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# Ascorbic Acid and Citric Acid Treatments Increase the Shelf Life of Fresh-Cut Potato: Cultivar Effect

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## Abstract

Potato cultivars were processed as minimally processed products (MPP) and treated with different concentrations of ascorbic (AA) and citric acids (CA) in order to investigate the effect of these treatments on the overall quality of MPP from 'Innovator', 'Newen INTA' and 'Spunta' cultivars. Colour changes, PPO activity and bioactive compounds of fresh-cut potato differed amongst potato cultivars and treatments. 'Innovator' had the least colour changes and low enzymatic activity. 'Newen INTA' highly susceptible to browning was the one that presented the highest values of polyphenol content and antioxidant capacity. Treatments applied kept microbiological counts and global appearance during 10 days of storage. Considering the different susceptibility of cultivars to enzymatic browning, the results obtained provide crucial information to select the best treatment to keep the overall quality of MPP of these important cultivars of Southeastern Buenos Aires, Argentina, as a useful tool for the industry.

**Keywords** Minimally processed products · Polyphenoloxidase · Sensory analysis · *Solanum tuberosum* · Total antioxidant capacity

## Abbreviations

| | |
|---|---|
| MPP | Minimally processed products |
| AA | Ascorbic acid |
| CA | Citric acid |
| PPO | Polyphenol oxidase |
| EB | Enzymatic browning |
| SM | Sodium metabisulphite |
| FDA | Food and Drug Administration |
| DW | Distilled water |
| $L^*$, $a^*$, $b^*$ | Lightness value, redness value and yellowness value |
| $\Delta L^*$, $\Delta a^*$, and $\Delta b^*$ | Changes in lightness, redness and yellowness, between values at each period of storage time and the value immediately after treatment ($t_0$) |

Extended author information available on the last page of the article

| | |
|---|---|
| $t_0$ | Initial time |
| $\Delta E^*$ | Total colour difference |
| TPC | Total polyphenol content |
| GAE | Gallic acid equivalent |
| TAC | Total antioxidant capacity |
| TE | Trolox equivalents |
| TAMB | Total aerobic mesophilic bacteria |
| CFU | Colony-forming units |
| LSD | Least significant difference |
| PCA | Principal component analysis |
| ISO | International Organization for Standardization |

## Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important food crop in the world in terms of human consumption, after wheat, maize and rice (Devaux et al. 2014). Due to changes in consumption habits, consumers demand fresh products with high-quality flavour, perfect appearance and high nutritional value, which favours the fresh-cut product industry. A characteristic of this industry is the need to introduce new cultivars of raw material (Putnik et al. 2017). However, not all cultivars are adapted to the production of minimally processed products (MPP) and the use of an inadequate variety would result in low-quality products that cause consumer dissatisfaction. The quality of fresh-cut products is affected by pre-harvest and post-harvest factors, and the choice of raw material is the most important step in the production, as well as the processing conditions (Silveira et al. 2017). Peeling and cutting increase tissue damage in potato MPPs, which reduces the shelf life of these products, as a result of physiological, biochemical and microbiological processes (Ma et al. 2010).

The main cause of quality deterioration in fresh-cut potatoes is enzymatic browning (EB). This is caused by reactions between the oxidative enzymes, polyphenol oxidase (PPO) and their phenolic substrates, which come into contact when cell membranes rupture due to damage (Toivonen and Brummell 2008). EB consists of the oxidation of phenolic substrates and the subsequent non-enzymatic polymerisation of o-quinones, reactive molecules that rapidly condense, forming brown pigments, which generates a rejection in the consumer. The content and types of bioactive compounds (phenols and antioxidants) and enzymatic activities depend on the cultivar, so the browning susceptibility of fresh-cut potatoes may differ from one cultivar to another (Cabezas-Serrano et al. 2009). To inhibit or delay EB, solutions of anti-browning agents containing sulphites, ascorbic acid (AA), citric acid (CA) or sulphur-containing amino acids are used (Rocculi et al. 2007). Sulphites are one of the most effective and economical chemical preservatives to inhibit EB, because they generate intermediate sulfoquinones that inhibit reaction (Sgroppo et al. 2010). However, the FDA has banned the use of sulphites in fruits and vegetables labelled 'fresh' due to the risk of allergic reactions in people sensitive to sulphites. AA acts by reducing quinones to phenolic compounds, preventing the formation of coloured compounds (Ma et al. 2010). However, once AA is fully oxidised to dehydroascorbic acid, quinones can accumulate, causing tissue browning. On the other hand, CA acts as a chelating and acidifying agent that inhibits PPO activity. In fact, low colour changes were reported in potato slices stored at refrigeration temperature after 10 days, with doses between 2.5–5% AA and 1.25–2.5% citric acid (Limbo and Piergiovanni 2006). Also, the use of CA (2%) combined with cysteine (0.5%) was effective in preventing browning, thus prolonging the shelf life of minimally processed potatoes (Gunes and Lee 2006). In addition, Ierna et al. (2017) demonstrated that immersion in AA + CA (2%) showed a good capacity to contain microbial growth during 9 days of storage in minimally processed potatoes.

The effects of treatments with different concentrations of AA and CA depend on the potato cultivar used as raw material for the MPP.

The objective of this study was to determine the effects of the potato cultivar as fresh-cut product, the treatments applied and the storage time, on the sensory, physico-chemical and microbiological characteristics in order to determine the shelf life of the product during the storage at 4 °C. It is unknown how the combinations of these acids affect the overall quality of MPP from different cultivars of Southeastern Buenos Aires, Argentina. This study will be done on three cultivars, the cultivar more used by the industry ('Innovator'), the main cultivar for fresh consumption ('Spunta') and additionally, 'Newen INTA' a cultivar with a high susceptibility to EB, but with good agronomic characteristics.

## Materials and Methods

### Plant Material

Tubers from three potato (*Solanum tuberosum* L.) cultivars were used: 'Innovator', 'Spunta' and 'Newen INTA'. The trial was carried out in Balcarce, Buenos Aires, Argentina (37° 45′ S; 58° 18′ W) in the 2018–2019 growing season. The planting season in the southeast of Buenos Aires is semi-late. The trial was planted at the beginning of November 2018 and harvested in mid-March 2019. The tubers of each of the genotypes were planted in plots, following a completely randomised block design with four repetitions. The tubers, once harvested, were cured at 18 °C for 15 days, and then they were taken to a storage chamber at 8 °C for 10–15 days, until processing.

### Post-harvest Treatments

Tubers for each cultivar were selected, 30 kg for each repetition, for their uniform shape and lack of mechanical damage. The raw potatoes were washed and disinfected using cold (4 °C) water and sodium hypochlorite (300 μL $L^{-1}$) for 5 min with agitation. The tubers were peeled to remove any residual skin and then were cut in sticks (1 cm × 1 cm × tuber length), using a manual cutting machine, and again rinsed in cold (4 °C) water, to eliminate the superficial starch. After removing the excess water by manual centrifugation, potato sticks were dipped for 3 min in different treatment solutions at 5 ± 1 °C: 1% AA + 0.5% CA; 1% AA + 1% CA; 1.5% AA + 0.5% CA; 1.5% AA + 1% CA; 0.1% SM; that is the currently concentration used in the fresh-cut potato industry and it was selected from a previous work (García Procaccini et al. 2014); and control: distilled water (DW), potatoes without added antioxidants.

The concentrations and combinations of natural antioxidants (AA and CA) were selected from a previous study (García Procaccini et al. 2014). The ratio between potatoes and the treatment solution was 1:3. All the chemicals were of food grade. After each dipping treatment, potato sticks were paper-dried, in order to eliminate as much surface water as possible. Then, about 300 g of sticks (approximately 25 and 30 sticks, depending on the length of the tuber) was packaged in 50-μm thick, low-density polypropylene bags (20 × 25 cm), which were hermetically sealed by a packaging machine. All samples were stored under refrigerated conditions at 4 ± 1 °C until analyses.

