Research for Practice LAIMBURG JOURNAL

Full Paper

Spraying treatment of fresh-cut apples as a sustainable alternative to dipping for browning inhibition: a preliminary lab-scale study

Spraying-Behandlung als nachhaltige Alternative zum Dipping von frisch geschnittenen Äpfeln zur Bräunungshemmung: eine Vorstudie im Labormaßstab

Trattamento spray di spicchi di mela fresca come alternativa sostenibile al dipping per inibire l'imbrunimento: uno studio preliminare su scala di laboratorio

Noreen Faller[1], Elena Venir[1], Daniele Zatelli[2], Flavia Bianchi[1]

[1] Laimburg Research Centre, 39040 Auer/Ora, BZ, Italy
[2] VOG Products Soc. agricola coop, 39055 Laives, Italy

ABSTRACT

Several fresh-cut apple snacks are available on the market, and their color is highly relevant for consumers. As apple slices brown very quickly after cutting, dipping them in an antioxidant solution for a few minutes is common to avoid this phenomenon. However, this procedure has some limitations. Using the same solution for several immersion cycles over several hours can lead to cross-contamination and microbial growth. In addition, osmotic exchange phenomena in the immersion tank lead to a reduction in the concentration of the active ingredients of the antioxidant solution over time, which requires continuous readjustment of the concentrations. These aspects, together with the large quantities of exhausted antioxidant solution to be disposed of, are limiting factors that drive the search for alternative and more sustainable methods than dipping. In this work, a comparison between a conventional dipping treatment of fresh-cut apples and spraying at increasing volume of antioxidant solution was performed. Color, considered as the quality reference parameter, was visually assessed (occurrence of dark spots) and CIE Lab colorimetric indices were measured over a five-day experimental period. Based on dark spots and the changes in brightness (Δ L*), hue angle (Δ h), and chroma (Δ C*), some of the spraying treatments applied were found to be comparable to dipping in controlling browning. For all treatments, high intra- and inter-batch variability and variability within slices of the same apple were observed concerning both instrumental data and dark spots development, indicating that further investigation is needed to validate this result and to apply this procedure at an industrial level.

KEYWORDS
anti-browning; minimally processed food; color; waste reduction

CITE ARTICLE AS
Faller Noreen, Venir Elena, Zatelli Daniele et.al. (2022). Spraying treatment of fresh-cut apples as a sustainable alternative to dipping for browning inhibition: a preliminary lab-scale study. Laimburg Journal 04/2022
DOI: 10.23796/LJ/2022.007

CORRESPONDING AUTHOR
Flavia Bianchi
Laimburg 6, I-39040 Auer
flavia.bianchi@laimburg.it
+390471969595

INTRODUCTION

Large quantities of apples and apple-based processed foods are consumed worldwide, and South Tyrol, with 18,500 hectares of apple orchards, represents the largest contiguous apple-growing site in Europe [1]. Diverse apple cultivars grown in South Tyrol were chemically characterized for their volatile profile [2] and the content of minerals [3], vitamins [4][5][6], and phenolic compounds [7][8]. The properties of apples have been known for a long time. They contain nutritionally relevant compounds and have beneficial properties against heart diseases, asthma, diabetes, cholesterol, and overweight [9][10][11][12][13].

The demand for ready-to-eat fruit- and vegetable-based products is constantly increasing [14]. This is due to the awareness by shoppers that a connection between nutrition and their well-being exists, guiding them to consume healthy food [15]. There are numerous types of apple snacks on the market, some of which, like fresh-cut apples, have a high dietary value because they are only minimally processed [16][17][18].

The color of such a product highly influences its acceptability by consumers [19][20]. Diverse studies are focused on color changes that occur after processing and storage of fruits and vegetables [20][21][22][23], and intensive research is being carried out on methods aimed at improving the appearance of fresh-cut apple pieces, their preservation over time [20][24][25][26][27][28][29][30][31][32][33][34][35], and thus, their shelf life. Common strategies to increase the shelf life of fresh-cut fruit include storage at low temperature, treatment with antioxidants, and packaging in a protective atmosphere [28].

Dipping in an antioxidant solution is the most commonly used method to prevent browning in fresh-cut fruit [29] and the best one for fresh-cut fruits and vegetables [36]. The disadvantages of this method include the risk of cross-contamination and microbial growth [32][37][38][39] as well as the dilution of the solution in the dip tank with multiple and frequent exposures [38] that results in the need to regularly replace or adjust the solution, with serious consequences on the costs of raw materials and disposal [39].

Alternatives to dipping for fresh-cut apples can be spraying [32] or coating [40]. Some advantages of spraying can be foreseen, such as: tailored use of antioxidant solution, hence optimizing the quantities of raw material needed and avoiding waste and disposal costs; prevention of cross-contamination; constancy of the concentration of solutes in the solution from the first to the last batch of production. A spraying treatment could be therefore suitable for industrial processes.

