16th day of storage. These control samples were also rejected by the panelists using the appearance criterion due to bombage formation (Fig. 3). Additionally, the textural deformation was shown to occur as a result of the microbial spoilage and it was considered an issue in the sensorial analysis results.

TABLE-3
MICROBIOLOGICAL ANALYSIS RESULTS OF MINIMALLY PROCESSED RADISHES

		1	1A	1B	2	2A	2B
1st day	Total aerobic mesophilic bacteria count (cfu g^{-1})	2.1×10^4	<10	3.3×10^2	3.7×10^4	1.2×10^2	<10
	Total psychrophilic bacteria count (cfu g^{-1})	5×10^4	<10	<10	6×10^2	5×10^1	<10
	Total coliform count (mpn g^{-1})	<3	<3	<3	<3	<3	<3
4th day	Total aerobic mesophilic bacteria count (cfu g^{-1})	6×10^4	9×10^2	2.6×10^3	2.4×10^5	5.9×10^2	4.5×10^2
	Total psychrophilic bacteria count (cfu g^{-1})	1.1×10^6	2.2×10^3	1.9×10^3	7.3×10^5	1×10^3	8.4×10^3
	Total coliform count (mpn g^{-1})	<3	<3	<3	<3	<3	<3
8th day	Total aerobic mesophilic bacteria count (cfu g^{-1})	4.9×10^5	1.2×10^3	5.7×10^3	2.8×10^5	6.6×10^3	3.3×10^3
	Total psychrophilic bacteria count (cfu g^{-1})	5.1×10^6	1.4×10^6	1.5×10^6	8×10^5	1.6×10^4	1.8×10^6
	Total coliform count (mpn g^{-1})	<3	<3	<3	<3	<3	<3
12th day	Total aerobic mesophilic bacteria count (cfu g^{-1})	3×10^6	5×10^4	1.3×10^4	3.7×10^5	1.7×10^4	2.1×10^4
	Total psychrophilic bacteria count (cfu g^{-1})	8.7×10^7	1.6×10^7	3.8×10^6	9.8×10^5	1.2×10^6	5.6×10^6
	Total coliform count (mpn g^{-1})	<3	<3	<3	1.8×10^2	<3	<3
16th day	Total aerobic mesophilic bacteria count (cfu g^{-1})	1.1×10^7	1.7×10^5	4×10^4	3.4×10^5	5×10^4	4.9×10^5
	Total psychrophilic bacteria count (cfu g^{-1})	2.6×10^8	1.6×10^7	3.7×10^6	2.3×10^7	2.5×10^6	3.1×10^7
	Total coliform count (mpn g^{-1})	1.2×10^4	<3	<3	1.1×10^3	<3	<3
20th day	Total aerobic mesophilic bacteria count (cfu g^{-1})	3.3×10^7	7.4×10^5	3×10^4	2.6×10^6	9×10^4	4.1×10^4
	Total psychrophilic bacteria count (cfu g^{-1})	3.9×10^8	5.7×10^8	8.5×10^8	7.2×10^7	2.5×10^7	3.3×10^7
	Total coliform count (mpn g^{-1})	4.9×10^4	75	1×10^4	1.4×10^3	1.2×10^4	2.2×10^3

Aguila *et al.*[29], used different sanitation methods for fresh cut radishes and determined that conventional sanitation (for 3 min in a solution of 200 mg L^{-1} of active chlorine) on the 10th day of storage [at 5 ºC (± 1 ºC) and 90 % (± 5 %) RH] resulted in psychotropic bacteria counts of 5.8×10^6 cfu g^{-1} that were equivalent to the maximum recommended limit. Heard[30] reported the total mesophilic bacteria count of shredded radishes as 3.9 log cfu g^{-1}.

In terms of colour parameters, the 1 coded control samples on the first day of storage were rejected by the panelists at 95 % probability and no difference was determined between the other samples on the 1st and the 4th storage days (Fig. 3). By the 8th day of storage, the 1A coded samples were rejected ($p < 0.05$). Similarly, Aguila *et al.*[9], confirmed that citric acid treatments caused strongly red colouration in the minimally processed radish and did not avoid browning during the cold storage.

Towards the end of the storage period, the preservation effect of the carbon dioxide became more pronounced and generally, these samples (2, 2A, 2B) were preferred.

