Quality of shredded carrots minimally processed by different dipping solutions

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Research highlights

- Dipping with acidic solutions affected positively the quality of shredded carrots
- A lowering of enzymatic activities was observed in carrots dipped in mix of salt and acids
- 1.5% citric acid dipping extended the shelf life of carrots to 14 days

Abstract

The whiteness of shredded carrots is generally caused by enzymatic reactions after removal of natural protection during the minimal processing. Moreover, the use of chlorinated solution in sanitizing step of processing, promotes the formation of halogenated by-products, with correlated environmental and health risks in processing areas. This study investigated the effect of different acidic solutions on the quality of shredded carrots during the storage at two refrigerated temperatures (4 °C and 7 °C), as alternative agents to chlorine in food industry. Carrots dipped in 1.5% citric acid solution did not present colour variation at both storage temperatures. Moreover they showed the lowest microbial charge after processing and during storage at 4 °C. Carrots dipped in 0.5% citric acid + 0.05 % ascorbic acid + 0.05 % calcium chloride evidenced lower PAL and POD activities during the storage respect to the other tested samples. Therefore, the dipping of shredded carrots in acidic solutions, as alternative sanitizers to chlorine, contributed to preserve their quality, also controlling the whiteness index of carrots' surface. In particular, the dipping in 1.5% citric acid extended the shelf life of shredded carrots up to 14 days of storage at 4 °C.

Key words: Acidic solutions, carrots, dipping, minimal processing, whiteness index

Introduction

Among minimally processed vegetables, shredded carrots are among the ten most popular ones, showing nutritional benefits and convenience (Ragaert et al., 2004). Visual characteristics of packed food products are important for consumers in the evaluation of ready-to-eat vegetables: the absence of colour modifications (browning and whitening of the cut surface, yellowing of green vegetables) as well as the absence of mechanical damages is the principal priorities. The removal of natural protection observed during minimal processing involves desiccation and wilting phenomena which can successively favour microbial growth and enzymatic reactions (Rocha et al., 2007), activation of phenolic metabolism, lignin production and colour change. In particular, the results of dehydration

and lignin synthesis by phenylalanine ammonia lyase (PAL) activity and/or of multiple deteriorative reactions by peroxidase (POD) are responsible of surface whiteness, off-flavours development, firmness loss and high respiration rate (Amanatidou et al., 2000). Furthermore, PAL activity increased in shredded carrot roots with correspondence to synthesis of phenolics (Babic et al., 1993). Carotenoids are the main pigments in carrots, susceptible to isomerization and oxidation during processing and storage of foods: the abrasion of the surface may in fact increase the potential for carotene oxidation during storage (Li et al., 1998). The most commonly used method for reducing initial microbiological contamination is the washing of the cut vegetables in chlorinated water: chlorine is in fact one of the most used sanitizers to assure safe food products, often at a concentration of 50-350 ppm (Delaquis et al. 2004). However, over the last years, the use of some methods for sanitize is questioned since it has been shown that chlorine has a limited effect for the control of microbial load, including pathogenic bacteria (Abadias et al., 2008) and also because the formation of halogenated by-products is correlated to environmental and health risks in processing areas. The main strategy to minimize the changes is the product cooling before cutting and the rigid control of the temperature in the processing area. For this reason, Italy stood out among the European states to have regulated the obligation to use refrigerated temperatures during the minimal processing, from raw vegetables transport to ready to eat vegetables sale (Italian Regulation, 2014). Various approaches have been applied in order to improve the quality of fresh-cut carrots: modified atmosphere (Dawange et al., 2016); coatings (Ranjitha et al., 2017); use of electrolyzed water (Koide et al, 2011); use of essential oils (Romeo et al., 2010). A calcium-based solution as pre-treatment or calcium in combination with ascorbic acid maintained firmness of carrot sticks stored at 2°C (Bruemmer, 1987), and acidic solution reduced the surface discoloration in minimally processed carrots (Bolin and Huxsoll, 1991). The aim of this work is the evaluation of efficiency of different dipping solutions, as alternative agents to chlorine in food industry, on the overall quality and shelf life of minimally processed shredded carrots. In particular, the effects of citric acid alone or in

combination with ascorbic acid and calcium chloride are investigated on the quality parameters of shredded carrots stored at two refrigerated temperatures.

Material and methods

Sample preparation

Minimally processed shredded carrots (Daucus carota L.) were produced by the C.O.F. s.r.l. farm located in Vibo Valentia (Southern Italy). To sanitize the shredded carrots, the farm applied the dipping in chlorinated water and commercial shredded carrots possessed a shelf life of 7 days. In the experimental plan, carrots were selected to eliminate physical defects, then peeled, removed of ends, and shredded. Four dipping solutions were tested: chlorinated water (300 mg L^{-1}), tap water, 1.5 % citric acid and 0.5% citric acid + 0.05 % ascorbic acid + 0.05 % calcium chloride solutions, named A, B, C, and D, respectively. The time of each dipping was of 5 minutes, and then the water excess was removed by centrifugation. Carrots were packaged in polypropylene antifog pouches (25 cm x 20 cm of size; 35 μm of thickness; OTR: 1600 cm^3 m^{-2} 24 h^{-1} atm^{-1}; WVTR: 6 g m^{-2} 24 h^{-1}) in normal atmosphere. Minimally processed packed shredded carrots (200 g of weight, 4-5 cm of length and 2 mm of thickness) were moved from farm to the laboratory and stored at 4 °C and 7 °C with 95% RH. The temperature of 4 °C is considered optimal for preservation of fresh food while 7 °C is the temperature to foods are exposed in refrigerators supermarket. According to the different dipping solutions, shredded carrots were named A, B, C and D and submitted for qualitative analyses after 1, 3, 7, 10 and 14 days. Three replications for each treatments and monitoring times were analysed.

Total Bacterial Count (TBC)

Ten grams of shredded carrots were diluted with a sterile Ringer's solution in a stomacher bag filter and homogenised with a Bag Mixer (Interscience, France) for 5 min. Decimal serially dilutions were prepared and plated on Petri plates. Total bacterial count was measured on PCA-Plant Count Agar-growth land (Oxoid) at 26 °C for 48 h and was expressed as Log_{10} CFU g^{-1}.

Headspace composition

Before the opening, the headspace composition inside pouches was determined using a CheckPoint handheld Gas Analyser (PBI Dansensor, Milan, Italy). The gas analysis was conducted by a needle inserted through a septum previously fixed on the bags. The results were given as Oxygen and Carbon dioxide concentrations (%).