Besides microbiological contamination, enzymatic browning is the most common cause of quality loss of a fresh food product that affects its quality and shelf life [20][34]. Therefore, numerous studies are focused on solving this issue [20][25][30][33][34][35][41][42]. Antioxidants extend the shelf life of fresh produce acting as reducing agents that slow down the browning process [20][33][43]. Ascorbic acid, commonly used as antioxidant in food industry and labeled as additive (E300) [20][29][33][34][44], its derivatives, or a combination of ascorbic acid and sodium chloride and calcium chloride are often used for fresh-cut apples [22][24][33][35][45].

While most of research is focused on dipping fresh-cut apples in antioxidant solutions [29][46], little is reported concerning spraying. A study compared the effects of these two treatments on carrots, using chitosan-based coatings [47], another work showed the application of starch-, carrageenan- and chitosan-based coatings through spraying on strawberries [48], and, concerning apples, only one study was found about the comparison of dipping and spraying treatments [32], and, in this case, as for another research from the same author focused on dipping [47], a commercial product (*NatureSeal®*) was used as antioxidant.

In the present study, the efficacy of spraying on the browning prevention of *Golden Delicious* fresh-cut apple slices was compared to the conventional dipping treatment. The aim of the research was to optimize the spraying procedure in a laboratory scale as an alternative to dipping for the application of the antioxidant solution on apple slices.

MATERIALS AND METHODS

CHEMICALS

Sodium chloride (99.9%) and calcium chloride 6-hydrate (99.9%) were purchased from PanReac & AppliChem. L-ascorbic-acid (≥ 99.0%) was purchased from Merck Life Science S.r.l.

APPLES

Apples of the cultivar *Golden Delicious* were purchased from a local retailer, stored at 2 °C under normal atmospheric conditions in darkness, and washed down with water before use. The apple peel was not removed before treatment, as fresh-cut apple pieces are currently marketed with the peel [24]. Immediately prior to the treatments, each apple was sliced using a hand household slicing machine.

TREATMENTS

Treatments were carried out at room temperature on 6 replicates. Each replicate consisted of one apple cut into 5 slices.

DIPPING

An antioxidant solution was freshly prepared by adding 1% ascorbic acid, 0.05% NaCl, 0.5% $CaCl_2$ to distilled water. Apples slices were dipped in the antioxidant solution for 5 minutes in a 1:4 w/w ratio between apple amount and antioxidant solution. The apple slices were then removed and allowed to drain at ambient conditions for 30 seconds.

SPRAYING

An antioxidant solution was freshly prepared by adding 2% ascorbic acid, 0.1% NaCl, 1% $CaCl_2$ to distilled water. The antioxidant solution was sprayed with a non-professional sprayer from a distance of 24 cm from the tabletop on which apple slices were placed, with a 90-degree angle between the sprayer outlet and the tabletop. Four different case studies were considered: 12-, 16-, 20-, and 24-sprays, obtained by the application of series of 4 sprays of antioxidant solution to the surface of apples repeated for 3, 4, 5, and 6 times at 30-second time intervals between consecutive applications.

ANALYSIS OF ASCORBIC ACID

SAMPLE PREPARATION

Five slices belonging to one apple (approx. 80 g) were placed in a household blender, and 50 mL of deionized water were added prior to grinding the apple slices for 30 seconds. Approximately 4 mL of the extract were then centrifuged (*ST160R*, Thermo Fisher Scientific) at 7000 rpm at 10 °C for 5 minutes, and an aliquot of the supernatant was further diluted 1:40 v/v with deionized water prior to analysis. The extraction was performed in triplicate (3 apples per treatment) on non-treated apples and apples treated with dipping and spraying.

SPECTROPHOTOMETRIC ANALYSIS

Ascorbic acid (AsA) standard mother solution at a concentration of 500 mg/L was prepared and further diluted with deionized water to construct a calibration curve in a concentration range between 5 mg/L and 50 mg/L. A UV-1800 spectrophotometer (Shimadzu Europa GmbH) was used for the analysis of AsA. The detection wavelength was set at 245 nm, as previously reported [44][48][49][50]. The instrumental autozero was always performed prior analysis and deionized water was used as blank sample. Quartz cuvettes with an optical path of 1 mm were used, and measurements were performed at room temperature. The amount of AsA absorbed by apple slices after each treatment was calculated based on the calibration curve by measuring the difference between the content of AsA in non-treated and treated apples.

COLOR EVALUATION

For the colorimetric measurements, the instrument *Chroma Meter CR-400* (Konica Minolta Sensing Europe B.V.) was used. The instrument was calibrated daily before measurement. The non-treated and treated apple slices were analyzed at defined time intervals from 0 h to 99 h after cut. For the non-treated apples and 12-spray treatment, measurements were carried out for a shorter period because the color of the apple flesh was clearly no longer visually acceptable one day after cut, for non-treated apples, and two days after cut, for 12-spray treatment. Measurements were made on 4 points per apple slice (two per each side), on 5 slices per each apple, and six replicates (apples) were analyzed per treatment. Subsequently, each sliced apple was placed in a commercial freezer bag and stored at 4 °C. Apples were not stored under controlled atmosphere, in order to avoid metabolic stress induced by the ascorbic acid on the respiration pathways of apples [30]. The CIE Lab color space coordinates (L*, a*, b*) were measured, and Δ L*, Δ a*, Δ b*, chroma (C), Δ C*, hue angle (h) [51], Δ h, and total color difference (Δ E*) were calculated.

