EVALUATION OF SOME QUALITY PARAMETERS OF MINIMALY PROCESSED CELERY BY QUANTITATIVE ANALYSIS

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ABSTRACT

The celeries were treated with citric acid (1.5%) and L-cysteine (0.5%) following preprocessing. The samples were packed in two different modified atmosphere conditions. After 20 days of storage at 4 ± 2C, weight loss, total dry matter, total acidity, total phenolics, ascorbic acid, total carotenoids, color, polyphenoloxidase (PPO) and antioxidant activity of the samples were determined, and total bacteria and total coliform were counted. At the end of the storage period, antioxidant activity was decreased as 26.23%. Generally, citric acid treatment with N_2 and CO_2 atmosphere application was more effective than L-cysteine treatment for preservation of phenolic compounds. The L-cysteine–treated samples had the minimum PPO activity and were also preferred by panelists according to color criteria. During storage period, because of oxidation of conjugated bond, carotenoids were oxidized and decreased by approximately 45.61%. Weight loss of the modified atmosphere packaging celeries during storage period was changed between 0.18 and 0.32%. The samples treated with L-cysteine preserved their original color until the 10 days of storage, but the same samples were rejected by panelists for odor criteria.

The big positive correlation coefficients showed was that the ratio of positive interactions was more than negative interactions. For this reason, lots of analytical criteria determined in celery increased with the increment of the other criteria. According to the results of the cluster analysis, analytical criteria were gathered in three main clusters. PPO activity element represented the first factor and antioxidant activity variable represented the second factor.

PRACTICAL APPLICATIONS

Celery is a popular ingredient of prepared soups and salads. Unfortunately, this vegetable is highly perishable and is therefore difficult to store in a fresh state for an extended period of time. In order to extend the shelf life of celery, several treatment methods are used to inactivate enzymes and kill pathogens and other microorganisms that may result in spoilage. The main contribution of this work was to determine the effect of different treatment on the quality attributes of minimally processed celery stored at 4 ± 2C for 20 days. For this reason, two different solutions (citric acid and L-cysteine) were used for following preprocessing. The samples were packed in two different modified atmosphere conditions. Physicochemical and microbiological analyses were done during storage. For statistical evaluation, factorial analysis with principal component and cluster analysis were used. The proposed procedure involves several analyses for dimension reduction of data that are conducted by principal component analysis.

INTRODUCTION

Celery (*Apium graveolens* L.) is a popular herb and vegetable in Europe and in the Mediterranean region; particularly, the roots are often used as a vegetable in Turkey (Yağar 2004). It is a popular component of prepared soups and salads. Celery is a hypocalorific vegetable; every edible 100 g gives only 20 Kcal, yet nutritionally, it has good vitamin C (32.00 mg) and vitamin A (0.207 mg) levels, and is rich in potassium (280.00 mg) (Rizzo and Muratore 2009). The consumption of root celery is recommended because of its dietary and therapeutic properties (Radziejewska-Kubzdela and Czapski 2004).

Because celery presents low respiratory activity, very low ethylene production rate and moderate sensitivity to this hormone, it is suitable for minimal processing (Cantwell 2001; Vina *et al.* 2007). Minimal processing of celery provides convenience for consumers and many economic benefits for producers.

Modified atmosphere packaging (MAP) is the alteration of the gaseous environment produced as a result of respiration or by the addition and removal of gases from small-sized food packages to manipulate the levels of O_2, CO_2, N_2 and/or C_2H_4. Active modification can be done by pulling a slight vacuum and replacing the package atmosphere with the desired gas mixture (Das 2004). Depleted O_2 and/or enriched CO_2 levels can reduce respiration, delay ripening, decrease ethylene production and sensitivity, retard textural softening, slow down compositional changes associated with ripening, reduce chlorophyll degradation and enzymatic browning, alleviate physiological disorders and chilling injury, maintain color, and preserve vitamins of fresh produce, thereby resulting an extension in shelf life and improvement in quality (Farber 1991; Day 1993).

Vina and Chaves (2006) studied the effect of storage temperature (0, 4 and 10C) and time on the antioxidant capacity (AC) of fresh-cut celery disinfected by immersion in chlorinated water (100 ppm active chlorine, pH 6–6.5, 8C) for 3 min and rinsed in a manual domestic centrifuge. Materials were packaged in polystyrene trays sealed with polyvinyl chloride (PVC) film. The antioxidant power presented similar behavior for all temperatures tested, decreasing after the first 7 days and then increasing up to day 14. Such increase coincided with an elevation of the ascorbic acid (AA) content, which was stronger for higher temperatures. As a general conclusion, minimally processed celery retained its initial AC for a period of 21 days at 0C, showing the lowest levels of browning potential at this temperature.