### Determination of Quality Parameters

The evolution of sensory, physico-chemical and microbiological parameters on MPP of the three potato cultivars was determined of three individual bags (repetition) at initial time ($t_0$) and after 10 days of refrigerated storage at 4 °C.

### Colour Determinations

The surface colour of minimally processed potatoes was measured using a colourimeter MINOLTA (Chromameter CR300) (Japan), based on the CIE Lab colour space, which measures three parameters: lightness ($L^*$), green–red hue ($a^*$) and blue-yellow hue ($b^*$).

In order to better assess the overall colour changes during storage, the total colour difference $\Delta E^*$ (Licciardello and Muratore 2011) was calculated as follows (Eq. 1):

$$\Delta E^* = \left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)^{1/2} \quad (1)$$

where $\Delta L^*$, $\Delta a^*$ and $\Delta$b* represent changes in lightness, redness and yellowness, respectively, between values at each period of storage time and the value immediately after treatment ($t_0$). Each measurement is the mean of three colourimeter shots of 10 sticks per bag (repetition).

### Polyphenoloxidase (PPO) Activity

PPO activity was tested as reported by Kahn (1977), 25 g of diced potato (from a sample of five potato sticks) was homogenised in 30 mL of 0.1 M phosphate buffer, together with 1 g of polyvinylpyrrolidone (PVP), and centrifuged at 12,000 × g for 15 min. The supernatant was used for PPO activity measured by determining the absorbance increase at 410 nm over a period of 2 min at 25 °C, with Spectrophotometer Spectronic 601, Milton Roy (USA). The reaction mixture contained 1.5 mL of extract, 1 mL of phosphate buffer and 0.5 mL of 100 mM 4-methylcatechol.

The results were expressed as units of enzymatic activities (U). One unit of enzyme activity was defined as the amount of the enzyme, which caused a 0.01

change in absorbance in the first 15 s, that were within the first linear region of each curve of ΔA410 plotted against time (up to 2 min). ΔA410 is defined as the difference in absorbances between 15″ and initial time.

### Total Polyphenol Content

Total polyphenol content (TPC) was estimated as gallic acid equivalent (GAE) using the Folin Ciocalteu method (Blessington et al. 2010). Fifteen millilitres of methanol was added to 5 g of diced potato (from a sample of five potato sticks). This mixture was homogenised for 1 min (T18 basic IKA Ultra-Turrax, Germany) at 11,000 g. After homogenisation, samples were centrifuged at 5000 g for 15 min. A 150-μL aliquot of the methanol extract was combined with 2.25 mL of nanopure water. The samples reacted with 150 μl of the 0.25 N Folin-Ciocalteu phenol reagent solutions for 3 min. Then, 300 μL of the 1.0 N $Na_2CO_3$ solutions was added and was incubated for 2 h at room temperature. The absorbance was measured at 725 nm with a spectrophotometer Spectronic 601, Milton Roy (USA) and compared to a gallic acid calibration curve. Results were expressed as μg of GAE $g^{-1}$ on fresh weight.

### Total Antioxidant Capacity

The total antioxidant capacity (TAC) was evaluated on the same extracts submitted to TPC determination. The assay was performed following the procedure described by Brand-Williams et al. (1995), with minor modifications. The absorbance was measured at 515 nm with a spectrophotometer (Milton Roy, Spectronic 601, USA) and compared to a Trolox calibration curve. The total antioxidant capacity was reported in μg of Trolox equivalents per gramme fresh weight (μg of TE $g^{-1}$).

### Microbiological Analysis

For sanitary and hygienic quality determinations, samples were selected immediately after processing (day 0) and during refrigerated storage. In sterile bags, 10 g (from a sample of five potato sticks) of minimally processed potatoes was taken to be homogenised in 90 ml of pH 7.0 phosphate buffer solution using a paddle homogeniser for 60 s. From this inoculum, successive dilutions were prepared and sown on the surface. The total aerobic mesophilic bacteria (TAMB) were carried out using the following working conditions: plate count agar incubated at $35 \pm 1$ °C for $48 \pm 3$ h. Three independent trials were performed, and the results reported correspond to the mean and its standard deviation (per bag), expressed as log CFU per gramme fresh weight (Mossel & Moreno García, 1985). Fungal and yeast counts of samples were tested as reported by Yousef and Carlstrom (2003), using as a medium dichloroaniline agar with 18% glycerol (DG18). The samples were sown in potato glucose agar culture medium to which chloramphenicol (0.1 g/l) was added, and were evaluated in Petri dishes, sowing 0.1 ml of the $10^{-1}$ to $10^{-3}$ dilutions in duplicate. The results were expressed as log CFU per gramme fresh weight.

### Sensory Evaluation

A six-people expert jury evaluated the sensory quality. The ISO 8586:2012 was followed for the selection, training and monitoring of expert sensory assessors. Analysed parameters of fresh-cut potato with treatments of the three cultivars included as follows: global appearance and the presence of off-odours. Because MPP is a raw product, the global appearance included just only visual and smell (evaluated just after opening the bag) characteristics. The evaluation was using a structured scale from 5 to 1, where 5 = excellent, 4 = very good, 3 = fair, 2 = poor and 1 = unacceptable. Samples of 10 sticks for each of the three replicates (bag) were evaluated by each person.

### Statistical Analysis

A factorial design (three factors: CULTIVAR, TREATMENT and STORAGE TIME) was adopted to determine the evolution of sensory, physico-chemical and microbiological parameters on minimally processed products. The results were expressed as mean ± standard deviation of the mean of three repetitions (bag). Analysis of variance (ANOVA) was used to determine if there were significant interactions between the factors. If the interaction was significant, the means between the levels of the factors were compared with least significant difference (LSD), $\alpha = 0.05$, considering the mean square of the error. Principal component analysis (PCA) was performed on all variables measured of the samples to differentiate the treatments and to analyse possible relationships between them. The correlation matrix gave the correlation coefficients between each pair of variables. Each term of the matrix was a number ranging from − 1 to + 1, the sign indicated a positive or negative interdependence between variables (direction) and the absolute value indicated the strength of the interdependence. Statistical analyses were performed using Program R (R Core Team 2017), and Origin Pro for the graphic.

## Results and Discussion

### Determination of Quality Parameters

*L** value, total colour changes, PPO activity, TPC, TAC and TAMB exhibited interaction amongst cultivars, treatment and storage time.

### Colour Determinations

Colour is an important food quality parameter. It affects consumer acceptance and even emotional feeling in humans. *L** value ranges from 0 to 100 of which values close to zero indicate dark, whilst values close to 100 indicate whiteness, so a decrease in *L** values indicates an increment in browning.

Table 1 shows the $L^*$ parameter results for all the MPP. $L^*$ value was different depending on the cultivar, treatment applied and between the beginning and end of storage at 4 °C. 'Spunta' was the cultivar with the lowest $L^*$ value, control and treated at the initial time. In general, the treatments with AA and CA, as well as with SM, showed higher values than the control samples, in the three cultivars.

After 10 days of storage at 4 °C, $L^*$ values had decreased in all samples. In general, high AA concentration treatments showed higher $L^*$ values, for all cultivars. Control samples of 'Innovator' cultivar showed high luminosity value until 10 days of storage at 4 °C, indicating that it is not a cultivar with a high susceptibility to browning. On the contrary, 'Newen INTA' is a cultivar with a very highly susceptibility to enzymatic browning, since control samples showed the lowest $L^*$ values during the storage.

Ma et al. (2010) studied the effect of treatments with different concentrations of sodium bisulphite (SB) and AA + CA on the enzymatic browning of potatoes and they reported that of 0.25% SB was able to maintain the initial $L^*$ and hue colour values, whereas 0.025% SB was not. In the present study, 0.1% SM was effective to maintain the initial $L^*$ values in the three cultivars evaluated. However, treatments with the higher concentrations of AA and CA were the only ones that allowed keeping high $L^*$ values even after 10 days of storage.