Photographs (*Canon EOS 850D*) of all samples were collected over storage. Since browning could be very heterogeneous even within the same apple, a visual overview of the color of the 5 slices simultaneously was made, evaluating the presence and abundance of dark spots as reported on literature studies [29][50][52] which described the secondary browning with a similar approach. Pictures of apple slices (5 slices belonging to one apple per each picture) subjected to the various treatments and collected over the entire experimental period were randomized and examined by three independent inspectors that evaluated them based on the following criteria: 1 = absence of dark spots, 2 = few, minor localized visible dark spots, and 3 = moderate to severe occurrence of dark spots.

STATISTICS

Statistical analysis of data was performed using *SPSS* (IBM SPSS 27 Statistics). An analysis of variance (ANOVA) with a p value of 0.05 was used to evaluate differences between treatments, using Tukey's post hoc test for pairwise comparisons.

RESULTS AND DISCUSSION

The efficacy of a dipping treatment of fresh-cut apples in an antioxidant solution based on ascorbic acid, sodium chloride, and calcium chloride was compared to that of spraying treatments performed with increasing amounts of antioxidant solution sprayed. The apple cultivar *Golden Delicious* was chosen because it is the most used in the food industry and widely cultivated in South Tyrol, and because previous studies reported that it is susceptible to enzymatic browning at rates suitable for the investigation of this phenomenon after the immersion in ascorbic acid-based antioxidant solutions [33].

Trials carried out before the experiments described in this paper (data not shown) suggested that a spraying treatment based on the use of the antioxidant solution containing each of the active ingredients at a double concentration compared to that used for dipping, with a minimum number of 12 sprays, allowed satisfactory preliminary results to be obtained. Besides dipping and 12 sprays, some other case studies were considered (16, 20, 24 sprays) and the content of ascorbic acid absorbed by apple slices immediately after each treatment was measured in order to verify that the apples had absorbed a quantity of active ingredients comparable to that measured after dipping.

To evaluate the effect of the various treatments on the color of apple slices and thus on their shelf life, the color changes were assessed over 5 days by measuring the three CIE Lab color space coordinates L*, a*, b* and their kinetics, and calculating total color difference, hue angle, and chroma. The differences between treatments were evaluated for each of the investigated colorimetric indices. Finally, the presence and the abundance of dark spots were visually determined.

Tab. 1: Amount (mean±SD) of ascorbic acid (AsA) absorbed by apples treated with dipping and spraying.

Treatment	Absorbed AsA [mg/g apple]
12 sprays	0.22 ± 0.07
16 sprays	0.22 ± 0.04
20 sprays	0.28 ± 0.02
24 sprays	0.24 ± 0.03
dipping	0.19 ± 0.02

COMPARISON OF ABSORBED ASA IN APPLES TREATED WITH DIPPING AND SPRAYING

A major challenge concerning the comparison of the dipping procedure with spraying was the necessity of reaching similar concentrations of active ingredients on the surface of apple slices in order to expect a similar anti-browning efficacy between treatments.

AsA is commonly used as antioxidant [23][25][26][32][42][43] and shown to be very effective against enzymatic browning [20][24][33][41]. Additionally, it is easily detectable spectrophotometrically, and therefore its absorption by treated apples could be readily measured.

A fast and easily applicable method for AsA measurements in laboratory as well as during processing consists of a spectrophotometric measurement at a wavelength of 245 nm of the watery extracts of apple slices. The method is not selective to detect AsA since at this wavelength an interference due to the presence of B-vitamins, polyphenols, and dehydroascorbic acid can occur [26][48]. However, since the only difference between treated and non-treated apples was the dipping or spraying in the antioxidant solution, it is to be expected that the increase in the absorbance signal at 245 nm is solely due to the presence of AsA in the antioxidant solution used. The amount of absorbed AsA was measured by subtracting the absorbance at 245 nm of non-treated apple to that of treated ones.

The absorbed amounts of AsA immediately after each treatment are summarized in Table 1.

Dipped apples absorbed the lowest amount of AsA compared to the other treatments but in the same order of magnitude. As expected, the absorbed amount of AsA tended to increase by increasing the number of sprays. Nevertheless, no difference was found between 12 and 16 sprays, which may be due to an intrinsic variability in the sample preparation procedure. Surprisingly, a lower value was observed after treating apples with 24 sprays compared to 20 sprays, and this may be due to the dripping of the solution with consequent reduction of absorbed AsA, thus the volume to be laid on apple slices must be taken into account with regards to the application procedure to use. Above a certain volume of sprayed solution, no increase in AsA concentration on apple slices could be obtained with 30 seconds intervals between series of sprays.

COLOR CHANGES AS A FUNCTION OF STORAGE TIME

A parameter used to assess color changes is the total color difference (Δ E*), as described in numerous studies [30][35][52][53][46][54][55][56]. Delta E is a standard parameter that quantifies the difference between the color under investigation (for example after shelf life) and the original color of a product. Low Δ E values indicate great similarity between two colors, while high Δ E values indicate a significant mismatch.