Vina and Chaves (2007) assessed the effect of temperature on respiratory activity and total phenol and flavonoid content in precut celery within the 24 h following minimal processing. To this end, celery petioles were cut in strips, conditioned in polyethylene terephthalate trays covered with PVC film and stored at 0, 10 and 20C. At 0C, the total phenol contents remained basically constant, although at 10C, it increased considerably 2 h after applying the cutting stress. At 20C, the increase observed was less important. The flavones identified in precut celery were apigenin and luteolin, whose concentrations also increased between 2 and 6 h after processing. However, exposure for 24 h at 0C produced a considerable decrease in total flavonoids.

One of the main problems in minimal processing of celery roots is enzymatic browning of the flesh. The mechanism of the browning reaction is connected with the activity of enzymes from the group of polyphenoloxidase (PPO), catalyzing phenolic oxidation with oxygen. In this reaction, quinones are formed. Then they polymerize to colorful high molecular weight compounds. The darkening of the shredded raw material is observed as a result of this reaction. The disadvantageous change in the product color lowers its commercial value and shortens its shelf life. For this reason, varieties with limited susceptibility to browning are recommended for processing. The flesh of raw material destined for minimal processing material should be compact and firm, with no tendency to form empty spaces. Thus, a proper selection of the raw material plays an essential role in determining the quality and shelf life of minimally processed vegetables and fruits (Radziejewska-Kubzdela and Czapski 2004).

Yağar (2004) reported the most effective inhibitor of PPO was L-cysteine. PPO changes phenolic compounds to brown pigments and also causes undesirable taste and loss of nutritional quality (Vamos-Vigyazo 1995; Lamikanra 2002).

Reyes *et al.* (2007) reported that wounding of fresh produce may elicit an increase in AC associated with wound-induced phenolic compounds. The amount and profile of wound-induced soluble phenolics are dependent on the type of tissue, initial levels of reduced AA and soluble phenolic compounds. Reduced AA is greatly affected by wounding. After a storage period of 15C for 2 days, phenolic matter content, AC and phenylalanine lyase activity of shredded celery were increased 30, 442 and 750%, respectively. Moreover, a decrease of AA content was determined as 53%.

Vina and Chaves (2003) assessed the effect of storage temperature (0 and 10C) on variations in texture (hardness) and lignin content of minimally processed celery. Increases in lignin content were observed, which could be related to corresponding texture increases during the first few days in cold storage. There was no evidence that lignification occurred by a cicatrix-forming process in the wounds caused during cutting.

A decay of fresh-cut celery segments stored at <5C in sealed film bags began with water soaking of the cut surfaces. Slimy moisture accumulated inside the bags. The segments completely soaked in water softened, discolored and sometimes disintegrated. Total aerobic bacterial populations isolated from decayed segments ranged from $\log_{10}$ 7.0–7.7 colony-

forming units (cfu/g) tissue weight. The predominant bacteria, identified by fatty acid analysis as *Pseudomonas fluorescens* and *P. marginalis*, caused water soaking, soft rot and discoloration in freshly inoculated celery tissues stored at 5 or 25C. *Leuconostoc mesenteroides* was also isolated and may have been responsible for slime production (Robbs *et al*. 2006).

Because of its hard shell and texture, peeling of celery is effortful. So, the consumers prefer using the fresh and also half-finished products for cooking. This research was undertaken to determine the conditions required for extending the shelf life of minimally processed celery by applying MAP. The chemical composition and the sensory properties of the materials during the 20 days of storage were then investigated in an attempt to determine the most effective treatment and the optimum processing parameters.

MATERIALS AND METHODS

Fresh celeries were purchased from local markets. Green leaves and damaged stalks were removed, and the rest was washed, peeled and cut by hand to 5 cm in thickness with a sharp stainless steel knife. Vegetables were put into 1,500 ppm Na-metabisulphite +1% NaCl solution for inhibiting enzymatic oxidation. After washing with tap water, they were dip-treated with 150 ppm Na-hypochloride (pH: 6.8) for 5 min then washed again with tap water to remove the dipping solution and the typical chlorine odor. Vegetables were divided into two groups. 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 L-cysteine (0.5%) for 10 min according to preexperiments related with literature data (Molnar-Perl and Friedman 1990; Richard-Forget *et al*. 1992; Güneş and Lee 1997; Rocculi *et al*. 2007). Centrifugation was used to remove of excess solution. They were then packed individually (approximately 200 g) in polypropylene dishes ($190 \times 140 \times 50$ mm^3) with 42 μ biaxially oriented polypropylene (BOPP) (top film) packages. The optimum packaging film selection was done according to the preliminary studies.