Physico-chemical analyses

Colour measurement was monitored in each carrot sample (15 replicates) using a tristimulus colorimeter (model CM-700d, Konica Minolta, Osaka, Japan) calibrated with a standard white plate. The colour was recorded in the CIELab colour space. Results were expressed as whiteness index score (WI) according to the following formula (Bolin and Huxsoll, 1991):

$$WI = 100 - [(100 - L^{*2}) + a^{*2} + b^{*2}]^{0.5}$$

Water activity (aw) was measured by Aqualab LITE (Decagon, Inc., Washington, USA) instrument. AOAC methods (1980; 2000) were performed for measurements of the pH extracts (pH meter Crison GLP, Barcelona, Spain) and the titratable acidity, expressed as % of citric acid.

Dry matter (% d.m.) was evaluated by loss weight in an oven at 70 °C until a constant weight was reached.

Carotenoids quantification was carried out according to Heinonen et al. (1989). Five grams of shredded carrots were homogenized with 30 mL of acetone. Afterwards, the homogenate was placed on filter paper and rinsed with acetone until the complete colour loss. The final volume of each sample was brought to 100 mL with acetone. The carotenoid content was determined by adding 3 mL of hexane to 3 mL of extract, followed by 8 mL of H_2O. Subsequently, the absorbance was measured at 450 nm. Results are expressed as mg g^{-1}.

Lipid peroxidation was determined through measuring the malonyldialdehyde (MDA) content by thiobarbituric acid method as described by Landi (2017). One hundred mg of shredded carrots were homogenized in 80% ethanol and centrifuged at 3,000 g for 10 min at 4 °C. The supernatant was collected, incubated for 25 min at 95 °C with 20% trichloroacetic acid (TCA) containing 0.01% hydroxytoluenebutylate, with and without 0.5% thiobarbituric acid (TBA), and quickly cooled in ice

for 10 min. The absorbance of the reaction mixture was measured at 450, 532 and 600 nm. The equivalents of MDA (nmol g^{-1}) were calculated based on the following formulas:

A = [(Abs532+TBA − Abs600+TBA) − (Abs532-TBA − Abs600-TBA)]

B = [(Abs440+TBA − Abs600+TBA) * 0.0571]

MDA equivalents (nmol g^{-1}) = (A − B/157000) * 106

Antioxidant activity capacity: DPPH and ABTS assays

Antioxidant capacity was determined using $ABTS^{+}$ radical cation decolourisation assay, according to Re et al. (1999). Twenty-five µL of sample extract were reacted with 2975 µL of ABTS solution for 6 min in the dark. The absorbance was measured at 734 nm. The antioxidant capacity of extracts was expressed as percentage of inhibition according to the following formula:

$$\% \text{ Inhibition} = ((A_{t0} - A_{t\ end})/ A_{t0}) \times 100$$

where:

A_{t0} is the value of absorbance of ABTS solution at initial time while, $A_{t\ end}$ is the value of the absorbance measured after 6 min.

DPPH radical scavenging activity was determined according to the method of Brand-Williams et al. (1995). Fifty µL of sample extract was reacted with 2950 µL of DPPH solution for 15 min in the dark. The absorbance was measured at 515 nm. The antioxidant capacities of extracts were expressed as percentage of inhibition according to the following formula:

$$\% \text{ Inhibition} = ((A_{t0} - A_{t\ end})/A_{t0}) \times 100$$

where:

A_{t0} is the value of absorbance of DPPH solution at initial time while, $A_{t\ end}$ is the value of the absorbance measured after 15 min.

Enzymatic activities

PAL activity was measured as reported by Ke and Saltveit (1986) with some modifications. Briefly, 1 g of shredded carrots was homogenized with 5 mL of 50 mM borate buffer (pH 8.5), containing 5

mM 2-mercaptoethanol and 0.2 g polyvinylpyrrolidone (PVP). The homogenate thus obtained was centrifuged at 20,000 g for 20 minutes at 4° C. The supernatant was recovered and used for the enzyme assay, adding 50 µL of 50 mM L-phenylalanine, and incubated at 40 °C for 60 min. Absorbance was measured at 290 nm, before and after incubation. The enzymatic activity was expressed as µmoles of *trans*-cinnamic acid g^{-1} fresh weight h^{-1}.

POD activity was performed as reported by Loiza-Velarde et al. (1986). Four grams of shredded carrots were homogenized with 12 mL of 50 mM phosphate buffer (pH 6.8). The homogenate thus obtained was centrifuged at 20,000 g for 20 minutes at 4 ° C. The supernatant was recovered and used for enzyme assay. POD was assayed by adding a volume of 50 µL supernatant to a solution containing 50 mM phosphate buffer (pH 7.0), 12 mM H_2O_2 and 70 mM guaiacol, for a final volume of 1 mL. The absorbance was determined at 470 nm for 1 min. Results are expressed as mmol quinone m^{-1} mg^{-1} protein.

Statistical analysis

The effects of treatments, temperature and storage time were evaluated by statistical analysis of variance (One-way ANOVA and Multivariate analysis) using SPSS software (version 15). Duncan's multiple range test was used to evaluate differences among values and the statistical significance was defined as $P<0.05$.

Results and Discussion

Total bacterial count (TBC)

Total microbial count on minimally processed vegetables is generally known to range from 3.0 to 6.0 Log_{10} units after processing (Ragaert et al., 2004). Concerning to the microbiological threshold of minimally processed vegetables, the European regulation (2005) the end of product commercial viability aligned to a microbial load of about 10^7 CFU g^{-1}. Corbo et al. (2006) estimated a shelf-life of 6-days for shredded carrots decontaminated with chlorinated-water, considering a higher microbiological criterion (7.7 Log_{10} CFU g^{-1}).

As shown in Figure1, the initial TBC of minimally processed carrots during the storage at 4 °C and 7 °C ranged from 3.7 to 4.9 Log CFU g^{-1}, with lower numbers than what reported by Garg et al. (1990) on fresh-cut vegetables. In particular, C sample possessed the lowest TBC after processing (3.7 Log CFU g^{-1}): these results were probably due to the residual bacteriostatic effect of citric acid used in the dipping solution, as observed also in leafy ready-to-eat vegetables (Zappia et al., 2018). According to previous report on other fresh-cut vegetables (Rocculi et al., 2009), no great differences were observed between carrots dipped in chlorinated water (A) and carrots dipped in tap water (B). Adams et al. (1989) supposed that chlorine can be neutralized by the component leaching of cut vegetables, whereby bacteria survive in the leaf surface when stored in protective hydrophobic pockets or folds.

TBC tended to increase more rapidly in all samples during the storage at 7 °C than 4 °C, due to better thermal condition for microbial growth. In particular, with reference to bacteria load threshold (7 Log_{10} CFU g^{-1}), the storage at 4 °C assured the preservation of D sample up to 10 days (6,93 Log_{10} CFU g^{-1}) and A, B and C samples up to 14 days (6.42, 7.12, and 6.13 Log_{10} CFU g^{-1}). The microbial quality of A and C samples stored at 7 °C was instead maintained up to 10 days. The multivariate analysis of TBC, in minimally processed shredded carrots, reported a high variability (P<0.05) as effect of treatments, storage temperature and storage time.

