New antioxidant treatment with yerba mate (*Ilex paraguariensis*) infusion for fresh-cut apples: Modeling, optimization, and acceptability

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Abstract

Enzymatic browning affects the sensory and nutritional quality of fresh-cut apples and limits their shelf-life. Yerba mate (*Ilex paraguariensis*), a plant widely consumed in South America as an infusion, could potentially be used in minimally processed fruits and vegetables as a natural additive to prevent browning, due to its high content of phenolic compounds with antioxidant capacity. The effects of the concentrations of ascorbic acid, citric acid, and yerba mate in an aqueous dipping solution on the instrumental color parameters, antioxidant capacity, and sensory quality of ''Granny Smith'' fresh-cut apples were modeled and the solution was optimized to obtain treated apples with maximum antioxidant capacity and minimum browning, without affecting the natural flavor of the fruits. The optimal composition obtained (1.2% yerba mate + 0.9% citric acid + 1.0% ascorbic acid) increased the antioxidant capacity of the apples by 36%. The sensory acceptability test carried out on the ''Granny Smith'' fresh-cut apples treated with the optimal dipping solution showed that more than 78% of the surveyed consumers liked the color, flavor, and texture of the apples.

Keywords

Natural antioxidant, minimally processed, sensory evaluation, response surface methodology, browning

INTRODUCTION

Apple slices are one of the most popular fresh-cut products around the world; however, their susceptibility to browning is a serious concern because it negatively affects the sensory and nutritional quality (Chen et al., 2015). Enzymatic browning occurs when orthophenols are oxidized to quinones by the action of the polyphenol oxidase enzyme (PPO), which then polymerize to brown pigments (Huque et al., 2013). Several methods have been proposed to prevent enzymatic browning in fresh-cut fruits, including the application of antibrowning agents, edible coatings, mild heat or high CO_2 treatments, and packaging under modified atmospheres (Cortellino et al., 2015; Rojas-Graü et al., 2007). However, dipping the fruits in antioxidant solutions after peeling and/or cutting is still the most commonly used method to control browning.

Ascorbic acid (AA) is a widely used antioxidant because it is effective in delaying browning and is generally recognized as safe by the Food and Drug Administration (FDA, 1979; Rojas-Graü et al., 2009). AA reduces quinones back to phenolic compounds, prior to the formation of brown pigments. However, after some time AA is oxidized to dehydroascorbic acid, allowing the o-quinones accumulation (Gil et al., 1998; Rojas-Graü et al., 2009). Citric acid (CA) is often used in conjunction with AA to maintain product color, due to its ability to reduce pH, therefore decreasing PPO activity, and for its metal chelating

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ability that limits the availability of ions required for PPO activation (Abbott et al., 2004; Huque et al., 2013). The consumers wish to reduce or eliminate the chemically synthesized additives in food has led to the interest of using natural compounds (Alandes et al., 2009). "Mate" is a traditional drink widely consumed in Uruguay, Argentina, Brazil, and Paraguay, which consists of an infusion of the milled dried leaves of *Ilex paraguariensis* St. Hil., Aquifoliaceae, commonly known by the name of "yerba mate" (YM) (Heck and De Mejia, 2007). Several properties have been claimed for YM, including antiobesity, hypocholesterolemic, anti-inflammatory, antithrombotic, antiaging, and analgesic (Bravo et al., 2007; Kim et al., 2015; Yu et al., 2015). YM has been used as a food antioxidant in cheese, bread, and beverages (Faccin et al., 2015; Faion et al., 2015; Orjuela-Palacio et al., 2014). It has been proved that the application of 1 and 2% YM infusions to an extract of the PPO enzyme of "Princesa" apples has an important inhibitory effect on the PPO activity (Martín et al., 2010). Several authors have studied the potential uses of YM in the food industry; however, to the best of our knowledge, there are only limited reports of the effects of applying YM infusions to minimally processed fruits (Rodríguez Arzuaga et al., 2016).