Alternatively, other indices could be considered, including Δ L* [45][47], as well as L* [21][25][30][41][52][56], chroma variation (Δ C*) [46][57], and hue angle [23][57][56][58][59]. The L* value is measured on a scale that goes from 0 (black) to 100 (white) and indicates the brightness of a color. Therefore, Δ L* expresses the difference in lightness/darkness between two colors (positive values indicate that the color became lighter and negative values indicate that the color became darker). The value of chroma C* is defined as colorfulness of an area judged as a proportion of the brightness of a similarly illuminated area that appears white or highly transmitting [60]. It represents the distance from the lightness axis (L*) and starts at 0 in the center. The difference in chroma (Δ C*) indicates difference in brightness/dullness between two colors (positive values indicate that the color became brighter and negative values indicate that the color became duller). Finally, the hue angle is a single number, corresponding to an angular position around a color wheel. It does not take into account the lightness and the saturation.

It should be noted that a colorimetric analysis with a *Chroma Meter CR-400* consists of punctual measures and therefore cannot cover the entire surface of the apple slice.

The colorimetric analyses showed a clear difference between non-treated apples and those treated with the antioxidant solution. The color change (Δ E*) kinetics over the experimental period for each treatment and for non-treated samples is shown (Fig. 1). Statistical analysis was performed for all sampling time-points. Non-treated apples were statistically different ($p = 0.05$) from all other treatments already 3 h after cut, while

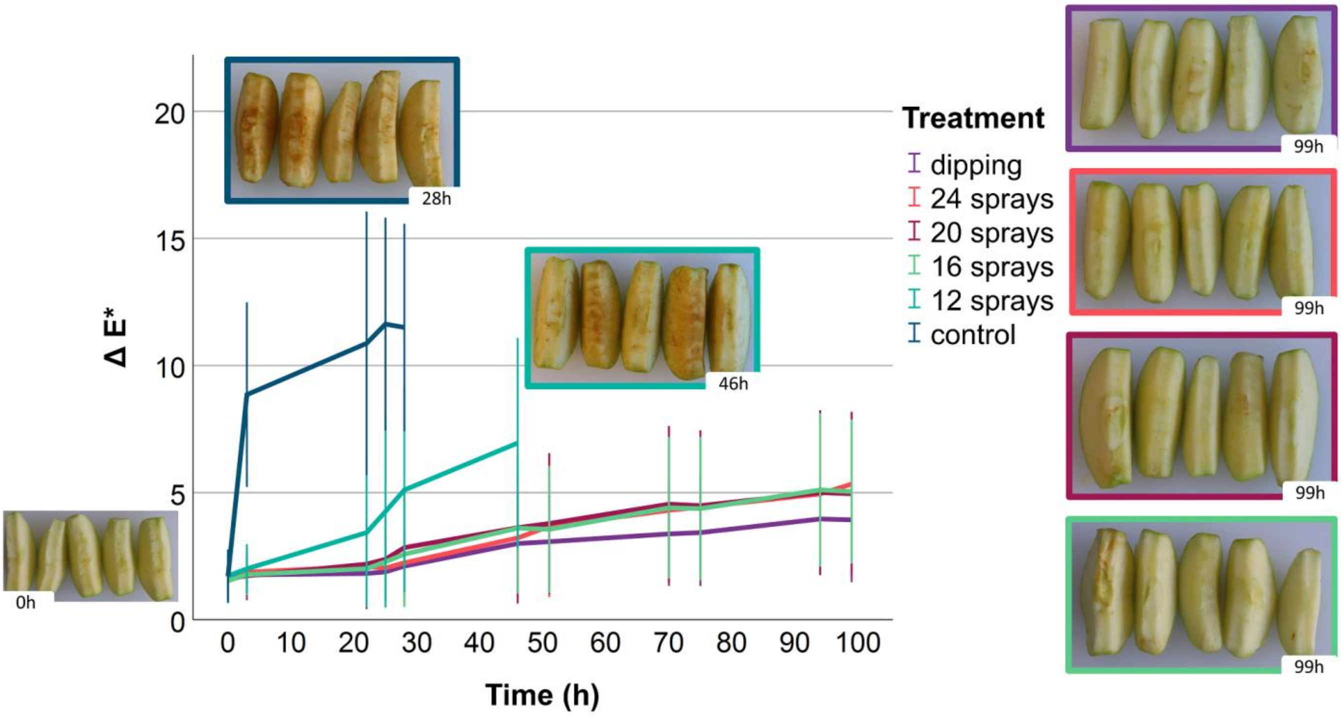

Fig. 1: Kinetics of the total color difference (Δ E*) of the various treatments over 99 h, showing the overall color change between the sample analyzed at timepoint 0 and the same sample analyzed at defined timepoints over storage. Pictures of apple slices after cut and at the last collection point are reported for each condition under investigation, framed in matching colors. Vertical lines represent the standard deviation for each timepoint. The slope of the curve is indicative of the speed and rate of color change over time (curves with a greater slope indicate that the color has changed very intensively and quickly compared to less steep curves).