Headspace composition

Changes in O_2 and CO_2 concentration of packaged shredded carrots dipped in different solutions are presented in Fig. 2. The O_2 % after 1 day of storage (12-13%) tended to decrease (about 5 %) with different rates due to the effect of storage temperature and of treatments. C samples showed a more reduced respiratory activity at 4 °C, due to the dipping in citric acid that, beyond antibrowning, is an inhibitor of the phosphofructokinase (PFK), a glycolysis enzyme (Kennedy et al., 1992). The trend of O_2 % in A, B and D was in fact similar from 1 to 10 days. At the end of monitoring, no significant (P <0.05) differences were observed in O_2 % in all the samples stored at 4 °C. Regarding the storage at 7 °C, the depletion of O_2 was similar among samples up to 7 days, probably due to the strong effect

of the higher temperature that promoted the respiration of microflora and the consumption of O_2. CO_2 concentration presented a similar increasing trend in all the samples, as effect of respiration reaction, with higher percentage during the storage at 7 °C. The greatest CO_2 contents were observed in the D sample from 1 to 10 days at 4 °C and to 14 days at 7 °C.

Physico-chemical analyses

The discoloration of carrots' surface, indicated as Whiteness index (WI), is considered to be an quality defect, since consumers relate it with loss of freshness and it can be used as measurement of carrot degradation (Lavelli et al., 2006). After 1 day of storage, no differences in WI were observed among samples, at both temperatures (Table 1). At the end of monitoring WI increased only in D sample stored at 4 °C ($P < 0.05$), probably due to a higher lignin formation. Among all the samples no colour variations were significantly ($P > 0.05$) observed during the storage at 7 °C. Generally, the microbial growth in fresh-cut carrots can be followed by the production of acetic and lactic acids (Watada et al., 2005) that causes a decrease in pH. An increase of titratable acidity in all treated carrots was in fact observed during storage time at both temperatures. C samples showed higher acidic content than the other shredded carrots from the start to the end of storage due to the applied acidic treatment, showing after 14 days 2.72 g% of citric acid at 4 °C and 3.05 g% of citric acid at 7 °C. The measured pH values in C samples were in line with the results of titratable acidity, with the lowest values from the start to the end of storage at both temperatures, compared to the other samples.

The dry matter of carrots tended to reduce during the storage period ($P < 0.05$), probably because of a nutrient leaching, according to Klaiber et al (2005). After 14 days of storage, the highest losses at 4 °C were observed in B (-0.62%) and at 7 °C in D samples (-1.42%). As just observed, both samples did not exhibit a slowing respiration during storage and so the metabolic activity probably promoted the degradation of sugars together with a reduction of dry matter content.

Concerning the results on lipid peroxidation, all the samples (A, B, C, D) did not shown any statistically significant differences among the treatments under storage at 4° C (Fig. 3 a). By contrast, the effect of different treatments was influenced by the storage temperature ($P=0.009$).

Indeed, both C and D samples exhibited a significant lower TBARS after 10 days of storage at 7 °C compared to the A and B samples, thus suggesting a lower lipid peroxidation process. The acids in the dipping solutions protected membrane lipids of shredded carrots from peroxidative degradation, thus maintaining physical integrity and providing a healthy environment for membrane bound enzymes to function in, also at higher storage temperature. According to Shewfelt and Del Rosario (2000) these results suggested that peroxidation cellular process could be controlled by manipulation of antioxidant concentrations and/or compositions to prevent or retard the development of storage disorders. Total carotenoid content significantly decreased starting from 7 days of storage in all the samples (Fig. 3 b). However, the treatment / time interaction was statistically significant (P = <0.001), highlighting that D shredded carrots showed, after 7 days, higher carotenoids content (92.47 mg g^{-1} at 7 °C and 94.23 mg g^{-1} at 4 °C) compared to the A, B and C samples. Differently, the treatment / temperature interaction was not statistically significant (P = 0.866), suggesting that the effect of different treatments did not depend on storage temperature. At both storage temperatures, the dipping solution with the mix of acids probably slowed down the depletion of antioxidants in carrots for the recognized reducing properties of ascorbic acid.

Antioxidant capacity: DPPH and ABTS assays

In both DPPH and ABTS assays, the greatest radical scavenging percentages after 1 day of storage were observed in A samples, carrots dipped in chlorinated water and without any acidic treatments (Table 2). In literature, an increase of fresh-cut carrots nutritional value was observed as consequence of phenolic components biosynthesis after cutting (Reyes et al., 2007). In particular, this increase was extremely evident respect to the other vegetable species by PAL activity. The treated samples with acids presented in fact lower initial antioxidant activity coincident with the partial enzymatic inhibition. Successively, an increase of radical scavenging was evident during the storage in all the samples. Limiting the discussion only to evaluate possible alternative dipping to chlorinated water, C samples expressed the highest % of DPPH inhibition at both temperatures of

storage and together with D samples manifested the strongest antioxidant activity by ABTS assay, respectively at 4 °C and 7 °C. Considering the decrease of total carotenoids on samples during the storage times, the observed results on antioxidant activity of carrot samples demonstrated that other antioxidant components, as probably phenolic compounds, are likely the main contributors to the changes in antioxidant activity, as confirmed by literature (Zappia et al., 2019).

The multivariate statistical analysis evidenced high significant effect ($P<0.01$) of all the variables (dipping, storage temperature and storage time) on physico-chemical characteristics and antioxidant capacity of shredded carrots (data not shown).

Enzymatic activities

Concerning the results of PAL activity, a significant increase in all the samples during storage was observed ($P = 0.02$). However, the D dipping resulted more significant efficient compared to the other treatments, showing a reduced enzymatic activity in carrots than that observed in A, B and C samples. These differences became marked already after 3 days of storage (Treatment * Time $P = 0.002$), in which a lower PAL activity was observed in the D samples (Fig. 4 a). This trend was also evident in the POD activity in which the treatment factor was significant ($P <0.001$), evidencing the best response in D samples (Fig. 4 b), in particular at the first monitoring times. Moreover, the POD activity, in addition to being correlated with the lignification process, also affected the carotenoids degradation process (Donnici et al., 2011). In fact, the higher POD activity in A, B and C compared to the D samples reflected on the previously commented greater decrease in the carotenoid content. Finally, in all the samples, the temperature did not significantly affect the POD activity (Treatment * Temperature $P= 0.675$).

Conclusions

In this study, an overall evaluation of quality in minimally processed shredded carrots was conducted, comparing the effects of different dipping solutions in the sanitizing step of processing and of two storage temperatures. The both dipping in acidic solutions of shredded carrots contributed to preserve their quality as ready-to-eat vegetables: the dipping in 1.5% citric acid solution preserved carrots by

colour variation at both storage temperatures and maintained under 4 °C the safe microbiological limits up to 14 days. The dipping in 0.5% citric acid + 0.05 % ascorbic acid + 0.05 % calcium chloride involved lower PAL and POD activities and an higher retention of total carotenoids at both storage temperatures.