According to the manufacturer's specifications sheet, the O_2 and the CO_2 transmission rates of the film were 1,775.40 cc/m^2/day and 6,428.60 cc/m^2/day, respectively at 24C. The ReeTray 25 total carotenoids (TC) model machine was used for the packaging process. The seal temperature was set at 160C and the seal time was 3 s. The packages were then separated into two groups. The first group was sealed with an 80% vacuum with 80% N_2 (20% atmospheric air +80% N_2) while the second group was sealed with an 80% vacuum with 70% N_2 + 10% CO_2 (20% atmospheric air +70% N_2 + 10% CO_2). The minimally processed vegetables were stored at 4 ± 2C for 20 days. The packaged celeries were coded as follow:

(1) the samples packaged in the N_2, the control sample of the first group,

1A: the samples packaged in the N_2 after the citric acid treatment,

1B: the samples packaged in the N_2 after the L-cysteine treatment,

(2) the samples packaged in the $N_2 + CO_2$, the control sample of the second group,

2A: the samples packaged in the $N_2 + CO_2$ after the citric acid treatment,

2B: the samples packaged in the $N_2 + CO_2$ after the L-cysteine treatment.

Chemical Analyses

The amount of the total dry matter (TDM) was analyzed using the oven-drying method. Ascorbic acid was determined directly by spectrophotometry using a 2,6-dichlorophenol indophenol dye (Cemeroğlu 2007). The antioxidant activity (AOX) was identified spectrophotometrically by using the 2,2-diphenylpicrylhydrazyl (DPPH) radical. The inhibition percentage of the DPPH free radical at 517 nm was calculated (Zhang and Hamauzu 2004). The method employed for the total phenolics (TP) was based on Folin–Ciocalteau's phenol reagent (Spanos and Wrolstad 1990). The spectrophotometric measurements for TP were carried out at 452 nm using a Shimatzu UV 1208 model spectrophotometer and the results were calculated as the gallic acid equivalent. The TC were determined by using the spectrophotometric method (Kiliç *et al*. 1991). The PPO activity was assayed spectrophotometrically by a modified method based on Galeazzi *et al.* (1981) and Tan and Harris (1995). The reaction mixture contained 0.1 mL crude extract and 2.9 mL substrate solution (0.02 mol/L catechol in 0.05 mol/L phosphate buffer, pH 6.5). The rate of catechol oxidation was followed at 420 nm for 10 min at 25C. The unit for the PPO activity was defined in a change of 0.001 in absorbance at the conditions of the assay. Total acidity (TA) was determined by titration of samples with 0.1 N NaOH and expressed in terms of % (w/w) citric acid (Cemeroğlu 2007). The color of the vegetables (reflectance values) was measured using D 25APC2Δ model Hunterlab colorimeter and expressed as L^*, a^* and b^* values (Bakker *et al*. 1986). All tests were conducted in triplicate along 20 days and averaged. Analyses were done in triplicate.

Gas Analyses

Head-space gas (O_2 and CO_2) composition was measured using a gas analyzer (PBI Dansensor – Checkpoint O_2/CO_2).

Physiological Losses in Weight (WL)

The initial weight of the packaged samples was noted and periodic observations on the WL were made by weighing the samples. The results were expressed as a cumulative percentage loss.

Microbiological Counts

Total bacteria count (TBC) (mesophilic aerobic) was determined by using plate count agar (Merck, Darmstadt, Germany) after 2 days incubation at 35C, and the count was expressed as cfu/g (Maturin and Peeler 2001). Coliform bacteria (TCC) were counted on Lauryl sulfate broth and brilliant green lactose broth by using most probable number (MPN) method. The results were expressed as MPN/g by using related tables (Blodget 2006).

Sensory Evaluation

The MAP samples were organoleptically evaluated for their quality attributes, such as color, appearance, odor and texture, by a panel consisting of eight members who were all from Food Engineering Department, using a ranking test (Kramer and Twigg 1984, Altuğ Onoğur and Elmaci 2011) and the results were analyzed using the expanded tables based on the number of panelists and the number of samples, a range of values for no significant difference at 5% level was obtained. Before the sensory analysis, the panelists, were told, trained and directed about the products and parameters. According to the procedure mentioned earlier, test samples with ranksum scores below the range were significantly superior and those with scores above the range were significantly inferior while the ones with ranksum scores within the range were not significantly different. The panelists would order the samples from the most favorite to the least favorite by giving a point between 1 and 6. 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