Figure 1 shows the colour changes ($\Delta E^*$) of the samples after 10 days of storage. The evaluation of $\Delta E^*$ is considered as more representative of the visual colour changes (including $L^*$, $a^*$ and $b^*$ parameters) occurring during storage. According to previous studies, values of $2 < \Delta E^* < 3.5$ are considered detectable by an untrained observer, whilst values of $3.5 < \Delta E^* < 5$ display obvious colour differences (Habekost 2013). Highest concentrations of AA and CA were the most efficient in preventing colour changes, keeping $\Delta E^*$ values below 5. Moreover, 1.5% AA + 1% CA was able to keep $\Delta E^*$ values below 3.5 for three cultivars. All treatments with AA and CA kept $\Delta E^*$ values below 3.5 for 'Innovator' cultivar. For 'Spunta' cultivar, just only treatments with higher concentrations of AA were able to avoid a high colour change, whilst the other treatments with AA and CA did not show significant differences with control sample. SM treatment showed smaller colour change (keeping $\Delta E^*$ values below 3.5) than the control sample; however, this treatment was not so efficient as treatments with high AA concentrations.

Finally, 'Newen INTA' was the cultivar with the higher colour change (see control sample), again indicating its high susceptibility to EB as was previously discussed, and just only the treatment with the highest concentrations of AA and CA was able to keep $\Delta E^*$ values below 3.5. Differences in $\Delta E^*$ value amongst potato cultivars were evident after 6 days of storage at 5 °C (Cornacchia et al. 2011).

### PPO Activity

PPO activity showed great differences between cultivars (Fig. 2). 'Newen INTA' was the cultivar with the highest enzymatic activity, followed by 'Spunta' and finally 'Innovator', which showed the lowest PPO activity. The best treatment in

**Table 1** $L^*$ value of fresh-cut potatoes from three potato cultivars treated with different concentrations and combinations of AA and CA, compared with SM-treated and control samples at 0 and 10 storage days

| Storage time (days) | Cultivar | Treatment | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Control | | 1% AA + 0.5% CA | | 1% AA + 1% CA | | 1.5% AA + 0.5% CA | | 1.5% AA + 1% CA | | 0.1% SM | |
| 0 | Innovator | 70.31 ± 1.36 | Abc | 69.67 ± 0.21 | Ac | 71.00 ± 0.85 | Abc | 72.44 ± 1.06 | Aa | 70.57 ± 0.64 | Abc | 73.06 ± 0.79 | Aa |
| | Newen INTA | 69.66 ± 0.33 | Ad | 70.22 ± 0.28 | Acd | 70.43 ± 0.16 | Acd | 71.27 ± 0.08 | Abc | 72.42 ± 0.62 | Aab | 72.65 ± 0.58 | Aa |
| | Spunta | 66.65 ± 0.06 | Bc | 68.13 ± 0.30 | Bab | 68.85 ± 0.04 | Ba | 67.10 ± 0.72 | Bbc | 67.11 ± 0.13 | Bbc | 66.31 ± 0.10 | Bc |
| 10 | Innovator | 65.83 ± 0.54 | Ac | 69.34 ± 0.18 | Aa | 66.19 ± 0.79 | Ac | 68.68 ± 0.64 | Aab | 68.89 ± 0.66 | Aab | 68.08 ± 0.20 | Ab |
| | Newen INTA | 55.48 ± 0.21 | Ce | 65.47 ± 0.71 | Bd | 67.24 ± 0.28 | Ac | 67.82 ± 0.95 | Abc | 68.52 ± 0.30 | Aab | 69.25 ± 0.44 | Aa |
| | Spunta | 60.49 ± 0.34 | Bc | 63.20 ± 2.26 | Cb | 63.27 ± 0.10 | Bb | 66.40 ± 0.37 | Ba | 66.28 ± 0.30 | Ba | 64.08 ± 0.23 | Bb |

Data are expressed as means ± standard deviation ($n = 3$)

Means followed by different capital letters indicate significant differences ($p \leq 0.05$) between cultivars for the same treatment on each storage day. Means followed by different lowercase letters indicate significant differences ($p \leq 0.05$) between treatments for the same cultivar on each storage day. Bold letters indicate significant differences ($p \leq 0.05$) between storage days for the same cultivar and treatment

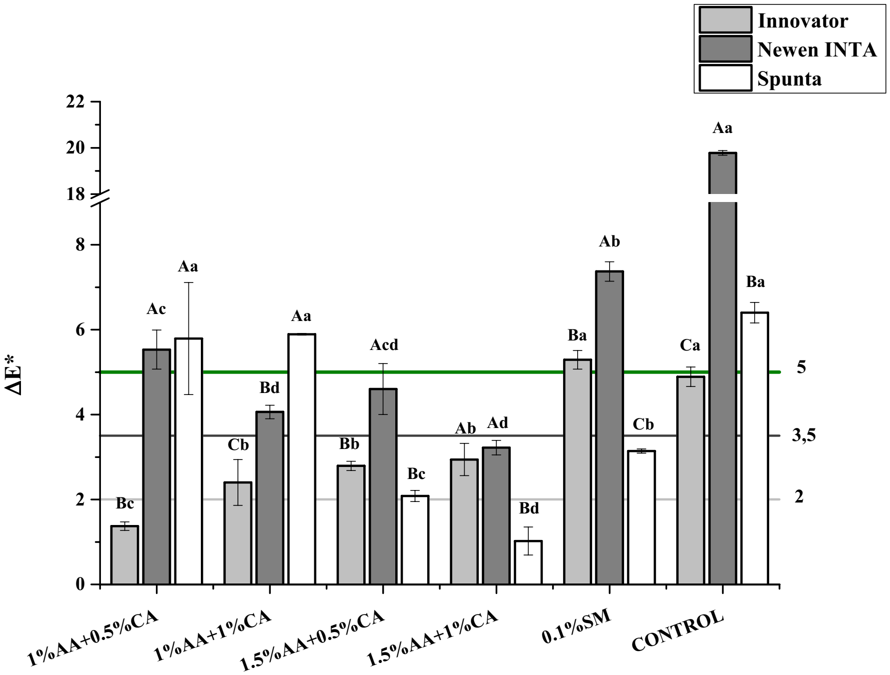
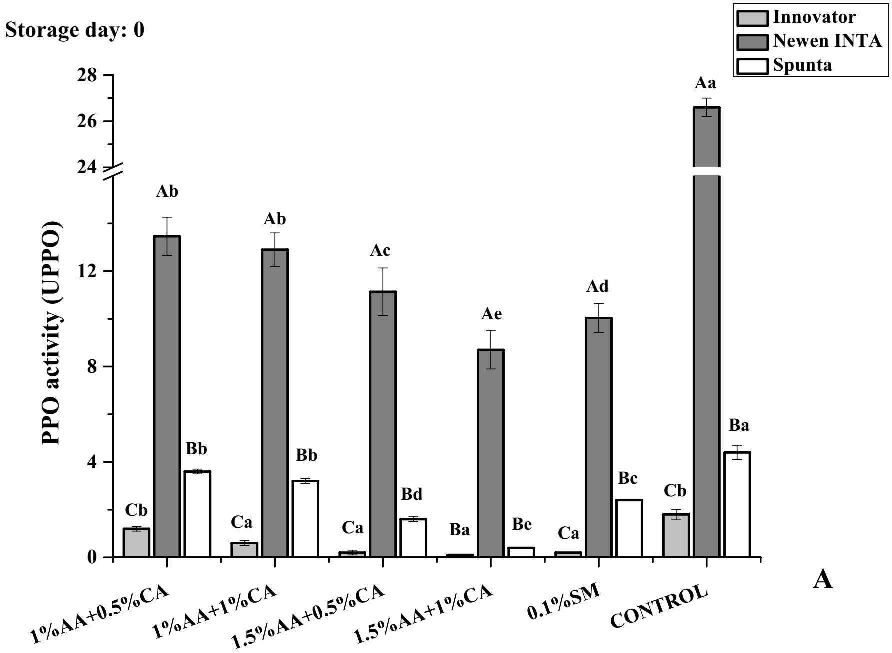