References

Abadias M, Usall J, Anguera M, Solsona C, Viñas I (2008) Microbiological quality of fresh, minimally-processed fruits and vegetables, and sprouts from retail establishments. Int J Food Microbiol 123: 121-129. doi:10.1016/j.postharvbio.2005.12.004

Adams MR, Hartley AD, Cox LJ (1989) Factors affecting the efficacy of washing procedures used in the production of prepared salads. Food Microbiol 6: 69-77. doi:10.1016/S0740-0020(89)80039-5

Amanatidou A, Slump RA, Gorris LGM, Smid D (2000) High oxygen and high carbon dioxide modified atmospheres for shelf-life extension of minimally processed carrots. J Food Sci 65: 61–66. doi:10.1111/j.1365-2621.2000.tb15956.x

AOAC, Association of Official Analytical Chemists (1980). Hydrogen-ion activity (pH) method. Method 14.022 In: Horwitz W (ed.), 13th ed. Washington, D.C, USA p. 213

AOAC, Association of Official Analytical Chemists (2000) Acidity of fruit products. Method 942.15 In: Horwitz W (ed.), 17th ed. Washington, D.C, USA p.11

Babic I, Amiot MJ, Nguyen-The C, Aubert S (1993) Changes in phenolic content in fresh ready-to-use shredded carrots during storage. J Food Sci 58: 351-356. doi: 10.1111/j.1365-2621.1993.tb04273.x

Bolin HR, Huxsoll CC (1991) Control of minimally processed carrot (Daucus carota) surface discoloration caused by abrasion peeling. J Food Sci 56: 416-418. doi:10.1111/j.1365-2621.1991.tb05293.x

Brand-Williams W, Cuvelier ME, Berset C (1995) Use of a free radical method to evaluate antioxidant activity. LWT – Food Sci Technol 28: 25–30. doi:10.1016/S0023-6438(95)80008-5

Bruemmer JH (1987) Stability of prepared carrot sticks in storage. Proc Fla State Hort Soc 100: 3638.

Corbo MR, Del Nobile MA, Sinigaglia M (2006) A novel approach for calculating shelf life of minimally processed vegetables. Int J Food Microbiol 106: 69−73. doi:10.1016/j.ijfoodmicro.2005.05.012

Dawange SP, Dash SK, Bal LM, Panda MK (2016) Quality of minimally processed carrots in perforation-mediated modified-atmosphere packaging (PM-MAP). J Food Meas Charact 10:746-754. doi:10.1007/s11694-016-9359-3

Delaquis PJ, Fukumoto LR, Toivonen PMA, Cliff MA (2005) Implications of wash water chlorination and temperature for the microbiological and sensory properties of fresh-cut iceberg lettuce. Postharvest Biol Tech 31: 81–91.

Donnini S, Dell'Orto M, Zocchi G (2011) Oxidative stress responses and root lignification induced by Fe deficiency conditions in pear and quince genotypes Tree Physiol 31(1):102-13.

European Regulation (2005) Official Journal of the European Union, L338, 22.12.2005. Commission Regulation (EC) N. 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs

Garg N, Churey JJ, Splittstoesser DF (1990) Effect of processing conditions on the microflora of fresh-cut vegetables. J Food Prot 53:701–703. doi:10.4315/0362-028X-53.8.701.

Heinonen MI, Ollilainen Linkola EK, Varo PT, Koivistoinen PE (1989) Carotenoids in Finnish foods: vegetables, fruits, and berries. J Agr Food Chem 37: 655-659. doi:10.1021/jf00087a017

Italian Regulation (2014) Regulation of the Italian Government of 20 June 2014. Implementation of art.4 of law 13th May 2011 no.77, laying down disposition to preparation, packaging and distribution of ready-to-eat vegetables. In Official Journal, DM n. 186, 12/08/2014

Ke D, Saltveit Jr ME (1986) Spotting and phenylalanine ammonia-lyase activity in iceberg lettuce. Hort Sci 21: 1169-1171.

Kennedy RA, Rumpho ME, Fox TC (1992) Anaerobic metabolism in plants. Plant Physiol 100: 1-6. doi:10.1104/pp.100.1.1.

Klaiber RG, Baur S, Wolf G, Hammes WP, Carle R (2005) Quality of minimally processed carrots as affected by warm water washing and chlorination. Innov Food Sci Emerg 6: 351-362. doi:10.1016/j.ifset.2005.03.002

Koide S, Shitanda D, Note M, Cao W (2011) Effects of mildly heated, slightly acidic electrolyzed water on the disinfection and physicochemical properties of sliced carrot. Food Control 22 (3-4) 452-456

Landi M (2017) Commentary to: "Improving the thiobarbituric acid-reactive-substances assay for estimating lipid peroxidation in plant tissues containing anthocyanin and other interfering compounds" by Hodges et al., Planta (1999) 207: 604–611. Planta 245: 1067. doi:10.1007/s00425-017-2699-3

Lavelli V, Pagliarini E, Ambrosoli R, Minati JL, Zanoni B (2006) Physicochemical, microbial, and sensory parameters as indices to evaluate the quality of minimally-processed carrots. Postharvest Biol Technol 40: 34–40. doi:10.1016/j.postharvbio.2005.12.004

Li P, Barth MM (1998) Impact of edible coatings on nutritional and physiological changes in lightly-processed carrots. Postharvest Biol Technol 14: 51-60. doi: 10.1016/S0925-5214(98)00020-9

Loiza-Velarde JG, Tomás-Barberán FA, Saltveit ME (1997) Effect of intensity and duration of heat-shock treatments on wound-induced phenolic metabolism in iceberg lettuce. J Am Soc Hortic Sci 122: 873-877

Ragaert P, Verbeke W, Devlieghere F, Debevere J (2004) Consumer perception and choice of minimally processed vegetables and packaged fruits. Food Qual Prefer 15: 259-270. doi:10.1016/S0950-3293(03)00066-1

Ranjitha K, Sudhakar Rao DV, Shivashankara KS, Singh Oberoi H, Kumar Roy T, Bharathamma H (2017) Shelf-life extension and quality retention in fresh-cut carrots coated with pectin. Innov Food Sci Emerg 42: 91-100. doi:10.1016/j.ifset.2017.05.013.

Re R, Pellegrini N, Proteggente A, Pannala A, Yang M, Rice-Evans C (1999) Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radical Biol Med 26: 1231–1237. doi:10.1016/S0891-5849(98)00315-3

Reyes F, Villarreal JE, Cisneros-Zevallos L (2007) The increase in antioxidant capacity after wounding depends on the type of fruit or vegetable tissue. Food Chem 101:1254–1262. doi:10.1016/j.foodchem.2006.03.032

Rocculi P, Romani S, Gómez Galindo F, Dalla Rosa M (2009) Effect of minimal processing on physiology and quality of fresh-cut potatoes: a review. Food 3: 18-30.