Factorial analysis with principal component and cluster analysis were used in the study to evaluate the obtained data by IBM Statistical Package for the Social Sciences software. The proposed procedure involves several analyses for dimension reduction of data that are conducted by principal component analysis (PCA). In the first phase, factor analysis has been used for identification of the number of principal components. In the second phase, the cluster method has been used to determine disparities and similarities. PCA is based on the maximum variance linear combinations of beginning variables (Johnson and Wichern 1992). The PCA method forms new independent sets that are different from the beginning set. Reflecting of the variables at "R" (dimensional space) is one of advantages of the method. The term of cluster analysis encompasses a large number of techniques developed to identify groups of observations with similar characteristics (Hair *et al*. 1995). It is based on the minimizing the variance in the group and maximizing the variance among groups (Fitzmaurice and Laird 1995). The theory behind clustering is an expected positive relationship between the variables' distance and the similarity of the observations. The most widely used method in cluster analysis as the similarity measure is Euclidean distance measure (Kendall 1980). Cluster analysis is based on minimizing the variance among groups. Clustering can be conducted directly on the data set or as a two-step procedure in combination with other statistical methods like factor analysis and PCA. According to the algorithm, the graphical display of grouping results of acquired data is made with drawing the two-dimensional diagram. The presentation of a graphic, which is also called as dendogram, can be presented in many forms such as single or complete linkage. The analysis filters automatically determine the primary and dominant variables that characterize each cluster (Vural 2007).

TABLE 1. THE RESULTS OF THE ANALYSIS OF FRESH CELERY (MEANS ± STANDARD DEVIATION)

Antioxidant activity (%)	93.98 ± 2.59
Total phenolic compounds (mg GAE*/100 g)	556.29 ± 6.17
Ascorbic acid (mg/100 g)	8.5 ± 0.25
PPO activity (U/g)	3,500.90 ± 0.00
Total dry matter (g/100 g)	11.14 ± 0.01
Total acidity** (g/100 g)	0.11 ± 0.00
Total carotenoids (mg/kg)	51.43 ± 1.74
*L** (brightness)	61.3
*a** (red – green)	0.8
*b** (yellow – blue)	17.0
Total bacteria count (cfu/g)	1×10^2
Total coliform count (MPN/g)	<3

* As gallic acid equivalent.

** As citric acid.

PPO, polyphenoloxidase; GAE, gallic acid equivalent; cfu, colony-forming units; MPN, most probable number.

RESULTS AND DISCUSSION

The mean width and length of the raw material were 8 and 9 cm, respectively. The average rate of waste was determined as 25%. Flesh/peel ratio was approximately 3:1. The results of the analysis of fresh celery were given in Table 1. TDM content of the raw material was similar to the results of the previous studies (Baysal 1988; Eşiyok *et al*. 2003). The amount of AA of celery samples was changed between 3.1 and 7.4 mg/100 g (Zhang *et al*. 2005; Reyes *et al*. 2007; Anon 2011). Kubzdela and Czapski (2004) determined PPO activity of the celery as 1180–4330 U/100 g. The sample used in this research has lower PPO activity than the results mentioned earlier. The differences between these results could be originated from variety, climatic conditions, maturation and storage conditions.

The change of AOX of celery samples was statistically significant according to application, storage period and application × storage period ($P < 0.01$). At the end of the storage period AOX was decreased as 26.23%. At every analysis period the samples 2A and 2B had higher AOX than 1A and 1B (Fig. 1). Also 2A and 2B had higher amount of AA, carotenoids and TP. Reyes *et al.* (2007) reported positive correlation between AOX and phenolic matter.

While the change of TP of celery samples was statistically significant according to application and storage period, it was nonsignificant for application × storage period ($P < 0.01$). Kubzdela and Czapski (2004) determined TP of four celery varieties as 49.6–136.6 mg/100 g. After storage at 4C for 6 months these values changed to 46.2–91.4 mg/100 g. Our results were higher than those obtained by these researchers. The statistically significant differences between the results could have originated from variety and process applied. Generally citric acid treatment was more effective than L-cysteine treatment for preservation of phenolic compounds. N_2 and CO_2 atmosphere have also more effective than CO_2 atmosphere for retention of phenolics (Fig. 1).

The change of AA of celery samples was statistically significant according to application, storage period and application × storage period ($P < 0.01$). Citric acid treatment decreased pH, stabilized AA and slowed down the activity of ascorbic acid oxidase enzyme and degradation of AA.

The change of PPO activity of celery samples was statistically significant according to application, storage period and application × storage period ($P < 0.01$). PPO activity increased rapidly at the beginning of the storage period, then decreased at the end (Fig. 1). This could be related to decrease of O_2 and increase of CO_2 concentrations. The samples 1B and 2B, which were treated with L-cysteine, had the minimum PPO activity and were also preferred by the panelists according to color criteria. The control samples (1 and 2) had the highest PPO activity and also the reductions of the amounts of AA and TC were also the highest. When comparing the treatment and gas atmosphere, L-cysteine and N_2 and CO_2 combination were the most effective.

The difference between TDM of fresh-cut celeries was statistically significant according to application, storage period and application × storage period ($P < 0.01$). TDM contents of fresh-cut celeries were found lower than TDM of the control samples because of the losses (sugar, vitamins, minerals etc.) during soaking in the solutions (Fig. 1). Eşiyok *et al.* (2003) determined TDM of Tall Utah Claret variety celeries harvested in different seasons as between 10.72 and 11.04 g/100 g. These values were consistent with our results.