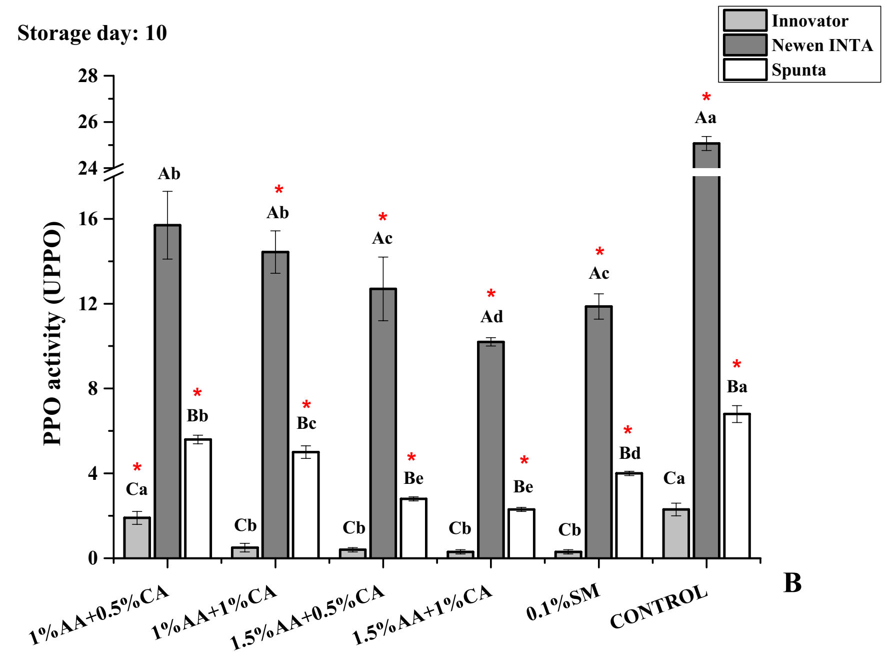

**Fig. 1** Total difference colour (Δ*E**) during the storage (from 0 to 10 days) of fresh-cut potatoes from three potato cultivars treated with different concentrations and combinations of AA and CA, compared with SM-treated and control samples. Vertical bars represent the standard deviation of the means ($n=3$). Different capital letters indicate significant differences ($p\leq0.05$) between cultivars for the same treatment on each storage day. Different lowercase letters indicate significant differences ($p\leq0.05$) between treatments for the same cultivar on each storage day. Horizontal grey line at 2, black line at 3.5 and green line at 5 indicate the differences visual perceptions according to Habekost (2013)

maintaining the lowest enzymatic activity at $t_0$ for 'Newen INTA' and 'Spunta' was the treatment with 1.5% AA + 1% CA. For 'Innovator' cultivar, a low PPO activity was observed even with treatments with lower concentrations of AA and CA and with SM treatment. Changes in the PPO activity of different fruits have also been reported. In apple cubes treated with AA (1%) and CA (0.2%) reported 90% to 100% inhibition of PPO activity. On the contrary, pears treated with 3% AA showed no differences with pears without treatment, both showing high PPO activity (Oms-Oliu et al. 2006).

After 10 days of storage, PPO activity increased on MPP for 'Newen INTA' and 'Spunta' cultivars, independent of treatment, and for 'Innovator', the PPO activity only increased in MPPs treated with low concentration of organic acids.

Calder et al. (2011) evaluated the effectiveness antibrowning of ozone and acidulant treatments on fresh-cut potatoes during 28 days at 4 °C and reported that a combined treatment of sodium acid sulphate with AA and CA was more effective to reduce enzymatic browning (lower value of PPO


Storage day: 0
Innovator
Newen INTA
Spunta
PPO activity (UPPO)
28
26
24
12
8
4
0
Cb
Ab
Bb
Ca
Ab
Bb
Ca
Ac
Bd
Ba
Ae
Be
Ca
Ad
Bc
Cb
Aa
Ba
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
A


Storage day: 10
Innovator
Newen INTA
Spunta
PPO activity (UPPO)
28
26
24
16
12
8
4
0
Ca
Ab
Bb
Cb
Ab
Bc
Cb
Ac
Be
Cb
Ad
Be
Cb
Ac
Bd
Ca
Aa
Ba
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
B

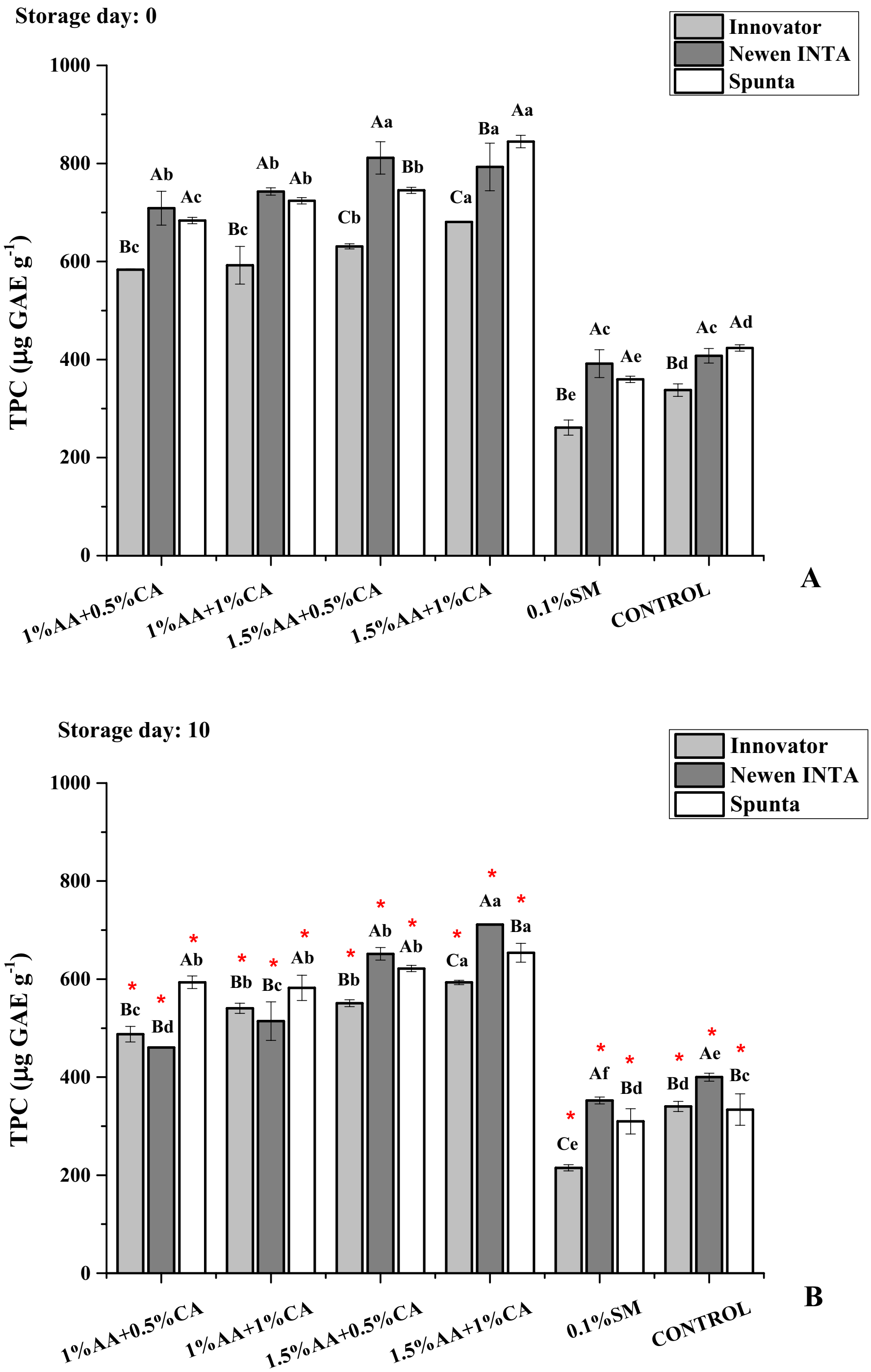
◀ **Fig. 2** Polyphenoloxidase (PPO) activity of fresh-cut potatoes from three potato cultivars treated with different concentrations and combinations of AA and CA, compared with SM-treated and control samples at 0 (**A**) and 10 (**B**) storage days. Vertical bars represent the standard deviation of the means ($n = 3$). Different capital letters indicate significant differences ($p \leq 0.05$) between cultivars for the same treatment on each storage day. Different lowercase letters indicate significant differences ($p \leq 0.05$) between treatments for the same cultivar on each storage day. Asterisks represent significant differences ($p \leq 0.05$) between storage day for the same cultivar and treatment