Therefore, the objectives of this paper were (i) to optimize the concentrations of AA, CA, and YM in an aqueous dipping solution with the aim to maximize the antioxidant capacity and minimize browning development without affecting the sensory quality of fresh-cut apples; and (ii) to study the consumer acceptability of "Granny Smith" fresh-cut apples treated with the optimal dipping solution.

MATERIALS AND METHODS

Modeling and optimization of the antioxidant dipping solution

YM infusions and dipping solutions preparation. Argentine commercial YM purchased at a local market of Santa Fe, with not less than 65% of dried milled leaves and not more than 35% of milled stems (Código Alimentario Argentino, 2013), was used. Infusions of YM were prepared by adding water at 90 °C to the corresponding quantity of YM, stirring and letting stand covered for 5 min. The extracts were filtered through cotton and Whatman paper no. 40.

The required masses of CA and/or AA were weighed and added to the corresponding YM infusion or water, stirring until complete dissolution, to obtain each dipping solution.

Fresh-cut apples preparation. "Granny Smith" apples (pH = 3.4, acidity = 0.52%, soluble solids content = 11.8 °Brix, Firmness = 68.6 N) were purchased at a local market and stored at 2 °C until processing. The cultivar was chosen due to its reduced susceptibility to enzymatic browning and higher firmness and juiciness (Piagentini and Pirovani, 2017). Whole fruits of uniform size and color were washed with a 100 mg l^{-1} solution of NaClO for 2 min, peeled with a sharp stainless steel knife, cored and cut into eight wedges. The wedges were dipped in the corresponding solution according to the experimental design (Table 1) for 3 min, in a 1:3 (m/v) ratio, drained and let stand on absorbing paper for 2 min. All samples were analyzed immediately after processing unless otherwise stated. Color parameters (evaluated immediately after processing and after 240 min), antioxidant capacity, and sensory attributes (browning, sour taste, and off-flavors) were determined for each sample.

Experimental design. Response surface methodology using a Box–Behnken design (Montgomery, 2004) with three factors in three levels (15 experiments with two replicates in the central point) was used to model the responses and to optimize the concentrations of YM, CA, and AA in the dipping solution (Table 1). The factors and levels studied, selected according to a previous study (Rodríguez Arzuaga and Piagentini, 2013), were YM concentration (C_{YM}): 0.0, 1.0, 2.0% (m/v); CA concentration (C_{CA}): 0.0, 0.5, 1.0% (m/v); and AA concentration (C_{AA}): 0.0, 0.5, 1.0% (m/v).

A second-order polynomial equation was proposed to model each response (Montgomery, 2004)

$$Y_k = \beta_{k_0} + \sum_{i=1}^{3} \beta_{k_i} X_i + \sum_{i=1}^{3} \beta_{k_{ii}} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{k_{ij}} X_i X_j \qquad (1)$$

where Y_k are the responses (antioxidant capacity, color changes: $\Delta x_i = x_{0\,min} - x_{240\,min}$, where x = L*, a*, b* and C_{ab}*, and browning, sour taste, and off-flavors); β_k are the coefficients of the model of each response; and X_i are the independent variables ($X_1 = C_{YM}$, $X_2 = C_{CA}$, and $X_3 = C_{AA}$).

Data analysis was performed by means of Statgraphics Centurion XV software (Addinsoft, New York, NY, USA). ANOVA analyses were performed for each response. Tests to verify the assumptions of the ANOVA were performed. The experimental data were fit to the second-order polynomial equations and the coefficients of the equations were obtained. The linear stepwise regression procedure was used for the elimination of the nonsignificant terms of each model. The lack of fit and the coefficient of determination (R^2) were calculated to verify the model adequacy.