Although the difference between TA of fresh-cut celeries was statistically significant ($P < 0.01$), it was not changed greatly during storage period. TA (as citric acid) of samples was determined in first day 0.10–0.12 g/100 g, third day and fifth day 0.09–0.11 g/100 g, seventh, 10th and 14th day 0.10–0.11 g/100 g, 20th day 0.10–0.12 g/100 g.

The difference between TC content of samples was statistically significant according to application, storage period and application × storage period ($P < 0.01$). During storage period, because of oxidation of conjugated bonds, carotenoids could be oxidized and decreased approximately 45.61%. When comparing the effects of the applications, the sample soaked in L-cysteine solution for 10 min (1B) had lower amount of TC than the sample soaked in with citric acid solution for 5 min (Fig. 1). It might be related with the longer treatment time, and so the higher diffusion of carotenoids from vegetable to the solution.

In general, carotenoids are hydrophobic molecules and thus are soluble only in organic solvents, having only limited solubility in water. Addition of hydroxyl groups to the end groups causes the carotenoid to become more polar, affecting its solubility in various organic solvents. Alternatively, carotenoids can solubilize in aqueous environments by prior integration into liposornes or into cyclic oligosaccharides such as cyclodextrins (Ishida and Bartley 2005).

Color values of MAP samples were given in Table 2. Although L^* values of the samples were similar, the sample 1B also preferred by panelists according to color determination, had the highest L^* value.

O_2 and CO_2 concentrations of MAP celeries were given in Table 3. O_2 in the packages exhausted with respiration in 10 days, and CO_2 ratio increased. In preliminary studies, vegetables were packaged in different type of films, when O_2 and CO_2 permeability of film were high, celeries browned because of their high-enzyme activity. On the contrary, when low permeability film was chosen, bulge formed. The most suitable film (BOPP), which solved these problems was used for packaging. However, equilibrium gas composition could not be reached and CO_2 concentration increased to a level that causing anaerobic respiration.

TBC of the control samples (1, 2) was higher than the other samples after the first day of storage and TCC increased after the fifth day of storage. Citric acid treatment with nitrogen and CO_2 atmosphere (2A) was the most effective and shelf life could be elongated up to 2 weeks (Table 4).

During the storage period, WL of the MAP celeries were determined as 0.27% (1), 0.32% (1A), 0.29% (1B), 0.22% (2), 0.23% (2A) and 0.18% (2B). Especially metabolic activity of the sample (2B) treated with L-cysteine and packaged in N_2 and CO_2 atmosphere slowed down and had the lowest weight loss.

According to the results of the sensory analysis, when the sample 2A was preferred for color criteria, the control sample 2 was rejected. The difference between the sample 1 and 1A was not statistically significant ($P < 0.01$). The samples treated with L-cysteine preserved their original color until 10 days of storage. Control samples oxidized rapidly at the

TABLE 2. *L**, *a**, *b** VALUES OF MODIFIED ATMOSPHERE PACKAGING CELERIES

		1st day	3rd day	5th day	7th day	10th day	14th day	20th day
1	*L**	71.4	59.3	63.7	53.1	66.1	60.0	60.8
	*a**	–2.4	0.1	–1.1	3.3	–2.1	0.2	–1.1
	*b**	19.3	18.4	21.8	19.2	23.1	19.5	19.1
1A	*L**	54.2	59.6	62.6	56.6	65.6	50.2	48.4
	*a**	2.3	–0.8	–1.7	–0.2	–2.0	1.2	0.7
	*b**	18.4	17.8	21.4	19.5	18.2	16.7	16.3
1B	*L**	71.9	65.5	68.5	75.0	65.6	57.6	58.7
	*a**	–3.0	0.1	–4.1	–3.4	–2.5	2.7	–2.3
	*b**	23.8	27.8	23.6	20.7	24.9	17.8	19.8
2	*L**	66.1	69.1	61.3	63.1	49.3	60.7	59.5
	*a**	0.2	–4.5	0.9	0.9	2.4	–0.3	0.6
	*b**	19.7	22.5	20.8	19.5	17.2	18.4	20.7
2A	*L**	67.4	52.5	53.3	59.3	52.5	51.3	53.4
	*a**	1.4	2.1	2.8	3.7	1.7	0.3	0.9
	*b**	18.5	16.5	18.8	18.7	17.4	16.7	17.7
2B	*L**	57.7	55.5	62.5	61.1	62.8	55.9	60.2
	*a**	1.3	0.6	–0.6	1.6	–2.2	2.8	–2.3
	*b**	20.7	19.9	26.4	18.3	24.8	19.2	21.4