Rocha AM, Ferreira JF, Silvam AM, Almeidam GN, Morais AM (2007) Quality of grated carrot (var. Nantes) packed under vacuum. J Sci Food Agric 87: 447–451. doi:10.1002/jsfa.2723

Romeo FV, De Luca S, Piscopo A, Poiana M (2010) Effect of some essential oils as natural food preservatives on commercial grated carrots. J Essent Oil Res 22: 283-287. doi:10.1080/10412905.2010.9700325

Shewfelt R, Del Rosario BA (2000) The role of lipid peroxidation in storage disorders of fresh fruits and vegetables. HortScience 35: 575-579.

Watada AE, Izumi H, Luo Y, Rodov V (2005) Fresh-cut produce. In: Environmentally friendly technologies for agricultural produce quality, CRC Press, pp. 157-211.

Zappia A, De Bruno A, Torino R, Piscopo A, Poiana M (2018) Influence of Light Exposure during Cold Storage of Minimally Processed Vegetables (Valeriana sp.). J Food Qual, vol. 2018. doi:10.1155/2018/4694793.

Zappia A, De Bruno A, Piscopo A, Poiana M (2019) Physico-chemical and microbiological quality of ready-to-eat rocket (Eruca vesicaria (L.) Cav.) treated with organic acids during storage in dark and light conditions

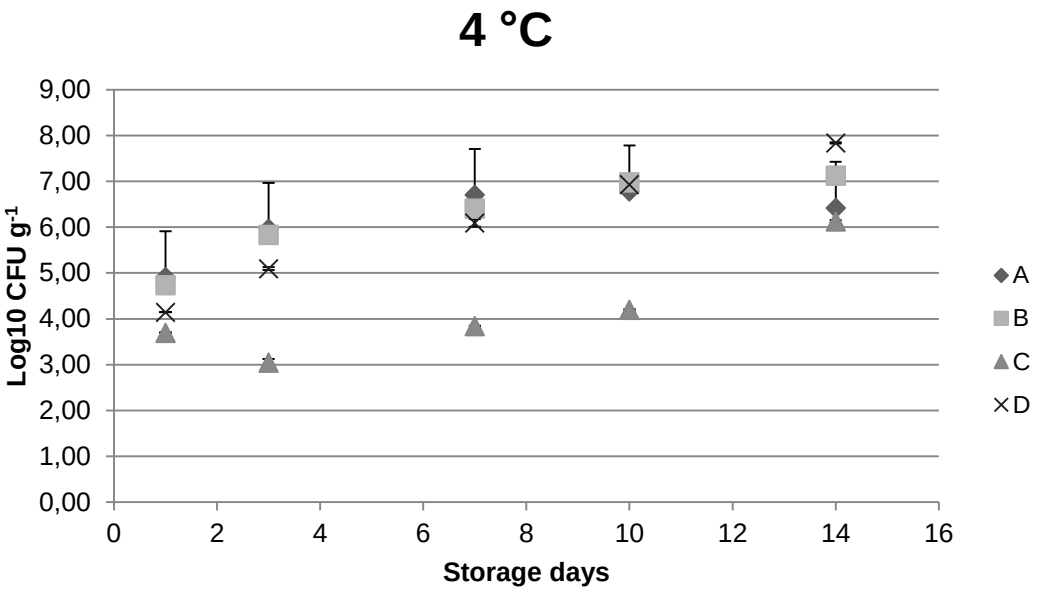
Figure caption

Fig. 1 Total bacterial counts of shredded carrots dipped in (A) chlorinated water, (B) tap water, (C) 1.5% citric acid, (D) 0.5% citric acid+ 0.05% ascorbic acid + 0.05% $CaCl_2$ during storage at 4 °C and 7 °C for 14 days. Values are given as means ± standard deviations (n = 3).

Fig. 2 Headspace composition during storage at 4 °C and 7 °C for 14 days of packed shredded carrots dipped in (A) chlorinated water, (B) tap water, (C) 1.5% citric acid, (D) 0.5% citric acid+ 0.05% ascorbic acid + 0.05% $CaCl_2$ during storage at 4 °C and 7 °C for 14 days of shredded carrots. Values are given as means ± standard deviations (n = 3).

Fig. 3 Lipid peroxidation (a) and total carotenoid content (b) of shredded carrots dipped in (A) chlorinated water, (B) tap water, (C) 1.5% citric acid, (D) 0.5% citric acid+ 0.05% ascorbic acid + 0.05% $CaCl_2$ during storage at 4 °C and 7 °C for 14 days. Values are given as means ± standard deviations (n = 3).