Table 1. Box–Behnken design and experimental results for fresh-cut "Granny Smith" apples treated with different solutions containing yerba mate infusions (YM), citric acid (CA), and ascorbic acid (AA)

				Responses								
Run. no.	C_{YM} (%)	C_{CA} (%)	C_{AA} (%)	AEAC (mg kg^{-1})	FRAP ($\mu\text{mol kg}^{-1}$)	ΔL^*	Δa^*	Δb^*	ΔC_{ab}^*	Browning	Sour taste	Off-flavors
1	2.0	1.0	0.5	1204.3	3702.4	−0.2	0.0	−1.7	−1.7	0.2	6.0	2.8
2	2.0	0.5	1.0	1410.9	4344.6	0.2	−0.2	−0.4	−0.3	0.6	4.7	3.5
3	0.0	1.0	0.5	924.2	4055.7	−0.2	0.0	0.0	0.0	0.5	6.3	2.0
4	0.0	0.0	0.5	783.5	3820.3	1.3	−0.6	−2.2	−2.2	2.5	5.8	2.2
5	2.0	0.5	0.0	830.6	2526.2	1.9	−2.0	−2.6	−2.6	2.1	5.7	3.8
6	1.0	0.0	1.0	920.2	3828.2	2.0	−1.7	−1.9	−2.0	0.6	4.3	2.4
7	1.0	0.5	0.5	900.0	3796.1	0.9	−0.3	0.0	0.0	0.3	5.4	2.1
8	1.0	1.0	1.0	853.1	4003.7	0.1	0.4	1.4	1.3	0.3	6.1	2.3
9	1.0	0.0	0.0	565.1	2940.5	2.8	−2.0	−4.4	−4.4	5.0	3.8	1.9
10	2.0	0.0	0.5	1034.6	3245.4	1.9	−1.9	−3.0	−3.0	0.6	5.3	4.0
11	0.0	0.5	0.0	445.1	2470.0	2.3	−2.0	−3.9	−3.8	2.4	5.8	2.3
12	0.0	0.5	1.0	736.5	3848.4	0.0	−0.3	0.0	0.0	0.5	6.2	2.0
13	1.0	0.5	0.5	1000.1	3456.9	0.1	0.0	−0.2	−0.2	0.3	6.0	1.9
14	1.0	1.0	0.0	981.9	2638.2	0.7	−0.5	−1.3	−1.3	1.7	5.6	1.5
15	1.0	0.5	0.5	1055.4	3267.5	0.5	−0.1	−0.3	−0.3	0.6	5.5	2.0

AEAC: AA equivalent antioxidant capacity; FRAP: ferric reducing-antioxidant power.

The multiple response optimization procedure, based on Derringer and Suich (1980), was performed to find the YM, CA, and AA concentrations that would give minimum browning development (minimize ΔL^* and sensory attribute browning and maximize Δa^*) and maximum antioxidant capacity (determined by 2,2-diphenyl-1-picryhydrazyl radical (DPPH*) and ferric reducing–antioxidant power (FRAP) methods), without negatively affecting the flavor (minimize sour taste and off-flavors). To optimize several responses, the models for each response were constructed $Y_k = f_k(C_{YM}, C_{CA}, C_{AA})$, a desirability function, d(y), was defined for each response and an overall desirability composite function, D(x), was created.

The models obtained for each response were validated by comparing the experimental results of the "Granny Smith" fresh-cut apples dipped in the optimal solution with the results predicted by the models. A t-test was run to determine significant differences among the experimental and predicted results in order to validate the models.

Acceptability study

An acceptability study was conducted for the "Granny Smith" fresh-cut apples, treated with the optimal antioxidant solution previously obtained, and stored at 2 °C for 24 h. A total of 96 consumers, aged between 18 and 68 years old (65% female), took part in the study. The consumers were asked to evaluate the color, flavor, texture, and overall liking of the sample, using a 9-point structured hedonic scale (1 = dislike very much; 5 = indifferent; 9 = like very much) and to answer if they would buy a similar product (Yes/No answer).

Quality assessment

Color. Color measurements were made at the middle area of the two cut faces of each apple wedge immediately after the fruit processing (0 min) and after 240 min at 25 °C, with a Minolta spectrophotometer (Model CM-508d/8, Minolta, Tokyo, Japan), using the standard illuminant D65, an observer angle of 10 °, with the specular component excluded. CIE parameters L*, a*, and b* were measured and $C_{ab}^* = (a^{*2} + b^{*2})^{0.5}$ was determined. Ten replicates of the color measurement were carried out for each sample at each evaluation time.