TABLE 3. GAS COMPOSITION OF MODIFIED ATMOSPHERE PACKAGING CELERIES

Storage period	O_2 concentration (%)	CO_2 concentration (%)
1st day	0.4–2.3	5.2–13.2
3rd day	0–1.6	11.2–19.5
5th day	0–1.0	15.7–23.3
7th day	0–0.3	19.6–31.8
10th day	–	24.4–34.6
14th day	–	27.5–34.7
20th day	–	31.1–35.4

beginning of the storage, but the other samples also browned through the end of the storage. The samples 1B and 2B treated with L-cysteine were rejected by panelists for odor criteria. L-cysteine, which is a sulfur-containing compound, left a foreign odor in vegetables. Control samples (1 and 2) were preferred by panelists because they were not treated with any chemical. The samples were evaluated for brightness, crusting on the surface and bulge formation for determining appearance criteria. Control samples rapidly browned and bulge formation occurred in their packages; for this reason they were rejected especially for the first 10 days. The appearance of the samples treated with L-cysteine was better than that of the samples treated with citric acid. The difference between the samples according to the appearance criteria was not statistically significant after the second week. Panelists could not evaluate texture criteria of the samples effectively because of their similar textural properties.

Factor analysis by principal component and the cluster analysis have been used in the study to evaluate available data.

TABLE 4. RESULT OF THE MICROBIOLOGICAL ANALYSIS OF MODIFIED ATMOSPHERE PACKAGING CELERIES

		1	1A	1B	2	2A	2B
1st day	Total bacteria count (cfu/g)	1×10^3	<10	<10	9.4×10^3	<10	<10
	Total coliform count (MPN/g)	<3	<3	<3	<3	<3	<3
3rd day	Total bacteria count (cfu/g)	4×10^4	<10	<10	1.2×10^4	<10	<10
	Total coliform count (MPN/g)	3.6	<3	<3	<3	<3	<3
5th day	Total bacteria count (cfu/g)	1.5×10^5	<10	<10	1.1×10^5	<10	<10
	Total coliform count (MPN/g)	43	<3	<3	95	<3	<3
7th day	Total bacteria count (cfu/g)	1.5×10^6	<10	<10	2.7×10^5	<10	1.2×10^2
	Total coliform count (MPN/g)	2.1×10^2	<3	<3	1.1×10^3	<3	<3
10th day	Total bacteria count (cfu/g)	4.2×10^6	6.8	5.5×10^1	1.2×10^6	6.5×10^1	3.3×10^2
	Total coliform count (MPN/g)	1.1×10^3	<3	<3	1.1×10^3	<3	<3
14th day	Total bacteria count (cfu/g)	4.3×10^6	3×10^1	3.9×10^4	2.1×10^6	2.7×10^2	3.4×10^2
	Total coliform count (MPN/g)	1.1×10^3	<3	<3	1.1×10^3	<3	23
20thday	Total bacteria count (cfu/g)	1.9×10^7	3×10^6	8.3×10^6	1.9×10^7	3.7×10^7	1.2×10^4
	Total coliform count (MPN/g)	1.1×10^3	2.7×10^3	1.1×10^3	1.1×10^3	15	23

cfu, colony-forming units; MPN, most probable number.

TABLE 5. RESULTS OF DESCRIPTIVE STATISTICS ANALYSES

	Number of samples	Mean ($\bar{x}$)	Minimum	Maximum	Standard deviation* (S_x)	Variation coefficient ($S_x/\bar{x})_x100$
Antioxidant activity	126	74.966	54.2200	94.420	9.483	12.65
Total phenolics	126	419.953	338.9800	519.300	38.149	9.08
Ascorbic acid	126	6.683	4.3800	8.220	0.914	13.68
Total acidity	126	0.103	0.0930	0.118	0.007	0.07
Total carotenoids	126	26.914	11.0900	55.350	8.429	31.32
Total dry matter	126	10.461	10.1955	10.878	0.210	2.01
Polyphenoloxidase activity	126	2,115.260	828.1000	4,864.300	1,180.838	55.82

* α, 0.05 test control level.

In the first phase, factor analysis has been used for identification of the number of PCAs. In the second phase, cluster method has been used to determine disparities and similarities. The results have been presented by graphs and tables.

The results of the descriptive statistical analysis were given in Table 5. Variation coefficients of TC and PPO activity were significantly high. The reason of this was due to their high standard deviations. According to procedures used in the tests, values of these elements showed important difference. The applied treatments caused big changes of the values of these elements. For other variables, important differences did not occur according to the procedures. The means of other five elements highly represented the values of the group. All of the variables indicated a normal distribution (1% confidence level) (Shapiro–Wilks *W*-test).