activity), compared with AA and CA treatment. Additionally, they used of ozone improved the colour of fresh-cut potatoes (higher *L** values and lower *a** values) compared to treatments without ozone. However, they did not evaluate sodium acid sulphate alone, and considering the health's risks of sulphites, it would be important to avoid the use of these compounds, optimising the concentration of AA-CA treatment.

In an interesting work, Tsouvaltzis and Brecht (2017) evaluated the effects of citric acid treatments at 0.5, 1 and 2% using sulphuric acid to control the pH in order to elucidate the mechanisms of citric acid in fresh-cut potato browning inhibition. They concluded that this inhibition is not solely due to pH reduction of the solution, since higher citric acid concentrations (1 and 2%), which promoted the highest pH reduction, resulted in the lowest discolouration scores, whilst the lowest concentration of citric acid (0.5%) did not prevent colour changes, but pH adjustment with sulphuric acid, up to the pH of the higher concentration of citric acid solutions, did not induce any additional prevent colour changes. Therefore, the authors verified the dual role of citric acid as an acidulant and as a chelating agent, bonding phenolic substrates or the cooper from PPO enzyme to form complexes.

## Total Polyphenol Content

Treatment and cultivar effects on the total polyphenol contents were observed (Fig. 3A and B). MPP treated with AA and CA had twice the TPC of control samples. The addition of AA in this type of treatment could be a way to enrich the plant tissue, contributing to an increase in the antioxidant capacity that normally derives from the bioactive endogenous compounds. 'Innovator' and 'Spunta' cultivar treated with SM showed a lower value of TPC than the control. Amongst the cultivars analysed, 'Newen INTA' and 'Spunta' showed higher TPC than 'Innovator'. Cutting of potatoes can induce the accumulation of polyphenols; in fact, wounding of fresh potatoes has been shown to cause changes in phenolic compounds and antioxidant capacity (Reyes et al. 2005). It was demonstrated that the wounding response is cultivar dependent (Reyes and Cisneros-Zevallos 2003). After 10 days of storage, TPC significantly decreased for all MPP; however, the trend between cultivars and treatments was similar. Phenolic compounds are the substrates of PPO enzymes in the enzymatic browning reaction, so as the storage time increases, these compounds react, so TPC could decrease as the storage time progresses and the reaction takes place.


Storage day: 0
Innovator
Newen INTA
Spunta
TPC (µg GAE g-1)
1000
800
600
400
200
0
Bc
Ab
Ac
Bc
Ab
Ab
Cb
Aa
Bb
Ca
Ba
Aa
Be
Ac
Ae
Bd
Ac
Ad
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
A
Storage day: 10
Innovator
Newen INTA
Spunta
TPC (µg GAE g-1)
1000
800
600
400
200
0
Bc
Bd
Ab
Bb
Bc
Ab
Bb
Ab
Ab
Ca
Aa
Ba
Ce
Af
Bd
Bd
Ae
Bc
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
B

◀ **Fig. 3** Total polyphenol content, TPC (μg GAE $g^{-1}$), of fresh-cut potatoes from three potato cultivars treated with different concentrations and combinations of AA and CA, compared with SM-treated and control samples, at 0 (**A**) and 10 (**B**) storage days. Vertical bars represent the standard deviation of the means ($n=3$). Different capital letters indicate significant differences ($p \leq 0.05$) between cultivars for the same treatment on each storage day. Different lowercase letters indicate significant differences ($p \leq 0.05$) between treatments for the same cultivar on each storage day. Asterisks represent significant differences ($p \leq 0.05$) between storage day for the same cultivar and treatment

## Total Antioxidant Capacity

TAC results for MPP are shown in Fig. 4A and B. Similar results to those observed for TPC were found, showing that the MPP treated with AA and CA had a higher activity than the MPP treated with SM or without treatment, which was expected by incorporating exogenous antioxidants during the treatments. Despite this, the control MPP of the three cultivars showed higher TAC than the MPP treated with SM, suggesting that the treatment with SM reduced the TAC of the MPP even since the initial time of storage. Between the cultivars, differences in the TAC values were observed, mainly at $t_0$. 'Newen INTA' showed higher TAC values, followed by 'Innovator' and finally 'Spunta' with the lowest content, for MPP treated with AA and CA. Compounds responsible for TAC in potatoes are polyphenols, anthocyanins and vitamin C (Reyes et al. 2005); therefore, differences amongst genotypes would be related to TAC. However, 'Innovator' showed higher TAC than 'Newen INTA' in the control samples and no differences were observed between both cultivars in MPP treated with SM.

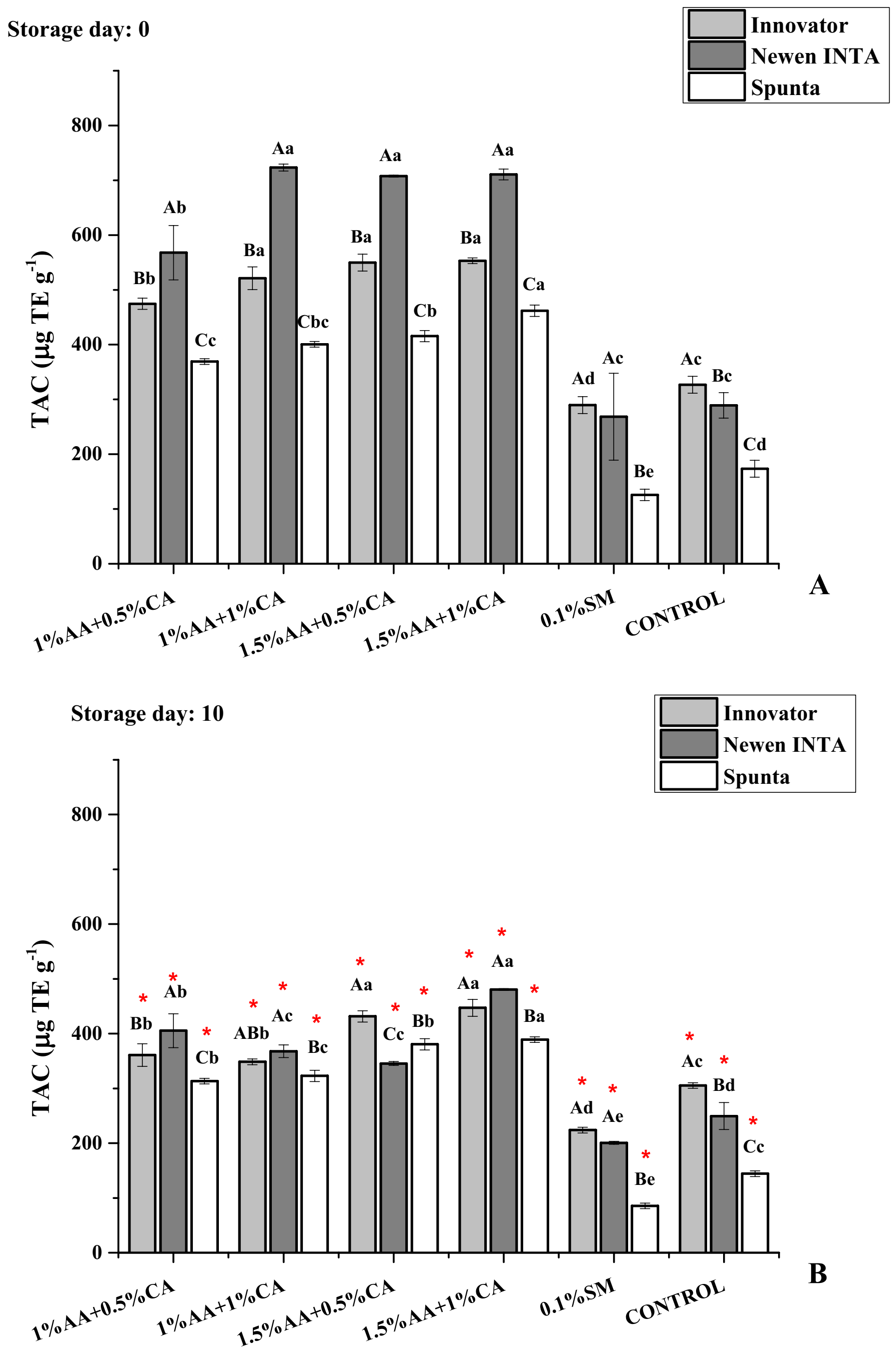
In a similar way as the observed for TPC (Fig. 3A), after 10 days of storage, TPC significantly decreased for all MPP (see asterisks in Fig. 3B). Additionally, after the storage, differences on the TAC values between cultivars were reduced (Fig. 4B).