Antioxidant capacity determination. For the antioxidant capacity determinations, two extracts were obtained per sample as described by Piagentini and Pirovani (2017), and each extract was analyzed in triplicates.

DPPH method.* The antiradical activity was quantified by the reduction of the absorbance at 517 nm

Table 2. Analyses of variance of regression models for antioxidant capacity, color, and sensory attributes

Variation source	DF	Sum of squares AEAC	FRAP	ΔL*	Δa*	Δb*	ΔC_{ab}*	Browning	Sour taste	Off-flavors
C_{YM}	1	3164.44*	456.40	0.01	0.18	0.29	0.31	0.82*	0.71	4.08**
C_{CA}	1	544.44	141.23	7.21*	4.64**	12.25**	12.23**	4.37**	2.86*	0.40*
C_{AA}	1	1506.94*	37114.3*	3.70*	2.68**	15.99**	15.93**	10.79**	0.03	0.08
C_{YM}^2	1	6.83	69.61	0.00	0.37*	2.71*	2.53*	0.00	0.67	2.30**
$C_{YM}C_{CA}$	1	2.10	0.12	0.09	0.40*	0.18	0.18	0.71*	0.00	0.20
$C_{YM}C_{AA}$	1	208.76	483.94	0.11	0.00	0.66*	0.58*	0.03	0.54	0.00
C_{CA}^2	1	5.39	358.76	0.21	0.11	1.84*	1.92*	0.97*	0.14	0.01
$C_{CA}C_{AA}$	1	585.03	568.28	0.01	0.06	0.02	0.01	2.30*	0.00	0.01
C_{AA}^2	1	754.74	2363.74	1.40	1.50*	1.77*	1.84*	3.65**	0.77	0.04
Lack of fit	3	872.04	5203.96	0.92	1.03	2.66*	2.60*	1.35	1.15	0.56
Pure error	2	124.04	1434.48	0.33	0.04	0.06	0.06	0.07	0.22	0.04
R^2		87%	86%	91%	90%	93%	93%	94%	81%	92%

AEAC: AA equivalent antioxidant capacity; DF: degree of freedom; FRAP: ferric reducing-antioxidant power.
* Significant at 0.05 level, ** Significant at 0.01 level.

(spectrophotometer Genesis 5, Milton Roy, Ivyland, USA) of a solution of DPPH* in methanol (30 mg l^{-1}) in presence of the sample extract, after 30 min of reaction. The antioxidant capacity was expressed as AA equivalent antioxidant capacity (AEAC), using equation (2) (Lim et al., 2007)

$$AEAC\left(mg\,Kg^{-1}\right) = \frac{IC_{50(AA)} \times 10^6}{IC_{50(sample)}} \qquad (2)$$

where $IC_{50(AA)}$ and $IC_{50(sample)}$ are the amount of AA or fresh weight of sample, respectively, in 1 ml of reaction, needed to reduce to 50% the initial DPPH* concentration, obtained from the plot of remaining DPPH* (%) versus concentration (mg ml^{-1}).

FRAP method. The antioxidant capacity was also evaluated by the FRAP assay as described by Rodríguez Arzuaga et al. (2016). FRAP reactant was prepared with an acetate buffer 300 mm (pH 3.6), a solution of 10 mm 2,4,6-tris(2-pyridyl)-s-triazine in HCl 40 mm and a 20 mm ferric(III) chloride solution, in a 10:1:1 ratio. Fifty microliters of sample were incubated with 900 µl of FRAP reactant and 130 µl of water for 30 min at 37 °C, before measuring the absorbance at 583 nm. Results were expressed as µmol of Fe in a kg of fresh weight (µmol kg^{-1}).

Sensory descriptive analysis. Eight descriptive panelists, with an average experience of 1500 h in evaluating different food products, including fresh-cut fruits, participated in the study after receiving three orientation sessions of 1 h each. During the orientation sessions, especially prepared fresh-cut apple samples were presented to the panelists, and the attributes and anchored terms were selected through panel discussion. The panelists used continuous 10 cm scales with two anchor terms located at 1 cm from each edge, to evaluate the selected sensory attributes: browning (1 = slight, 9 = severe), sour taste and off-flavors (1 = slightly perceptible, 9 = very perceptible). The samples were identified with three-digit random codes and assessed in random order.