The results of the correlation analysis of variables were given in Table 6. Except from five correlation coefficients (marked), other coefficients were determined as statistically significant at lower than 95% level. Between some variables, there were some negative coefficients. For this reason, it could be said that some variables negatively interact with some others, but the ratio of these negative interactions were low. However, big positive coefficients showed that the ratio of positive interactions was more than negative interactions.

TABLE 6. CORRELATION COEFFICIENTS OF VARIABLES ANALYZED

	AOX	TP	AA	TA	TC	TDM	PPO
AOX	1.00	0.72	0.39	0.00	0.75	–0.47	–0.28
TP	0.72	1.0	0.74	–0.34	0.89	0.09	0.17
AA	0.39	0.74	1.00	–0.31	0.72	0.35	0.36
TA	0.00*	–0.34	–0.31	1.00	–0.22	0.22	–0.25
TC	0.75	0.89	0.72	–0.22	1.00	0.03	0.08
TDM	–0.47	0.09*	0.35	–0.22	0.03*	1.00	0.64
FPPO	–0.28	0.17*	0.36	–0.25	0.08*	0.64	1.00

* Marked correlations are statistically significant at $P > 0.05$ level.
AOX, antioxidant activity; TP, total phenolics; AA, ascorbic acid; TA, total acidity; TC, total carotenoids; TDM, total dry matter; PPO, polyphenoloxidase.

Analytical criteria for statistical analyses were coded as follows:

V1: AOX, V2: TP, V3: AA, V4: TA, V5: TC, V6: TDM and V7: PPO activity.

According to the results of the cluster analysis, analytical criteria were gathered in three main clusters (Fig. 2). While PPO activity and TP were separated as a different group, others built up the third group because of their connections between them. AOX as a member of the third group had the highest connection between others in its respective group. Between all analytical criteria, PPO activity had the highest common connection.

As seen in Table 7, variables were separated into two groups. While TA, TDM and PPO were presented in the first group, AOX, TP and AA were presented in the second group. According to the very high variance value of TA, this variable had no important connection between the others. For this reason in the first factor only two variables were statistically important. As regards to these groups range of the data were presented at Fig. 2.

CONCLUSION

Generally N_2 and CO_2 atmosphere had also more effective than CO_2 atmosphere for protection of phenolics and also AOX. Besides, the citric acid treatment was more effective than L-cysteine treatment for preservation of phenolic compounds. The L-cysteine–treated samples (1B and 2B) had the minimum PPO activity and also preferred by panelist according to color criteria. According to microbiological analysis results, the citric acid treatment with N_2 and CO_2 atmosphere (2A) was more effective and shelf life could be elongated up to 2 weeks. The same treatment also preserved the AA levels of celery. Especially metabolic activity of the sample treated with L-cysteine and packaged in N_2 and CO_2 atmosphere slowed down and had the lowest weight loss. L-cysteine, which is a sulfur-containing compound left foreign odor in vegetables, so these samples (1B and 2B) were rejected by panelists for