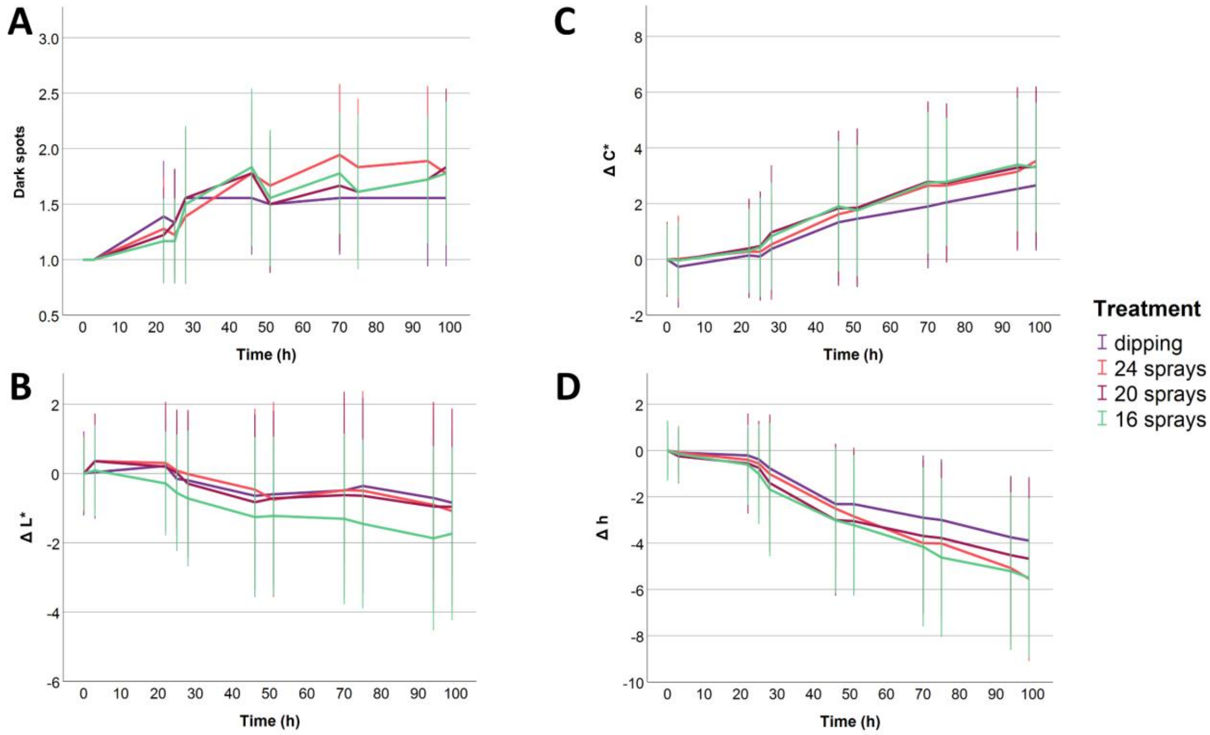

Fig. 2: Kinetics of: (A) Presence and abundancy of dark spots; (B) difference of the brightness (Δ L*); (C) difference of the chroma (Δ C*), (D) difference of the hue angle (Δ h) of apple slices subjected to the various treatments, measured during storage up to 99 h at 4 °C. Vertical lines represent the standard deviation for each timepoint. The curves show the color changes that occurred over storage between the sample analyzed at timepoint 0 and the same sample analyzed at defined timepoints, concerning all parameters under investigation. The slope of the curve is indicative of the speed and rate of change of color over time (curves with a greater slope indicate that the color has changed very intensively and quickly compared to less steep curves). The direction on the y axis indicate that for all treatments dark spots tend to increase over time (values going from 0 to 3), that lightness and hue angle tend to decrease (negative values) over time (samples get darker and the color changes from yellow/light green to red/brown), and that chroma increases (the samples assume a brighter/intensified color as the color darkens).

all treatments were statistically equal up to that point. Afterwards, the 12-spray treatment started to significantly differentiate from the others, while up to 51 h, all other treatments were not statistically different from each other. From 70 h, dipping started to statistically differentiate from all the other treatments and at the end of the storage period was significantly different from 24 sprays, 20 sprays, and 16 sprays.

For illustrative purposes, representative images of the product at the end of the storage time have been inserted in Figure 1. Apples treated with dipping, 16, 20, 24 sprays did not visually differ in browning at the end of the storage period. However, it could be observed that browning occurred in an inhomogeneous manner even within the slices of the same apple. To include the intrinsic heterogeneity of the color of the apple surface in the evaluation of browning, the presence of dark spots over the entire slice's surface was visually ranked through a numerical classification.

It should be noted that, as the trial was not performed with industrial equipment, the hand-cutting of the apple resulted in an uneven/wounded surface, which led to an increased release of cellular juice and oxidative enzymes in some parts of the slice, causing the high variability observed.

The highest absorption of AsA was observed with 20 sprays (Tab. 1), but the lowest Δ E* occurred with the dipping treatment (Fig. 1), characterized by the lower AsA absorption (Tab. 1). Therefore, not only the concentration of active ingredients on the surface of apple slices is important to reduce the enzymatic browning, but also the method adopted to apply the antioxidant solution.