RESULTS AND DISCUSSION

Modeling and optimization of the antioxidant dipping solution

Our preliminary study (Rodríguez Arzuaga and Piagentini, 2013) showed that treating "Granny Smith" fresh-cut apples with an infusion of up to 2% YM in combination with AA and CA delayed the enzymatic browning development, improving the sensory quality and increasing the total phenolic content (TPC) and antioxidant capacity, and it was the basis for the optimization study.

Table 1 presents the experimental design and the results obtained for each response.

The models obtained for the antioxidant capacity by AEAC and FRAP (equations (3) and (4)) adequately described the experimental data (Table 2)

$$AEAC\left(\mathrm{mg\,kg^{-1}}\right) = 573.6 + 198.9C_{YM} + 274.5C_{AA} \qquad (3)$$

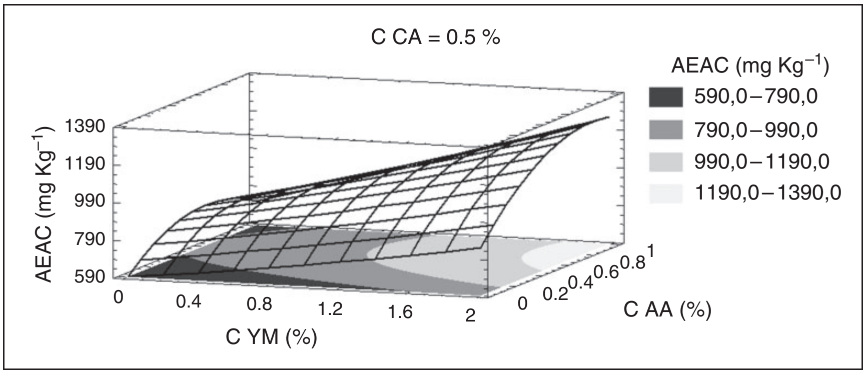

Figure 1. Response surface plot for antioxidant capacity (AEAC) of ‘‘Granny Smith’’ fresh-cut apples treated with different concentrations of yerba mate (C_{YM}) and ascorbic acid (C_{AA}), for a citric acid concentration (C_{CA}) of 0.5%, by DPPH* method. AEAC: AA equivalent antioxidant capacity.

$$FRAP\left(\mu\text{mol kg}^{-1}\right) = 1362.2 + 2766.5C_{AA} \quad (4)$$

AEAC increased linearly with the YM and AA concentrations, while FRAP depended only on the AA concentration.

As shown in Figure 1, the addition of YM and AA increased the antioxidant capacity of the fresh-cut apples from an initial AEAC value of about 590 mgkg^{-1} (fresh-cut apples treated with a solution without YM and AA) to near 1300 mg kg^{-1} (fresh-cut apples treated with a solution of 2%YM+0.5% CA+1%AA). The AEAC of fresh-cut apples treated with 1%CA+1%AA, predicted by the model (equation (3)), was about 848 mg kg^{-1}; however, if the samples were treated with 2%YM+1%CA, the AEAC would be higher (972 mg kg^{-1}). These differences could be explained by the high antioxidant capacity of the YM infusions. Rodríguez Arzuaga and Piagentini (2012) reported a TPC of 552 mg l^{-1} and an AEAC of 1013 mg l^{-1} (by DPPH* method) for a 1% YM infusion, and a TPC of 1094 mg l^{-1} and an AEAC of 2059 mg l^{-1} for a 2% YM infusion. It is well known that phenolic compounds have a role as antioxidants promoting health benefits; however, their antioxidant capacities differ depending on their structure and number of hydroxyl groups, as well as the matrix where they are embedded (Robles-Sánchez et al., 2009). Also, the addition of AA and CA has shown to increase the antioxidant capacity in fresh-cut fruits (Robles-Sánchez et al., 2009; Rodríguez Arzuaga et al., 2013). The results obtained herein showed that the solutions containing the combination of the three components (YM+CA+AA) produced fresh-cut apples with higher antioxidant capacity.