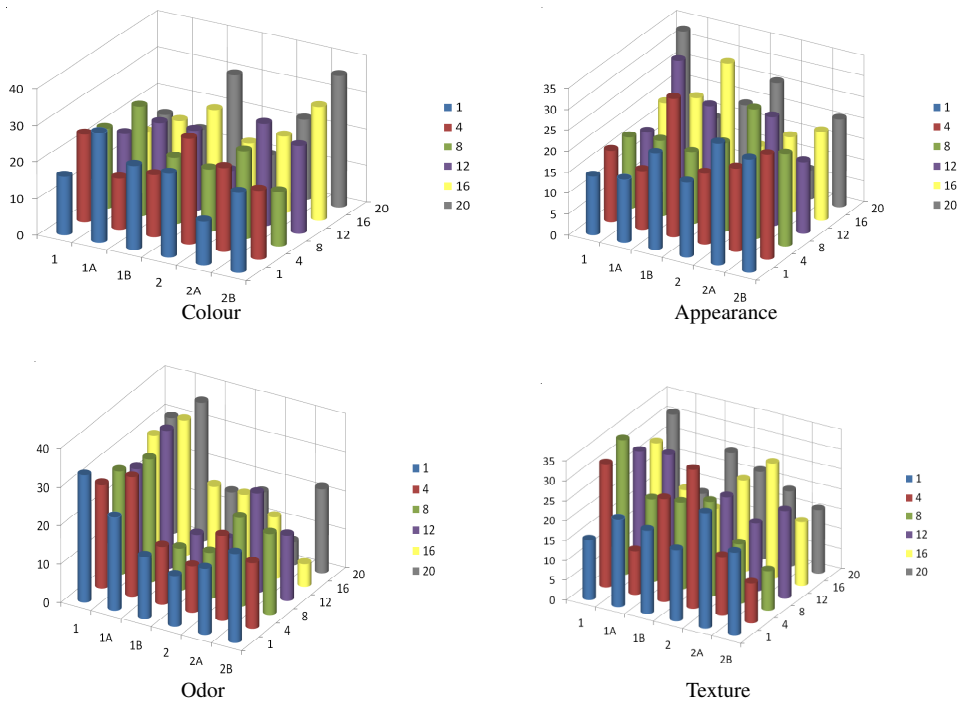

Fig. 3. Sensorial analysis results of minimally processed radishes

Aguila *et al.*[9], reported that in the minimally processed (shredded) radish roots that were immersed in the citric acid solution at a 2000 mg L^{-1} concentration; an ascorbic acid solution at a 2000 mg L^{-1} concentration and a citric acid solution (1000 mg L^{-1}) + ascorbic acid solution (1000 mg L^{-1}) with storage at 5 ºC (± 1 ºC) and 90 % (± 5 %) RH for 10 days had decreased lightness (L) values over time.

According to the appearance parameter, the samples were evaluated by brightness, crusty structure and bombage formation. While the 1 coded control samples were rejected on the 8th storage day, the 2B samples were preferred on the 4th and the 8th days and the 1B samples were preferred on the 12th day. There were no significant differences between the other days ($p < 0.05$). Generally, the citric acid with the Ca-ascorbate solution and the CO_2 enriched atmosphere conditions were more effective for preserving the product.

There were no significant differences between the samples during the 20 days storage in terms of the odour criterion, but on the final day, the control samples in group 2 were preferred and those in group 2B were rejected. The conservation of the carbon dioxide gas was limited and there was no protective effect between the citric acid alone or with the citric acid and the Ca-ascorbate together.

As a texture criterion, the 1B sample on the 4th and 16th days of storage, the 1A sample on the 12th day and the 1 sample on the 20th day of storage were rejected ($p < 0.05$). The samples in group 2 on the 12th day and those in group 2A on the

20th day were preferred. In general, because of the small changes that occurred between the samples, the panelists could not comment on the texture differences effectively.

Conclusion

After 20 days storage at 4 ± 2 °C, ascorbic acid, total phenolics, total carotenoids content and antioxidant activity of the radishes decreased; whereas aerobic mesophilic, psychrophilic and total coliform bacteria counts were increased. Generally, the greater reductions occurred in the control samples that were not treated with any chemicals and that were packed under modified atmosphere conditions. These samples were also rejected by the panelists at the 95 % probability because of their deleterious texture and appearance. The Ca-ascorbate + citric acid treatment with the carbon dioxide enriched atmosphere was found to be more effective with regard to limiting the weight and total dry matter losses, as well as the microbiological spoilage of the packaged radishes. This treatment also preserved the vegetables organoleptically.