Dipping consists in a full immersion of apple slices in a large water amount, therefore capillary effects are favored in these conditions, and, presumably, active compounds easier penetrated in the fruit compared to the spraying procedures used. The degree of tissue impregnation is associated to a considerable extent with porosity [61][62], and a higher mass transfer could be related to higher porosity [63]. It can be inferred that dipping improves conveyance of the antioxidant solutes thanks to the effect of capillarity, which is more relevant in porous substrates compared to plain ones. Moreover, it was reported that immersing apples in an ascorbic acid solution leads to a change in permeability of the cell wall and cell membrane [27]. Water and pigment release occurs, resulting in vacuole shrinkage [27], leading to an optimal permeation of the antioxidant solution through the dipping treatment. Ascorbic acid can cause a stress reaction and thus damage the cell structure [31]. This results in enlarged interstitial spaces within the tissue and increases the capacity to absorb substances and ions [31]. The enlarged interstitial spaces may have allowed the apple to better absorb the antioxidant solution during dipping, consequently slowing down the enzymatic browning more than with spraying.

The capillarity effect has more importance on rough surfaces than on smooth ones, and it is expected that this higher effectiveness

Tab. 2: Results of the multiple comparisons (Tuckey´s post hoc test) of the ANOVA for all colorimetric indices and dark spots between dipping and spraying treatments at 99 h. Significant differences were indicated using asterisks (* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$) and not significant differences were indicated as "ns".

	16 sprays	20 sprays	24 sprays
Δ L*	*	ns	ns
Δ h	**	ns	***
Δ C*	ns	ns	*
Dark spots	ns	ns	ns
Δ E*	*	*	***

of dipping compared to spraying is more evident on rough surfaces. Since apple slices produced in the present experimentation were unusually rough as an effect of manual cutting, it is expected that using a professional cutter that produces smoother apple slices would reduce this phenomenon, and the effect of the concentration of AsA deposited on the surface would prevail.

A Δ E* between 3 and 6 is visible to the human eye [64]. Since for all treatments except 12 sprays the average Δ E* after 99 h never exceeded a value of 6, a sensory test could be performed in order to ascertain whether this color change would be still approvable by consumers.

Samples with an average Δ E* greater than 6 (non-treated apples and apples treated with 12 sprays) were too browned (see inner pictures in Figure 1), and therefore were excluded from subsequent evaluations.

A visual assessment of browning was performed on randomized pictures of apple slices collected over storage to rank the occurrence and abundance of dark spots in a 1-3 range (Fig. 2 A). Based on this analysis, the development of browning over time was not statistically different ($p = 0.05$) among all treatment over the whole storage time.

As for dark spots, the colorimetric indexes Δ L*, Δ C and Δ h were calculated on samples with an average Δ E* lower than 6 (Fig. 2 B-D).

Spraying could be expected to give a high variability within apple slices since a non-professional sprayer was used, and the nebulization of the solution could have been not

ZUSAMMENFASSUNG

Eines der wichtigsten Merkmale zur Bestimmung der Qualität von frischen Apfelscheiben, die als Snacks verkauft werden, ist ihre Farbe. Da die Scheiben nach dem Schneiden schnell braun werden, ist es üblich, sie einige Minuten lang in eine antioxidative Lösung zu tauchen (dippen). Dieses Verfahren hat jedoch einige Einschränkungen. Die Verwendung derselben Lösung für mehrere Eintauchzyklen über mehrere Stunden kann zu Kreuzkontamination und mikrobiellem Wachstum führen. Außerdem führen osmotische Austauschphänomene im Tauchbecken dazu, dass die Wirkstoffkonzentration der antioxidativen Lösung im Laufe der Zeit abnimmt, was eine ständige Nachjustierung der Konzentrationen erfordert. Diese Aspekte sowie die großen Mengen an verbrauchter Antioxidans-Lösung, die entsorgt werden müssen, sind wichtige Faktoren, welche die Suche nach einer alternativen und nachhaltigeren Methode als dem Eintauchen, vorantreiben. In dieser Arbeit wurde ein Vergleich zwischen einer herkömmlichen Dipping-Behandlung von frisch geschnittenen Apfelscheiben und der Besprühung (Spraying), mit steigender Konzentration der Antioxidans-Lösung, durchgeführt. Die Farbveränderungen wurden visuell (Vorhandensein von dunklen Flecken) und instrumentell (CIE-Lab-Farbindizes) während der fünftägigen Lagerung bewertet. Anhand der dunklen Flecken und der Veränderungen der Helligkeit (Δ L*), des Farbtonwinkels (Δ h) und des Chromas (Δ C*) waren einige der Sprühbehandlungen ebenso wirksam wie das Eintauchen. Im Allgemeinen wurde eine hohe Variabilität der Daten innerhalb und zwischen den Chargen festgestellt, was darauf hindeutet, dass weitere Untersuchungen erforderlich sind, um dieses Ergebnis zu validieren und dieses Verfahren auf industrieller Ebene anwenden zu können.