The coefficients of determination for all the color parameters models were above 90%; however, a significant lack of fit ($p < 0.05$) was found for Δb* and ΔC_{ab}* (Table 2). Equations (5) and (6) represent the predictive models, for ΔL* and Δa*

$$\Delta L^* = 2.87 - 3.76C_{CA} - 1.90C_{AA} + 2.40{C_{AA}}^2 \quad (5)$$

$$\begin{aligned}\Delta a^* = &-2.05 + 0.14C_{YM} + 0.89C_{CA} + 3.66C_{AA} \\ &- 0.31{C_{YM}}^2 - 2.50{C_{AA}}^2 + 0.64C_{YM}C_{CA}\end{aligned} \quad (6)$$

ΔL* presented a minimum (L* values of the processed samples after 240 min at room temperature were similar to initial L* values) at intermediate AA concentrations (0.6–0.7%) and high CA concentrations (Figure 2). A decrease in Δa* (higher negative values) means a loss of green hue, associated to the natural color of the flesh of ‘‘Granny Smith’’ apples, and development of red hue, associated with enzymatic browning (Piagentini et al., 2012). Δa* (difference between the a* values at 0 and 240 min) decreases (i.e. becomes more negative) when C_{YM}, C_{CA}, and C_{AA} decrease within a range (more browning development). However, Δa* reaches the highest value (minimum or no browning development) for a given combination of YM and AA concentrations. The interaction between C_{YM} and C_{CA} (equation (6)) indicates that at low CA concentrations Δa* decreases when C_{YM} increases, while at high CA concentrations the increase of the C_{YM} increases Δa* (reduces browning development). Therefore, while YM does not significantly delay browning development at low CA concentrations, when CA is at concentrations near 1%, YM and CA act synergistically delaying enzymatic browning.

The three components of the antioxidant solutions significantly affected the browning development on fresh-cut apples (Table 2). The dependence of browning with C^2_{AA} and C^2_{CA} indicates that there was a minimum

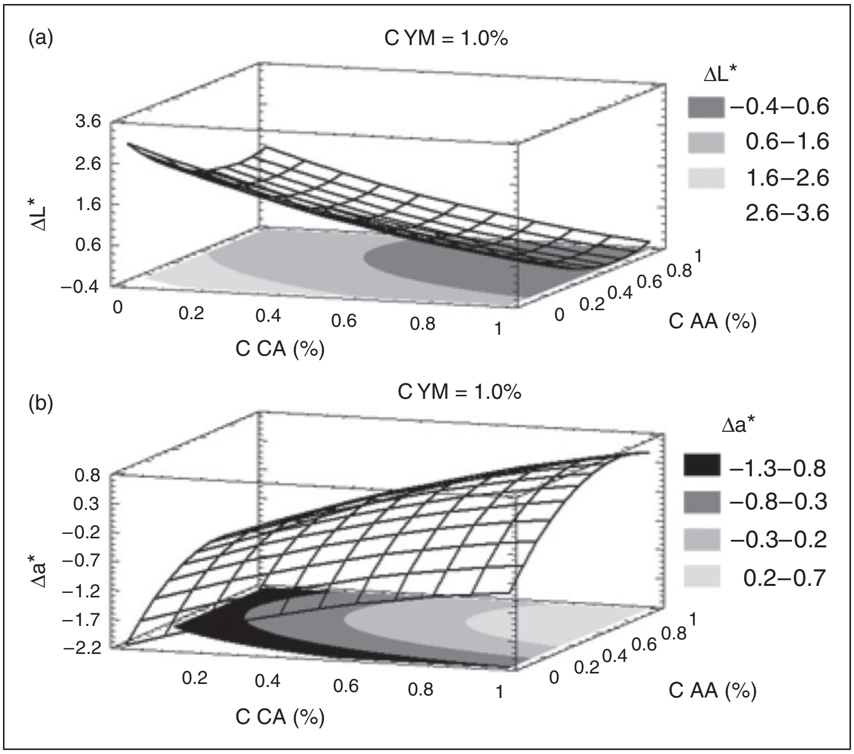

Figure 2. Response surface plots for ΔL* (a) and Δa* (b) of "Granny Smith" fresh-cut apples treated with different concentrations of citric acid (C_{CA}) and ascorbic acid (C_{AA}), for a yerba mate concentration (C_{YM}) of 1.0%. DL: ▮▮.