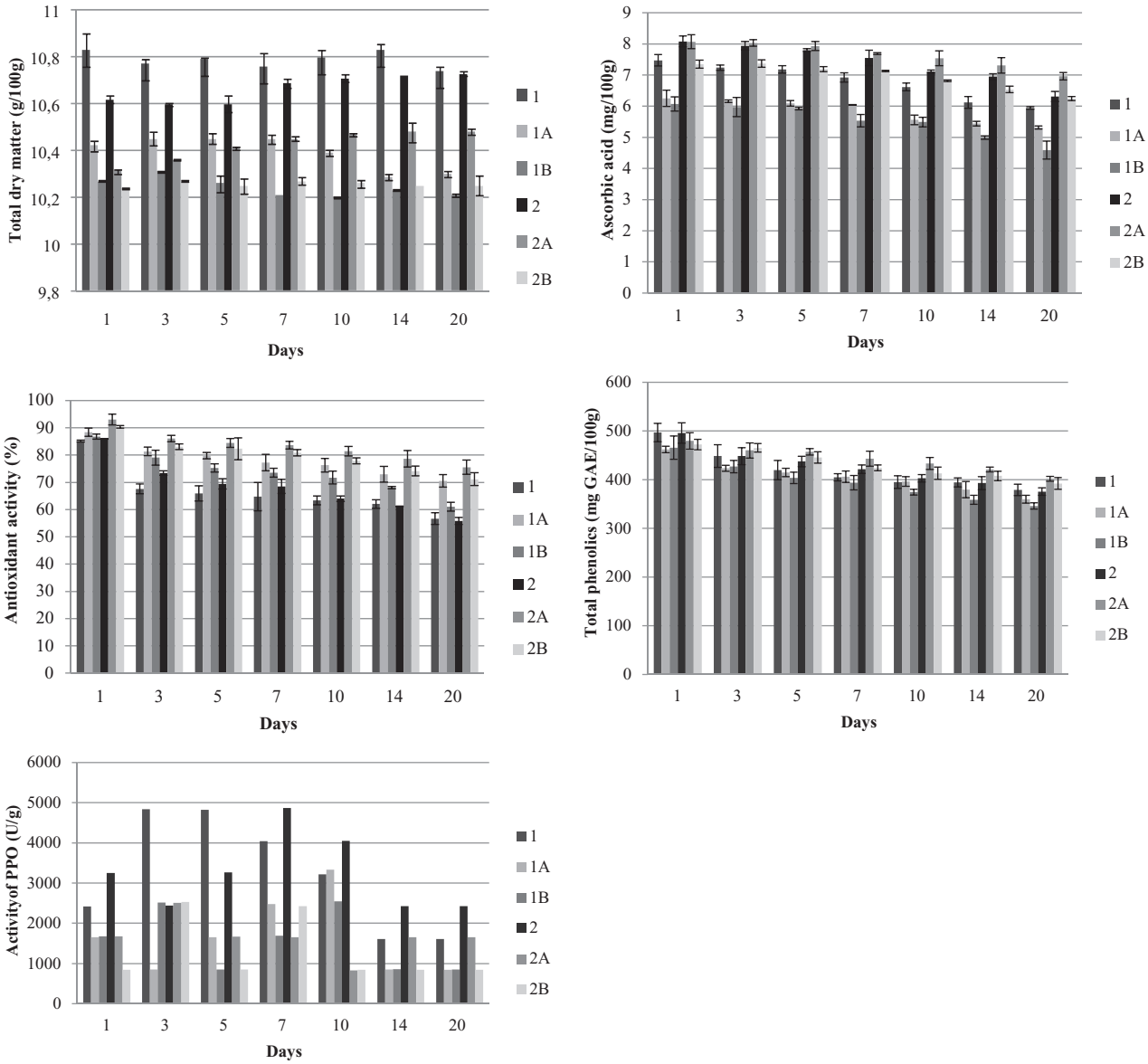

FIG. 1. CHANGES IN QUALITY OF MAP CELERIES DURING STORAGE
PPO, polyphenoloxidase.

TABLE 7. FACTORS VALUES AND VARIANCE MATRIX OF VARIABLES ANALYZED

Variables	Factor 1 loadings	Factor 2 loadings	Multiple R^2	Variance matrix (ε_i,Ψ)
Antioxidant activity	–0.709306	**0.646061**	0.8602	0.1398
Total phenolics	–0.958599	**0.073337**	0.8699	0.1301
Ascorbic acid	–0.848614	**–0.260011**	0.6618	0.3382
Total acidity	**0.394438**	0.375740	0.2712	0.7288
Total carotenoids	–0.935158	**0.168763**	0.8426	0.1574
Total dry matter	**–0.141744**	–0.885508	0.6890	0.3110
Polyphenoloxidase activity	**–0.235627**	–0.814872	0.4561	0.5439
Eigenvalues	3.2478	2.1082	–	–
Total variance	46.398	30.117	–	–

Important variables were indicated as bold for each factor.

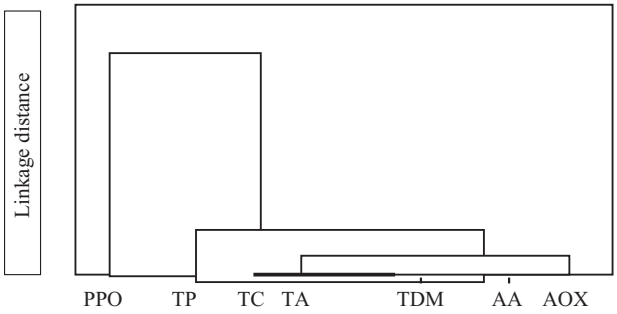

FIG. 2. DENDOGRAM OF THE RESULTS OF THE CLUSTER ANALYSIS OF THE ELEMENTS
AOX, antioxidant activity; TP, total phenolics; AA, ascorbic acid; TA, total acidity; TC, total carotenoids; TDM, total dry matter; PPO, polyphenoloxidase.

odor criteria. But the same samples were preserved their original color during 10 days of storage.

The large positive correlation coefficients showed that the ratios of positive interactions among the response variables measured in this experiment was more than negative interactions. For this reason, lots of analytical criteria determined in celery increased with the increment of the other criteria. According to the results of the cluster analysis, analytical criteria were gathered in three main clusters. When PPO activity and TP were separated as a different group, others built up the third group because of their connections between them. Between all analytical criteria, PPO activity had the highest common connection. PPO (V7) element represented the first factor and AOX variable (V1) represented the second factor. As a consequence, the regression analysis of these two elements had importance.

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