Differences amongst cultivars may be attributed to genotypes and harvest location which influence the accumulation of phenolic compounds by synthesising different quantities and/or types of phenolics compounds (Šulc et al. 2008). This discrepancy amongst cultivars makes them nutritionally interesting when choosing a cultivar to use as a raw material for minimal processing. According with the antioxidant treatments, MPP treated with AA-CA in the three cultivars showed higher total polyphenol contents (above 50%) than the control samples and those treated with SM, until the end of storage.

It could be because phenolic compounds, as well as AA, are involved in delaying the action of the PPO enzyme to avoid the browning reaction. On the other hand, MPP treated with SM showed a significant lower TAC than MPP without treatment, in agreement with Ierna et al. (2016).

## Microbiological Analysis

The TAMB values (Fig. 5) showed an effect between the cultivars, 'Newen INTA' showed the lowest counts, although it did not show any difference between the treatments. 'Innovator' showed the highest TAMB counts after treatment (> 4 log CFU $g^{-1}$), followed by 'Spunta' (3–4 log CFU $g^{-1}$) and 'Newen INTA' with the lowest


Storage day: 0
Innovator
Newen INTA
Spunta
TAC (μg TE g-1)
800
600
400
200
0
Bb
Ab
Cc
Ba
Aa
Cbc
Ba
Aa
Cb
Ba
Aa
Ca
Ad
Ac
Be
Ac
Bc
Cd
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
A
Storage day: 10
Innovator
Newen INTA
Spunta
TAC (μg TE g-1)
800
600
400
200
0
Bb
Ab
Cb
ABb
Ac
Bc
Aa
Cc
Bb
Aa
Aa
Ba
Ad
Ae
Be
Ac
Bd
Cc
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
B

◀ **Fig. 4** Total antioxidant capacity, TAC (μg TE $g^{-1}$), of fresh-cut potatoes from three potato cultivars treated with different concentrations and combinations of AA and CA, compared with SM-treated and control samples, at 0 (**A**) and 10 (**B**) storage days. Vertical bars represent the standard deviation of the means ($n=3$). Different capital letters indicate significant differences ($p \leq 0.05$) between cultivars for the same treatment on each storage day. Different lowercase letters indicate significant differences ($p \leq 0.05$) between treatments for the same cultivar on each storage day. Asterisks represent significant differences ($p \leq 0.05$) between storage day for the same cultivar and treatment

counts at the initial time (2.5–3 log CFU $g^{-1}$). Differences in microbial growth between potato cultivars ('Bruja', 'Michuñe roja', 'Michuñe azul' and 'Asterix') were previously studied (Silveira et al. 2017) and it was related with metabolic activity and browning. After 10 days of storage at 4 °C, an increment in the count of bacteria was observed in all samples, and an effect of cultivar and treatment was observed.

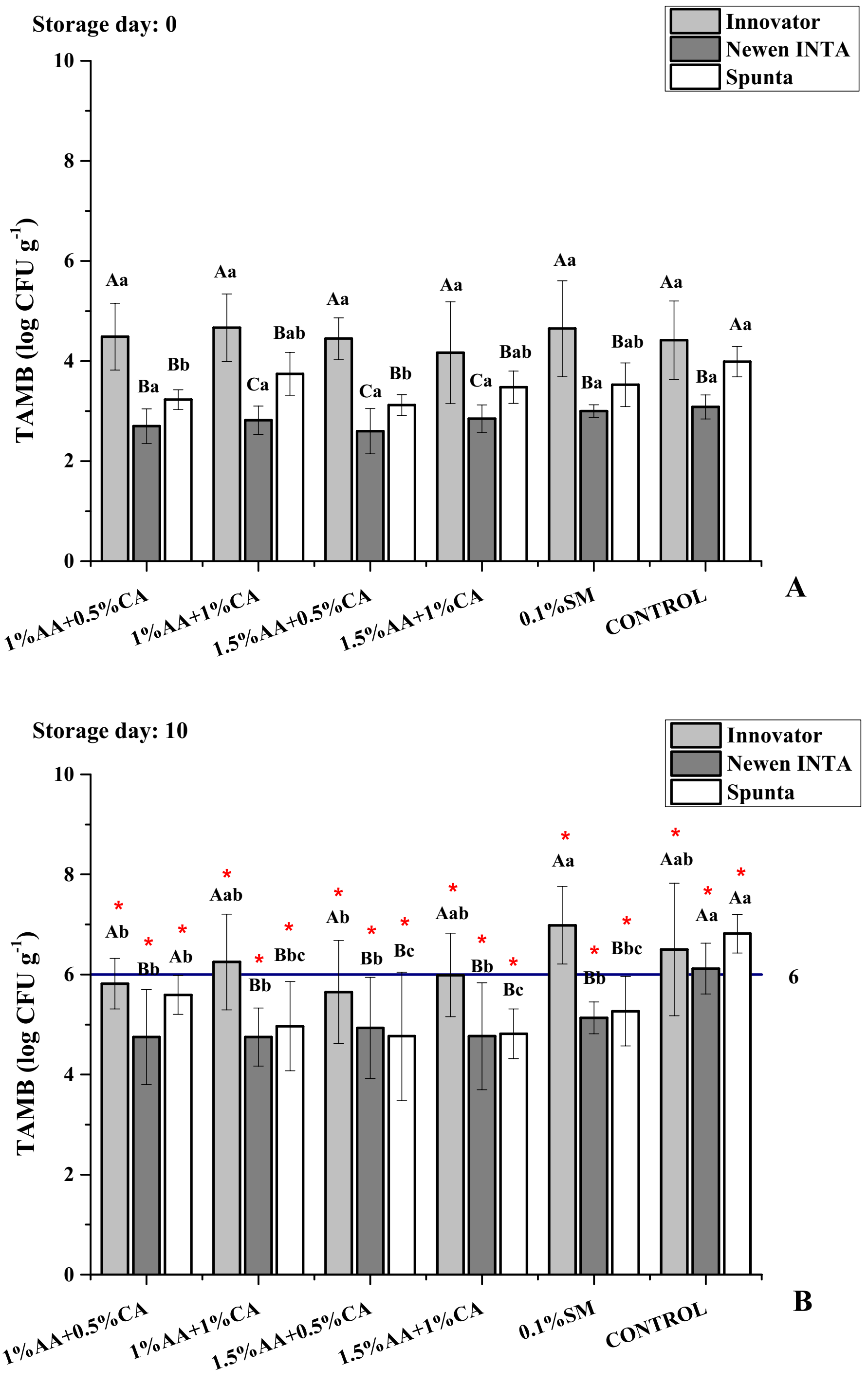
Considering 6 log CFU $g^{-1}$ as the maximum recommended count value in MPP (Siroli et al. 2015), all treatments applied in 'Newen INTA' and 'Spunta' were effective in terms of the microbiological quality of these products. In 'Innovator' MPP, some of the treatments with AA and CA were able of keeping TAMB counts below 6 log CFU $g^{-1}$, whilst SM and control samples exceeded that value.