Fig. 4 PAL (a) and POD (b) activities of shredded carrots dipped in (A) chlorinated water, (B) tap water, (C) 1.5% citric acid, (D) 0.5% citric acid+ 0.05% ascorbic acid + 0.05% $CaCl_2$ during storage at 4 °C and 7 °C for 14 days. Values are given as means ± standard deviations (n = 3).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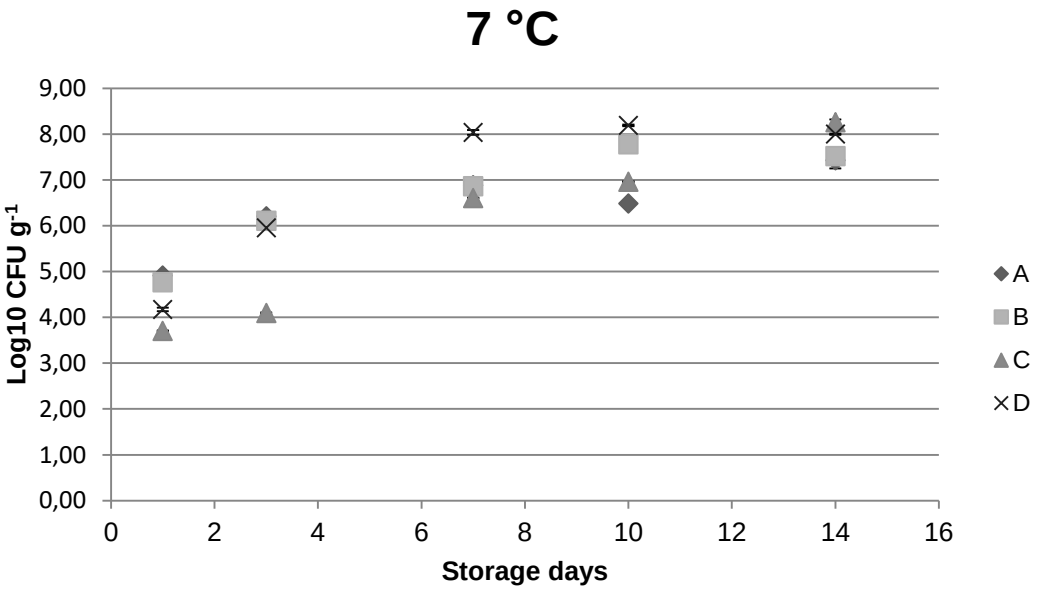
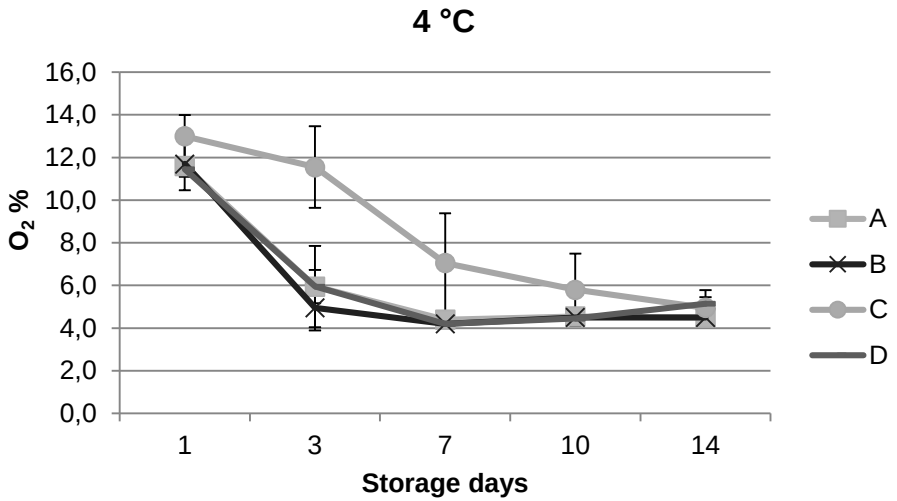
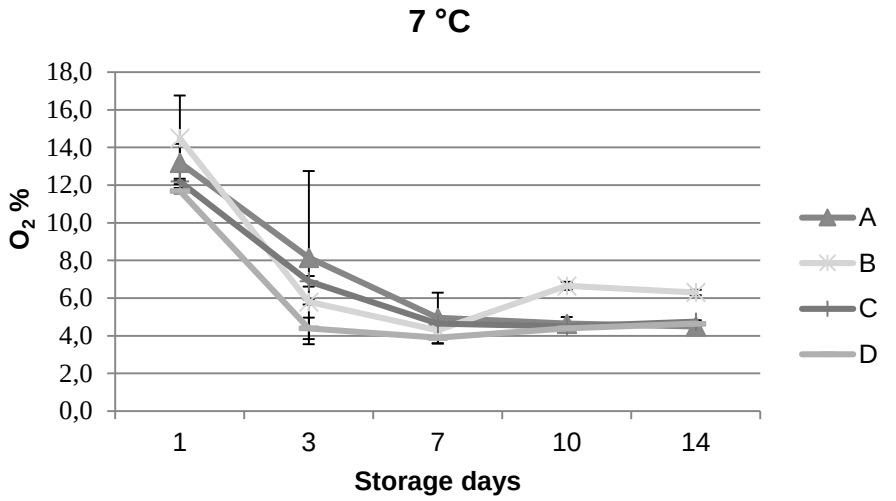
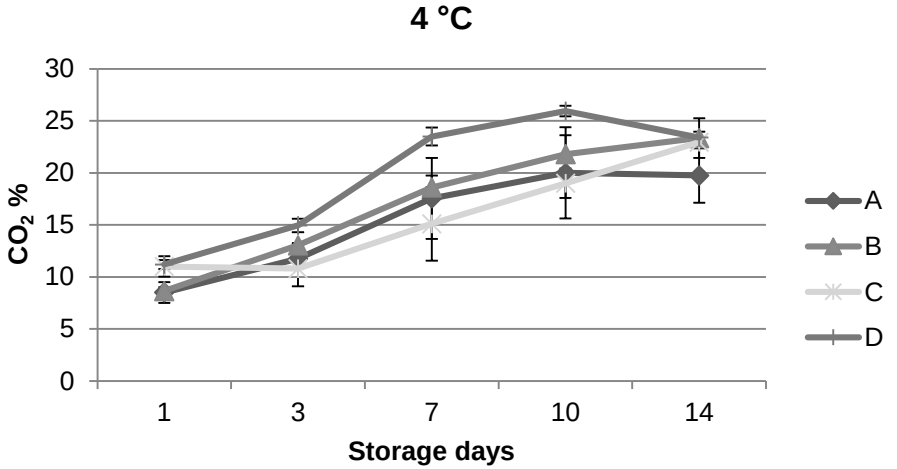
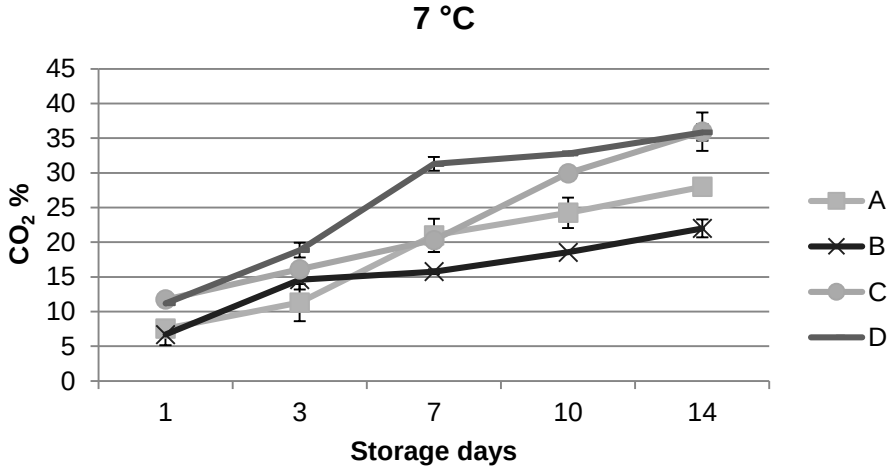
C
D