RIASSUNTO

Una delle caratteristiche piú importanti per definire la qualitá degli spicchi di mela fresca venduti come snack è il colore. Dato che, una volta tagliati, gli spicchi imbruniscono rapidamente, è prassi immergerli (dipping) in una soluzione antiossidante per alcuni minuti. Questa procedura presenta, tuttavia, alcune limitazioni. L'uso di una stessa soluzione per diversi cicli di immersione durante l'arco di molte ore può dar luogo a fenomeni di contaminazione incrociata e crescita microbica. Inoltre, fenomeni di scambio osmotico nella vasca di immersione determinano la riduzione della concentrazione dei principi attivi della soluzione antiossidante nel corso del tempo, che richiede un continuo riaggiustamento delle concentrazioni. Questi aspetti, unitamente alle grandi quantità di soluzione antiossidante esausta da smaltire, costituiscono fattori limitanti che spingono alla ricerca di metodi alternativi e più sostenibili rispetto al dipping. In questo lavoro, è stato effettuato un confronto tra un trattamento di immersione convenzionale e uno di spraying a volume crescente di soluzione antiossidante su spicchi di mela fresca. Sono stati valutati i cambiamenti di colore visivamente (presenza di macchie scure) e strumentalmente (indici colorimetrici CIE Lab) per cinque giorni di stoccaggio. In base alle macchie scure ed ai cambiamenti di luminosità (Δ L*), angolo di tinta (Δ h) e croma (Δ C*), alcuni dei trattamenti spraying sono risultati efficaci quanto il dipping. In generale, si è osservata un'elevata variabilità dei dati intra- e inter-lotto, indicando che sono necessarie ulteriori indagini per convalidare questo risultato e per poter applicare questa procedura a livello industriale.

as homogeneous as that obtained with industrial devices. Dipping, on the other hand, is not affected by the use or non-use of industrial equipment, as it simply consists of immersing a solid into a liquid. Surprisingly, a high variability was observed also among dipped apples concerning all colorimetric indices and dark spots, indicating that an effect of the roughness of the slices surface produced by the manual cutting on the antioxidant efficacy occurs. Presumably, a more a standardized industrial-scaled methodology, with performing blades, would reduce variability and increase precision.

Owing to the high variability, there were not always overlapping results for the pairwise comparisons among treatments based on the different colorimetric indices, which were, therefore, all taken into account in the overall evaluation. In table 2, a summary of the statistical comparison of 16, 20, and 24 sprays with dipping for each of the color indices under investigation and for dark spots at 99 h is reported.

Despite the high variability, results in Table 2 show that 20-spray treatment was not significantly different from dipping, suggesting that process optimization could allow the efficient use of spray as an alternative to dipping.

Under the present experimental conditions, the volume of solution (2% AsA, 0.1% NaCl, 1% CaCl2 in distilled water) required to effectively spray (20 sprays) 1 kg of apples is estimated as 188 mL. Considering that the method can be highly improved by means of more performing devices, this volume could be even lower, allowing the reduced consumption of reagents and reducing waste. The solution could be stored in sterile dark refrigerated conditions hence preserving its titre and its microbial stability.

CONCLUSIONS

Dipping treatments for fresh-cut fruit are widely used, nevertheless cross-contamination and microbial growth can occur. The variation of the reagent's concentration and, in turn, the reduction of the antioxidant efficacy over subsequent immersions can be of concern. In addition, the large volume of antioxidant solution to be disposed of can be an economic and environmental cost. Therefore, alternative methods such as spraying can be of interest for companies.

In this study, spraying was compared with dipping for antioxidant treatments of fresh-cut apples. Spraying treatments were performed with a non-professional sprayer at increasing number of sprays from 12 to 24 with an antioxidant solution at twice the concentration of active ingredients compared to dipping. The ascorbic acid absorbed by apples was measured immediately after each treatment. The color changes that occurred in samples over an experimental period of 99 hours were assessed both visually (as dark spots) and colorimetrically, through the measurement of CIE Lab parameters and calculating Δ E, Δ L*, Δ h and Δ C* indices.

Results show that, based on Δ L*, Δ h, Δ C* and dark spots, the color of apples treated with 20 sprays or dipped was not significantly different after 99 h of storage at 4 °C.

Dipping resulted in a lower uptake of AsA in apple slices than all spraying treatments under investigation, however it was as effective as the most effective spraying treatment tested in preventing browning, indicating that the application technique is more important than the amount of antioxidant absorbed by the apple surface.

In order to obtain comparable efficacy of spraying with dipping, it is therefore important to modulate the application technique and the concentration of reagents in order to reach a sufficient amount of active ingredients on the surface of apple slice and to avoid runoff of the antioxidant solution due to the overload of successive sprays. An approach based on the measurement of at least one of the ingredients of the antioxidant solution could help in developing an optimal spraying treatment to be used in order to reach a similar efficacy to dipping.

These findings indicate that spraying could be a valid alternative to dipping for the treatment of fresh-cut apples, with potential advantages related to waste and costs saving, constancy of the titre of the antioxidant solution, and reduction of microbial growth. A scale-up to an industrial level, based on the use of professional instrumentation for apple cutting and spraying, should be further performed with the aim of validating the possibility to apply a spraying treatment for the reduction of the enzymatic browning of fresh-cut apples.