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REFERENCES

1. C.L.G. Chu, W.T. Liu and J. Ma, *Int. J. Food Sci. Tech.*, **40**, 879 (2005).
2. S. Basay and A. Eris, *Bahçe*, **32**, 35 (2003).
3. K. Minami and J.T. Netto, Cultura do Rabanete, ESALQ-Departamento de Horticultura, Piracicaba (1994).
4. J.B. Salah-Abbès, S. Abes, Z. Ouanes, Z. Houas, M.A. Abdel-Wahhab, H. Bacha and R. Oueslati, *J. Appl. Toxicol.*, **28**, 6 (2008).
5. Anonymous, USDA National Nutrient Database for Standard Reference, Release 22 http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl (2009).
6. A.E. Watada, *Food Biotech.*, **6**, 229 (1997).
7. R. Ahvenainen, *Trends Food Sci. Tech.*, **7**, 179 (1996).
8. G.A. Gonzalez-Aguilar, C.Y. Wang and J.G. Buta, *Lebensm.-Wiss. u.-Tech*. **34**, 324 (2001).
9. J.S. Aguila, F.F. Sasaki, L.S. Heiffig, E. Moisés, M. Ortega, M.J. Trevisan and R.A. Kluge, *Braz Arch. Biol. Tech.*, **51**, 1217 (2008).
10. J.S. Aguila, F.F. Sasaki, L.S. Heiffig, E. Moisés, M. Ortega, A.P. Jacomino and R.A. Kluge, *Postharvest Biol. Tech*., **40**, 149 (2006).
11. B. Cemeroglu, Gida Analizleri, Gida Teknolojisi Dernegi Yayinlari, No: 34, Bizim Büro Basimevi. Ankara, p. 535 (2007).
12. D. Zhang and Y. Hamauzu, *Food Chem.*, **88**, 503 (2004).
13. G.A. Spanos and R.E. Wrolstad, *J. Agric. Food Chem.*, **38**, 817 (1990).
14. T. Altug, Duyusal Test Teknikleri. Ege Üniversitesi Mühendislik Fakültesi Ders Kitaplari, Yayin No: 28, Izmir, p. 56 (1993).
15. G.L. Robertson, Food Packaging, Principles and Practice, Edited by Marcel Dekker, New York (1993).
16. J.S. Aguila, F.F. Sasaki, L.S. Heiffig, E. Moisés, M. Ortega, A.P. Jacomino and R.A. Kluge, *Ciência Rural*, **37**, 565 (2007).

17. L.F. Reyes, J.E. Villarreal and L. Cisneros-Zevallos, *Food Chem.*, **101**, 1254 (2007).
18. S.K. Lee and A.A. Kader, *Postharvest Biol. Tech*., **20**, 207 (2000).
19. M. Bandyopadhyay, R. Chakraborty and U. Raychaudhuri, *J. Food Process Preserv.*, **31**, 714 (2007).
20. W. Kalt, *J. Food Sci.*, **70**, 11 (2005).
21. M.E. Saltveit, Physical and Physiological Changes in Minimally Processed Fruits and Vegetables, In eds.: F.A. Toma's-Barbera'n and R.J. Robins, Phytochemistry of Fruit and Vegetables, Proceedings of the Phytochemical Society of Europe (Vol. 41, pp. 205-220), New York, NY: Oxford University (1997).
22. R.A. Dixon and N.L. Paiva, *Plant Cell*, **7**, 1085 (1995).
23. J.B. Heredia and L. Cisneros-Zevallos, Wounding Stress on Carrots Increases the Antioxidant Capacity and the Phenolics Content, Institute of Food Technologists Annual Meeting Book of Abstracts, p. 180 (2002).
24. H. Kang and M.E. Saltveit, *J. Agric. Food Chem.*, **50**, 7536 (2002).
25. L.F. Reyes and L. Cisneros-Zevallos, *J. Agric. Food Chem.*, **51**, 5296 (2003).
26. Y.S. Velioglu, G. Mazza, L. Gao and B.D. Oomah, *J. Agric. Food Chem.*, **46**, 4113 (1998).
27. G.A. Francis, C. Thomas and D. O'beirne, *Int. Safety Food Sci. Tech.*, **34**, 1 (1999).
28. V.G. Reyes, *Food Aust.*, **48**, 87 (1996).
29. J.S. Aguila, F.F. Sasaki, L.S. Heiffig, M.G. Ongarelli, C.R. Gallo, A.P. Jacomino and R.A. Kluge, *Horticult. Brasil.*, **24**, 75 (2006).
30. G.M. Heard, Microbiology of Fresh-Cut Produce, In: Fresh-Cut Fruiits and Vegetables Science, Technology and Market. Ed. By. O. Lamikanra, CRC Press LLC (2002).

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