browning score for a given C_{AA} and C_{CA}, while browning always decreases when C_{YM} increases. The interaction terms showed that the effect of YM and AA concentrations on browning depends on the concentration of CA (equation (7)). Sour taste was only affected by C_{CA} (equation (8)), therefore, at higher C_{CA}, higher sour taste, which suggests that C_{CA} has a bigger impact than C_{AA}. Similarly, an increase in the CA concentration was found to have a significantly greater effect on the pH reduction of fresh-cut spinach than an increase in the AA concentration (Piagentini et al., 2003). Equation (9) indicates that the increase in the YM concentration induces the development of off-flavors, while the addition of CA decreases the off-flavors level, whether because the CA prevents the development of the compounds responsible for the off-flavors or because the sour taste associated to the addition of CA masks their detection. Further analytical study would be useful to understand the effect of YM and CA on the development of compounds responsible for off-flavors

$$\begin{aligned} \mathit{Browning} = {} & 5.31 - 0.74C_{YM} - 5.88C_{CA} - 7.80C_{AA} \\ & + 2.05{C_{CA}}^2 + 3.97{C_{AA}}^2 + 0.84C_{YM}C_{CA} \\ & + 3.03C_{CA}C_{AA} \end{aligned} \tag{7}$$

$$\mathit{Sour\ taste} = 4.90 + 1.20C_{CA} \tag{8}$$

$$\mathit{Off-flavors} = 2.10 - 0.86C_{CA} + 0.79{C_{YM}}^2 \tag{9}$$

Optimization and models validation. The results of the multiple response optimization indicated that the optimal concentrations in the antioxidant dipping solution were 1.2% YM, 0.9% CA, and 1.0% AA. According to the results of the models validation, the experimental values of every response were within the 95% confidence interval of the predicted values, and there were no significant differences ($p > 0.05$) between the predicted and the experimental values (Table 3). The results obtained in the present study for the samples treated with the optimal dipping solution (1.2% YM + 0.9% CA + 1.0% AA) were compared with those obtained by Rodríguez Arzuaga and Piagentini (2013) for browning development and antioxidant capacity of "Granny Smith" fresh-cut apples untreated, treated with a traditional dipping solution (1% CA + 1% AA), and raw material (whole apple). It can be noticed that the optimal solution gives apples with the lowest browning (lower ΔL* and browning score and higher Δa*) and the highest healthy potential (antioxidant capacity 36% higher than the raw material). The improvements in the color and the antioxidant

Table 3. Experimental and predicted values of quality attributes for fresh-cut ''Granny Smith'' apples treated with the optimal solution[a]

Response	Experimental value	Predicted value	Confidence interval (95%)
ΔL*	−0.1 ± 0.5	−0.2	[−0.7–0.3]
Δa*	0.3 ± 0.2	0.3	[0.0–0.7]
Browning	0.3 ± 0.4	0.6	[0.0–1.1]
Sour taste	5.6 ± 0.8	6.0	[5.5–6.5]
Off-flavors	3.0 ± 1.0	2.4	[1.9–3.0]
AEAC (mg kg^{-1})	1144.0 ± 190.0	1087.0	[930.0–1244.0]
FRAP (μmol kg^{-1})	3749.0 ± 368.0	4029.0	[3672.0–4386.0]

AEAC: AA equivalent antioxidant capacity; FRAP: ferric reducing-antioxidant power.
[a]Optimal: [1.2% YM + 0.9% CA + 1.0% AA].

capacity of the apples dipped in the optimal solution show that the addition of YM has a positive impact on the quality of the samples.