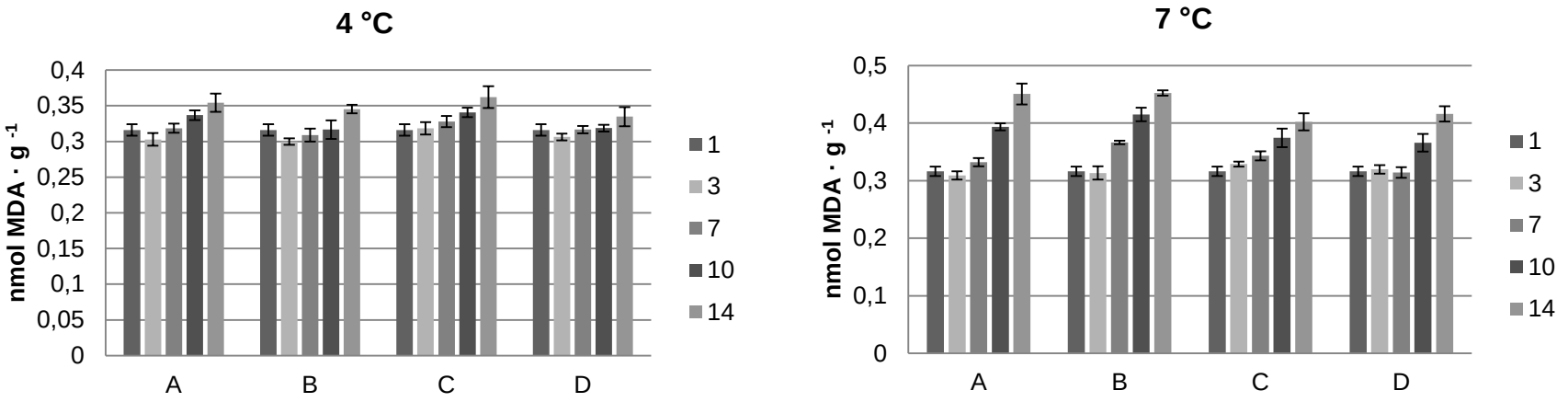

7 °C
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
Log10 CFU g-1
0
2
4
6
8
10
12
14
16
Storage days
A
B
C
D


4 °C
16,0
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
O2 %
1
3
7
10
14
Storage days
A
B
C
D


7 °C
18,0
16,0
14,0
12,0
10,0
8,0
6,0
4,0
2,0
0,0
O2 %
1
3
7
10
14
Storage days
A
B
C
D

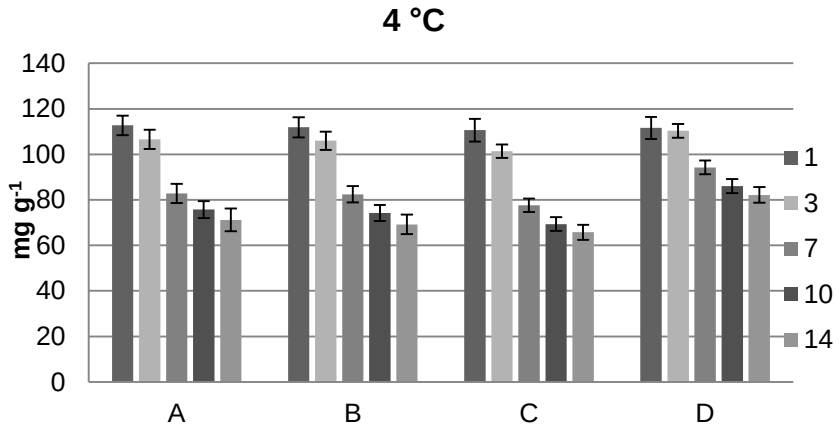

4 °C
30
25
20
15
10
5
0
CO2 %
1
3
7
10
14
Storage days
A
B
C
D

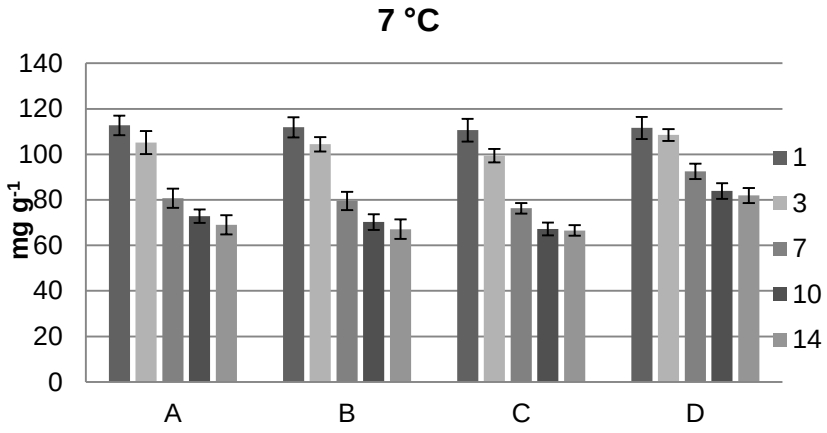

7 °C
45
40
35
30
25
20
15
10
5
0
CO2 %
1
3
7
10
14
Storage days
A
B
C
D


4 °C
nmol MDA · g -1
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
A
B
C
D
1
3
7
10
14

7 °C
nmol MDA · g -1
0,5
0,4
0,3
0,2
0,1
0
A
B
C
D
1
3
7
10
14

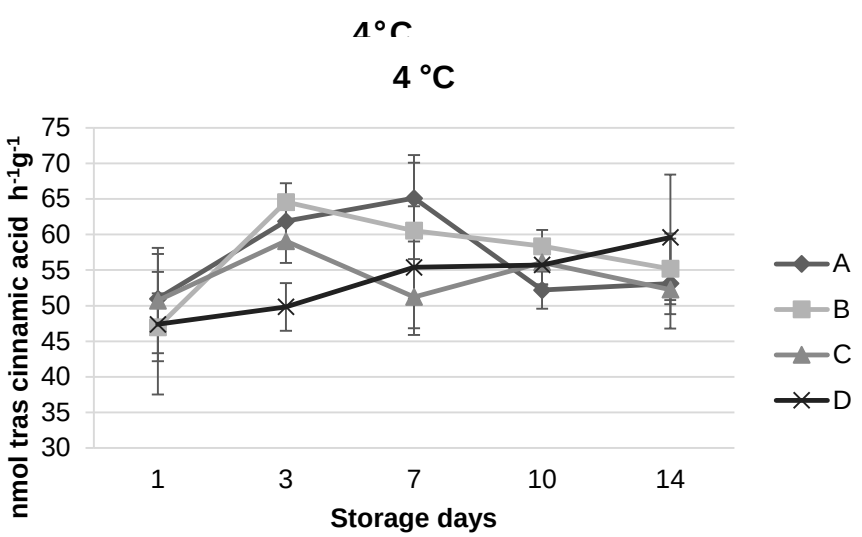
a


4 °C
mg g-1
140
120
100
80
60
40
20
0
A
B
C
D
1
3
7
10
14


7 °C
mg g-1
140
120
100
80
60
40
20
0
A
B
C
D
1
3
7
10
14

b

a


4 °C
nmol tras cinnamic acid h-1g-1
75
70
65
60
55
50
45
40
35
30
1
3
7
10
14
Storage days
A
B
C
D