These results suggest that the treatments with AA and CA could help to reduce the counts of aerobic microorganisms, in comparison with MPP without treatment, for all cultivars and even compared with the SM treatment for 'Innovator'. In fact, it has been previously reported that dipping fresh potato in AA and CA showed a good ability to contain microbial growth during whole storage time (Ierna et al. 2017). It is noteworthy that almost all samples treated with antioxidants, after 10 days of storage, showed counts in compliance with the recommended limit proposed in fresh-cut vegetables. Even if fresh-cut potato are cooked before consumed, it is desirable to maintain a low value of microbial growth during storage because of the remarkable relation found between shelf life, calculated by microbial load limit, and changes in the product appearance (Beltrán et al. 2005). Obviously, this is crucial for other factors such as colour that could reduce or compromise marketable life of food.

The results of the fungal and yeast count did not show growth in the samples during the evaluated storage time.

## Global Appearance

After the treatments were applied, the MPP treated presented greater global appearance than the control samples for 'Innovator' and 'Newen INTA' cultivars, whilst there were no differences between treatments and control for 'Spunta' MPP (Fig. 6A). The treatments with high concentrations of AA and with SM in MPP of 'Newen INTA' had better global appearance than the other treatments and the control, being this last the MPP with the lowest score, showing a value close to the limit of acceptability. A score of 3 was considered as the limit of marketability and a score of 2 as the limit of edibility. After 10 days of storage,


Storage day: 0
Innovator
Newen INTA
Spunta
TAMB (log CFU g-1)
10
8
6
4
2
0
Aa
Ba
Bb
Aa
Ca
Bab
Aa
Ca
Bb
Aa
Ca
Bab
Aa
Ba
Bab
Aa
Ba
Aa
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
A
Storage day: 10
Innovator
Newen INTA
Spunta
TAMB (log CFU g-1)
10
8
6
4
2
0
Ab
Bb
Ab
Aab
Bb
Bbc
Ab
Bb
Bc
Aab
Bb
Bc
Aa
Bb
Bbc
Aab
Aa
Aa
6
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
B

◂ **Fig. 5** Total aerobic mesophilic bacteria, TAMB (log CFU $g^{-1}$), of fresh-cut potatoes from three potato cultivars treated with different concentrations and combinations of AA and CA, compared with SM-treated and control samples, at 0 (**A**) and 10 (**B**) storage days. Vertical bars represent the standard deviation of the means ($n=3$). Different capital letters indicate significant differences ($p \leq 0.05$) between cultivars for the same treatment on each storage day. Different lowercase letters indicate significant differences ($p \leq 0.05$) between treatments for the same cultivar on each storage day. Asterisks represent significant differences ($p \leq 0.05$) between storage day for the same cultivar and treatment. Horizontal line at 6 log CFU $g.^{-1}$ indicates the maximum recommended count value in MPP (Siroli et al. 2015)

in general, a loss in global appearance was observed; however, some of the cultivars treated with the higher concentration of AA or with SM did not show differences during the storage time. Since global appearance includes visual and smell characteristics, this loss in the score could be related to the appearance of some signs of browning, changes in colour and to the beginning of dehydration of the samples. Additionally, all MPP of three cultivars without treatment had lower score than MPP treated; however, just only control of 'Innovator' kept a global appearance higher than 3. No differences between treatments were observed for MPP for 'Innovator' cultivar. For 'Newen INTA' and 'Spunta' cultivars, some significant differences were observed between treatments, being more efficient the treatments with higher concentrations of AA and CA and with SM. It is important to highlight that control MPP for 'Newen INTA' and 'Spunta' showed a score for global appearance lower than 3, indicating that the MPP of these cultivars strictly require some type of treatment to extend the useful life and acceptance by consumers.

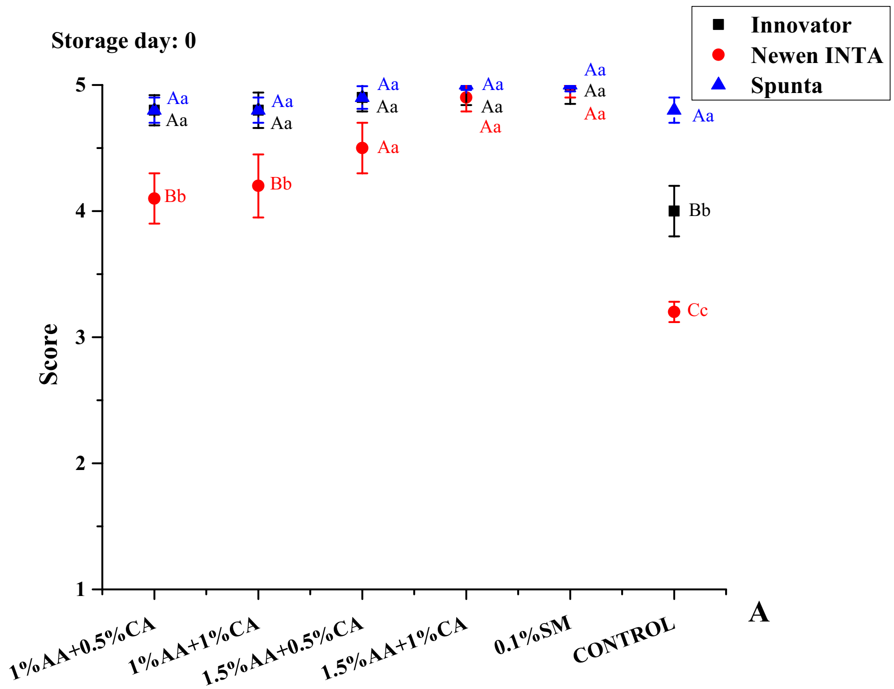
Sulphites usually provide excellent control of browning (Ierna et al. 2016; Ma et al. 2010); however, it develops off-odours after the treatment is applied. In fact, presence of off-odours, defined as 'metallic' odours by the judges' observations, was detected in 'Newen INTA' and 'Spunta' samples treated with SM at $t_0$; however, it disappeared after 10 days of storage.

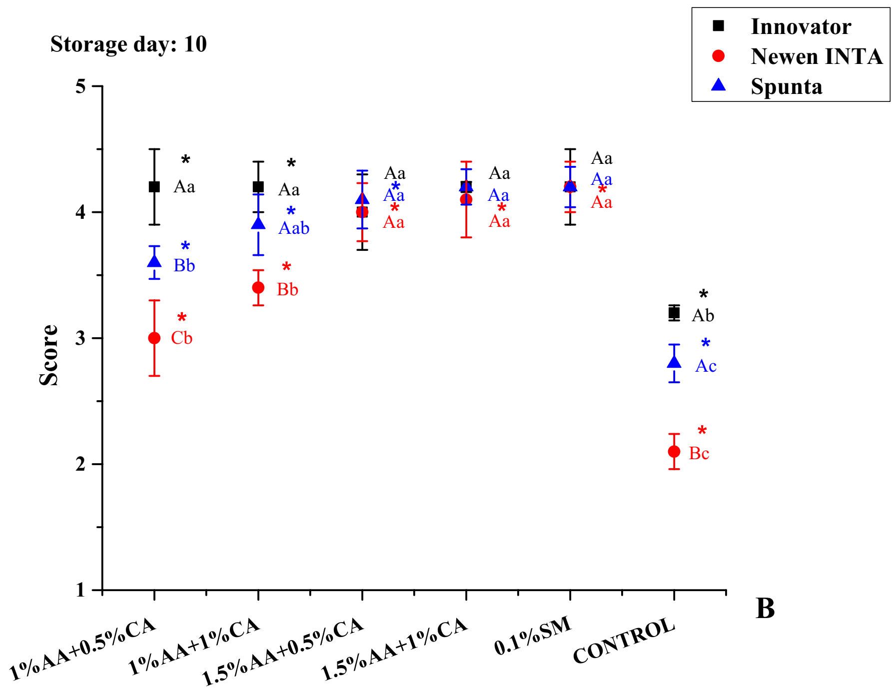
## PCA Analysis

The PCA biplot showed that the first two principal components accounted for 78.34% of the total variance (PC1 = 51.93% and PC2 = 26.41%) (Fig. 7). The most important contributors to the PC1 were TPC, TAC and global appearance. The most important contributors to PC2 were PPO and $\Delta E^*$.