Acceptability study

The sensory acceptability of fresh-cut apples has been previously studied (Giacalone and Chiabrando, 2013; Raybudi-Massilia et al., 2007; Rocha and Morais, 2003), as well as the consumer acceptability of YM infusions and food products containing YM (De Godoy et al., 2013; Orjuela-Palacio et al., 2014). However, there are no reports of the effect of the YM application on the acceptability of fresh-cut fruits. Several instrumental methods were compared with the acceptability of fresh-cut apples of various cultivars, and it was concluded that no instrumental measurements adequately predict the acceptability scores (Abbott et al., 2004). Rodríguez Arzuaga et al. (2016) determined the population of total aerobic mesophilic microorganisms, psychrotrophic bacteria, mold, and yeasts in fresh-cut apples treated with the optimal dipping solution obtained herein, the untreated fresh-cut apples, and the raw material (whole apple). The authors found that the microbiological counts for the three samples were lower than 1.8 log, at the processing day. The acceptability study was carried out supported on these results, since the samples were apt to be eaten from a microbiological point of view. The results obtained in the acceptability study did not significantly vary with gender or age. More than 78% of the participants liked the apples treated with the optimal solution, their color, flavor, and texture (Figure 3). The consumers especially liked the texture of the sample, since it was the attribute with the highest acceptability (89%, Figure 3). In average, the samples scored 7.0 ± 1.6 in color, 6.8 ± 1.9 in flavor, 7.5 ± 1.6 in texture, and 7.1 ± 1.6 in overall liking. The scores were above 6.0 in a 9-point scale for all the studied attributes, which indicates that the fresh-cut apples treated with the optimal antioxidant solution were accepted by the consumers, being their global acceptability higher than the obtained in previous studies for ''Fuji'' apples cubes (Varela et al., 2005). Moreover, 89.5% of the participants stated that they would buy a similar product.

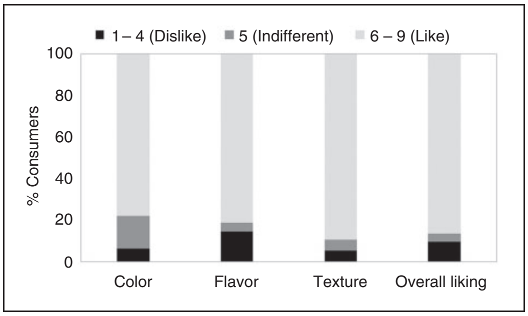

Figure 3. Consumer acceptability of ''Granny Smith'' fresh-cut apples treated with the optimal antioxidant solution (1.2% YM + 0.9% CA + 1.0% AA).

CONCLUSIONS

The effects of the concentrations of YM, CA, and AA in the dipping solution, on the sensory attributes (browning, sour taste, and off-flavors), the antioxidant capacity, and the changes in the instrumental color parameters (L* and a*) of ''Granny Smith'' fresh-cut apples were modeled adequately. The YM, CA, and AA concentrations in the dipping solution were optimized to minimize browning development (minimizing the sensory attribute browning and ΔL* and maximizing Δa*) and maximize the antioxidant capacity, without negatively affecting the flavor (minimizing off-flavors and sour taste) of ''Granny Smith'' fresh-cut apples. The concentrations obtained using the multiple response optimization procedure were 1.2% YM, 0.9% CA, and 1.0% AA.

The acceptability study carried out on fresh-cut apples treated with the optimized solution proved that more than 78% of the surveyed consumers liked the color, flavor, and texture of the apples. These results suggest that the chemical treatment with YM applied to the fresh-cut apples was successful in delaying the enzymatic browning development, providing compounds with antioxidant capacity with a potential benefit for the consumer health (antioxidant capacity approximately 36% higher than the raw material), without impairing the sensory quality (maintaining acceptable flavor and texture), resulting in a good general consideration of the product and a high purchase intention by consumers.

Further investigation regarding the stability of the fresh-cut apples treated with the optimal dipping solution during longer storage periods should be conducted in the future.

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DECLARATION OF CONFLICTING INTERESTS

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