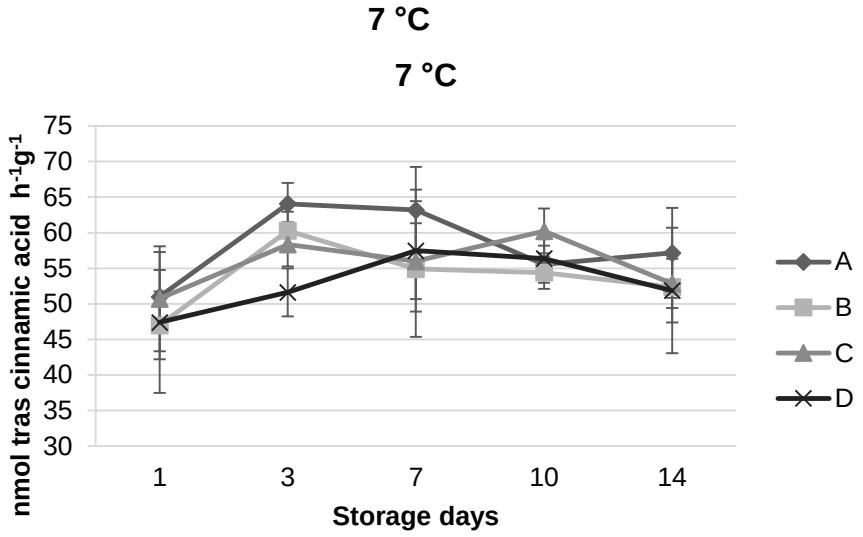

7 °C
7 °C
nmol tras cinnamic acid h-1g-1
75
70
65
60
55
50
45
40
35
30
1
3
7
10
14
Storage days
A
B
C
D

Table 1. Physico-chemical analyses of of shredded carrots dipped in (A) chlorinated water, (B) tap water, (C) 1.5% citric acid, (D) 0.5% citric acid+ 0.05% ascorbic acid + 0.05% $CaCl_2$ during storage at 4 °C and 7 °C for 14 days.

Samples	T	Storage days	A	B	C	D	Sign.
WI	4 °C	1	36.44	39.03A	37.87	38.12AB	n.s.
		3	37.09	35.14C	34.38	34.52B	n.s.
		7	36.26	35.71BC	36.89	36.92AB	n.s.
		10	36.05	38.93B	36.14	37.26AB	n.s.
		14	36.81	34.41D	37.71	39.61A	n.s.
		Sign.	n.s.	*	n.s.	*	
	7 °C	1	36.44	39.03	37.87	38.63	n.s.
		3	38.00	35.67	34.61	37.39	n.s.
		7	36.20	37.65	36.29	34.86	n.s.
		10	38.37	37.24	39.05	37.39	n.s.
		14	35.11	36.68	37.83	36.49	n.s.
		Sign.	n.s.	n.s.	n.s.	n.s.	
Titratable acidity (g% citric acid)	4 °C	1	0.10dC	0.12cC	0.41cA	0.16dB	**
		3	1.03abB	0.68aC	2.75aA	1.05aB	**
		7	0.99bB	0.68aC	2.43bA	0.69cC	**
		10	0.69cC	0.64bD	2.72aA	0.97abB	**
		14	1.01aB	0.69aD	2.72aA	0.91bC	**
		Sign.	**	**	**	**	
	7 °C	1	0.10dC	0.13cD	0.41dA	0.16dB	**
		3	0.66cC	0.98aB	2.59cA	0.68cC	**
		7	0.67bcC	1.05aB	3.01bA	0.69cC	**
		10	1.01aC	0.68bD	3.07aA	1.34aB	**
		14	0.69bC	1.08aB	3.05aA	0.99bB	**
		Sign.	**	**	**	**	
pH	4 °C	1	6.19cB	6.35bA	4.43dD	5.53dC	**
		3	6.39aB	6.43aA	4.71cD	6.00bC	**
		7	6.20cB	6.37bA	4.81abD	6.04aC	**
		10	6.30bA	6.27cA	4.78bC	5.89cB	**
		14	6.27bB	6.43aA	4.83aD	5.47eC	**
		Sign.	**	**	**	**	
	7 °C	1	6.19B	6.35bA	4.43cD	5.54cC	**
		3	6.38B	6.44aA	4.71bD	6.18aC	**
		7	6.35A	6.31cA	4.87aC	5.88bB	**
		10	6.30A	6.37bA	4.70bC	5.42dB	**
		14	6.38A	6.31cB	4.23dD	5.23eC	**
		Sign.	n.s.	**	**	**	
D.m.(%)	4 °C	1	8.59cA	8.81aB	8.74bB	8.82aA	**
		3	8.52bB	8.37cD	8.50bC	8.63aC	**
		7	8.47dC	8.62Cc	8.87aA	8.68bB	**
		10	8.08dD	8.95aA	8.89bA	8.63cC	**
		14	7.86dE	8.19cE	8.51aC	8.38bD	**
		Sign.	**	**	**	**	
	7 °C	1	8.50bAB	8.81aA	8.74aB	8.84aA	*
		3	8.30B	8.57B	8.45C	8.36B	n.s.
		7	8.20bBC	8.37bC	8.86aA	8.33bC	**
		10	8.75aA	8.38bC	8.46abC	8.28bC	*
		14	7.80bC	8.02aD	7.68bD	7.42cD	**
		Sign.	*	**	**	**	

Results are presented as the mean value ± standard deviation. n=3; **Significance at P < 0.01; * Significance at P < 0.05; n.s. not significant. Results followed by different letters are significantly different by *Post-hoc* Duncan test: capital letters indicate differences in the rows. lowercase letters indicate differences in the lines

Table 2. Antioxidant activity by ABTS and DPPH assays of shredded carrots dipped in (A) chlorinated water. (B) tap water. (C) 1.5% citric acid. (D) 0.5% citric acid+ 0.05% ascorbic acid + 0.05% $CaCl_2$ during storage at 4 °C and 7 °C for 14 days.

Antioxidant activity	T	Storage days	A	B	C	D	Sign.
ABTS (% of inhibition)	4 °C	1	43.14cA	21.40cC	15.92cD	20.50cB	**
		7	64.83bA	40.93bC	44.36bB	39.70aD	**
		14	77.21aA	51.24aC	57.30aB	38.55bD	**
		Sign.	**	**	**	**	
	7 °C	1	43.14cA	21.40cB	15.92bC	12.10cD	**
		7	55.25aC	59.29aB	42.54aD	73.87aA	**
		14	48.13bB	49.50bB	42.29aC	54.87bA	**
		Sign.	**	**	**	**	
DPPH (% of inhibition)	4 °C	1	36.91bA	15.68bC	9.31bD	28.90aB	**
		7	27.50cB	15.25bD	23.98aC	30.37aA	**
		14	42.14aA	19.32aD	26.09aB	22.37bC	**
		Sign.	**	**	**	**	
	7 °C	1	36.91aA	15.68cC	9.31cD	28.90aB	**
		7	20.69bB	28.14aA	18.98bB	30.50aA	**
		14	15.61cC	21.52bB	31.54aA	21.40bB	**
		Sign.	**	**	**	**	

Values are given as means ± standard deviations. n=3; **, *, n.s.. capital and lowercase letters see Table 1