TPC and TAC were positioned close to each other which indicates a high positive correlation between them (79.7%) (data not shown). Global appearance showed negative correlation with $\Delta E^*$ (77.0%), indicating that the global appearance has a close relationship with the colour of the samples, because of the high correlation with the instrumentally measured values.

Regarding the cultivars, untreated samples of 'Newen INTA' at 0 and 10 days of storage and samples treated with AA and CA with 10 days of storage, grouped close to PPO activity, which would be related with their highest enzyme activity.


Storage day: 0
Innovator
Newen INTA
Spunta
Score
5
4
3
2
1
Aa
Aa
Bb
Aa
Aa
Bb
Aa
Aa
Aa
Aa
Aa
Aa
Aa
Aa
Aa
Aa
Bb
Cc
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
A


Storage day: 10
Innovator
Newen INTA
Spunta
Score
5
4
3
2
1
Aa
Bb
Cb
Aa
Aab
Bb
Aa
Aa
Aa
Aa
Aa
Aa
Aa
Aa
Aa
Ab
Ac
Bc
1%AA+0.5%CA
1%AA+1%CA
1.5%AA+0.5%CA
1.5%AA+1%CA
0.1%SM
CONTROL
B

◀ **Fig. 6** Global appearance of fresh-cut potatoes from three potato cultivars treated with different concentrations and combinations of AA and CA, compared with SM-treated and control samples, at 0 (**A**) and 10 (**B**) storage days. Vertical bars represent the standard deviation of the means ($n = 3$). Different capital letters indicate significant differences ($p \leq 0.05$) between cultivars for the same treatment on each storage day. Different lowercase letters indicate significant differences ($p \leq 0.05$) between treatments for the same cultivar on each storage day. Asterisks represent significant differences ($p \leq 0.05$) between storage day for the same cultivar and treatment

Additionally, the samples without treatment and SM treated from the three cultivars were observed close to TAMB, in advanced stages of storage, according with their higher numbers of counts than MPP with AA and CA treatments.

On the other hand, 'Newen INTA' MPP treated with antioxidants were close to TPC and TAC which would indicate a contribution of the treatments to increase the antioxidant capacity, even after the storage at 4 °C.

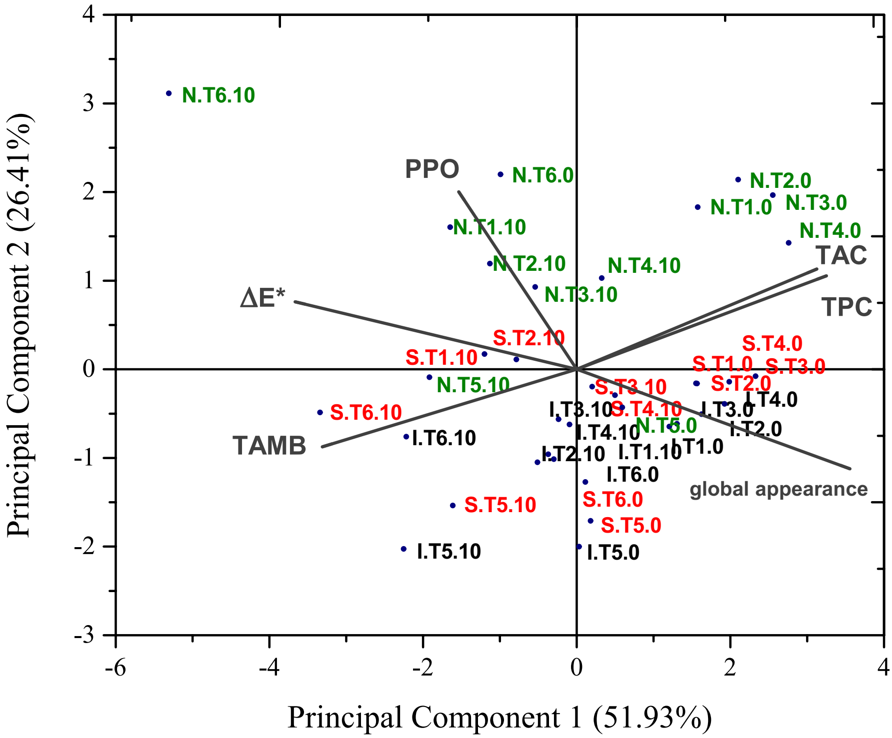



**Fig. 7** Biplot from principal component analysis of sensory, physical–chemical and microbiological parameters of minimally processed products of three potato cultivars ('Innovator', 'Newen INTA', 'Spunta') treated with different antioxidant treatments, over refrigerated storage time. PPO, polyphenoloxidase activity; TPC, total polyphenol content; TAC, total antioxidant capacity; TAMB, total aerobic mesophilic bacteria and global appearance. T1, 1% AA + 0.5% CA; T2, 1% AA + 1% CA; T3, 1.5% AA + 0.5% CA; T4, 1.5% AA + 1% CA; T5, 0.1% SM; T6, without treatment. Example of key of abbreviation for samples: I.T1.0 means 'Innovator' cultivar MPP, treated with the antioxidant treatment T1 at the initial time of storage ($t_0$)

## Conclusion

The browning susceptibility of fresh-cut potato differed amongst potato cultivars. Moreover, each treatment of AA and CA had different effects depending on the potato cultivar and storage time analysed. All combined AA and CA treatments were effective against the EB process compared with the control samples for each cultivar. The best treatment that was able to maintain the optimal colour, high TPC and TAC values, and microbiological characteristics during 10 days at 4 °C on three cultivars was 1.5% AA + 1% CA, although for 'Innovator' and 'Spunta' cultivars, treatments with lower concentrations of AA and CA were also effective, with a good global appearance and microbiological quality. AA and CA can be used to replace SM, improving the quality of MPP of potato cultivars grown in the Southeastern Buenos Aires during storage at 4 °C. SM treatment was effective in maintaining the colour of MPP but decreased their physical–chemical (TPC and TAC) quality and showed a negative effect on global appearance, showing off-odours.

The results obtained in the present work demonstrated that the choice of cultivar represents a key issue in determining the overall quality of MPP. 'Newen INTA' was the most susceptible cultivar to EB; however, it can be used as raw material in MPP with the use of AA and CA treatment. These results will help to develop methods for the industry, to preservative of fresh-cut products by using these antioxidant treatments, increasing their added value, and making them more attractive and more convenient for consumers to use. Other studies are currently underway to determine the effects of antioxidant treatments on the sensory quality of the fresh-cut potatoes as raw material and after cooking, like frying, to determine their feasibility for application and evaluate their acceptability.

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**Author Contribution** LMGP carried out the work, investigation, methodology, writing—original draft, writing—reviewing and editing preparation. MH: conceptualisation, supervision, analysis. MGG: supervision, microbiology analysis. MJM supervised the work and edited the manuscript.

## Declarations

**Competing Interests** The authors declare no competing interests.

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