ACKNOWLEDGMENTS

This research was funded by the Autonomous Province of Bolzano, which is gratefully acknowledged, through the following programs: Capacity Building 1 (Decision n. 1472, 07.10.2013), Step-Up (Decision n. 864, 04.09.2018), and “Action Plan for Mountain Agriculture and Food Sciences 2016-2022” (Decision n. 1016, 01.09.2015).

REFERENCES

[1] Dalla Via J., Mantinger H. (2012). Agricultural Research in the Field of Fruit Growing in South Tyrol. Evolution and Outlook. Erwerbs-Obstbau 54, 83-115, DOI: 10.1007/s10341-012-0171-x.

[2] Ciesa F., Höller I., Guerra W. et al. (2015). Chemodiversity in the fingerprint analysis of volatile organic compounds (VOCs) of 35 old and 7 modern apple cultivars determined by proton-transfer-reaction mass spectrometry (PTR-MS) in two different seasons. Chemistry & Biodiversity 12 (5), 800-812, DOI: 10.1002/cbdv.201400384.

[3] Agnolet S., Ciesa F., Soini E. et al. (2017). Makroelemente Und Qualitätsparameter von 34 Alten Und Acht Kommerziellen Apfelsorten Angebaut Am Selben Standort in Südtirol, Italien. Erwerbs-Obstbau 59, 171-183, DOI: 10.1007/s10341-017-0336-8.

[4] Bassi M., Lubes G., Bianchi F. et al. (2018). M. Ascorbic Acid Content in Apple Pulp, Peel, and Monovarietal Cloudy Juices of 64 Different Cultivars. International Journal of Food Properties 20 (sup. 3), S2626-S2634, DOI: 10.1080/10942912.2017.1381705.

[5] Bianchi F., Soini E., Ciesa F. et al. (2020). M. L-Ascorbic Acid and α-Tocopherol Content in Apple Pulp. A Comparison between 24 Cultivars and Annual Variations during Three Harvest Seasons. International Journal of Food Properties 23, 1624-1638, DOI: 10.1080/10942912.2020.1820515.

[6] Bianchi F., Soini E., Ciesa F. (2021) The Biodiversity of Apples Hosts Remarkable Chemodiversity. A Study on Sixteen ‘True-to-Type’ Cultivars from the Laimburg Core Collection and Their Vitamin C and E Content. Acta Horticulturae 1329, 27-32, DOI: 10.17660/actahortic.2021.1329.5.

[7] Ceci A.T., Bassi M., Guerra W. et al. (2021). Metabolomic Characterization of Commercial, Old, and Red-Fleshed Apple Varieties. Metabolites 11 (6), 378, DOI: 10.3390/metabo11060378.

[8] Serni E., Venir E., Romano G. et al. (2020). Determination of Major Phenolics Content in Dried Apples from Three New Cultivars (Malus Domestica Borkh.) Using HPLC-UV-FL with Pentafluorophenyl Stationary Phase. Food Analytical Methods 13, 863-871, DOI: 10.1007/s12161-020-01703-9.

[9] Ferretti G., Turco I., Bacchetti T. (2014). Apple as a Source of Dietary Phytonutrients: Bioavailability and Evidence of Protective Effects against Human Cardiovascular Disease. Food and Nutrition Sciences 05 (13), 1234-1246, DOI: 10.4236/fns.2014.513134.

[10] Boyer J., Liu R.H. (2004). Apple phytochemicals and their health benefits. Nutrition Journal 3 (1), 5-13, DOI: 10.1186/1475-2891-3-5.

[11] Hyson D.A. (2011). A Comprehensive Review of Apples and Apple Components and Their Relationship to Human Health. Advances in Nutrition 2 (5), 408-420, DOI: 10.3945/an.111.000513.

[12] Décordé K., Teissèdre P.L., Auger C. et al. (2008). Phenolics from Purple Grape, Apple, Purple Grape Juice and Apple Juice Prevent Early Atherosclerosis Induced by an Atherogenic Diet in Hamsters. Molecular Nutrition and Food Research 52, 400-407, DOI: 10.1002/mnfr.200700141.

[13] Conceição De Oliveira M., Sichieri R., Sanchez Moura A. (2003). Weight Loss Associated with a Daily Intake of Three Apples or Three Pears among Overweight Women. Nutrition 19, 253-256, DOI: 10.1016/S0899-9007(02)00850-X.

[14] Ragaert P., Verbeke W., Devlieghere F. et al. (2004). Consumer Perception and Choice of Minimally Processed Vegetables and Packaged Fruits. Food Quality and Preference 15 (3), 259-270, DOI: 10.1016/S0950-3293(03)00066-1.

[15] Gilbert L.C. (2000). The Functional Food Trend. What’s Next And What Americans Think About Eggs. Journal of the American College of Nutrition 19 (sup. 5), 507S-512S, DOI: 10.1080/07315724.2000.10718973.

[16] Toivonen P.M.A. (2006). Fresh-cut apples: Challenges and opportunities for multi-disciplinary research. Can. J. Plant Sci. 86, 1361-1368, DOI: 10.4141/P06-147.

[17] Klein B.P. (1993). Nutritional consequences of minimal processing of fruits and vegetables. Journal of Fruit Quality 10 (3), 179-193, DOI: 10.1111/j.1745-4557.1987.tb00857.x.

[18] Bansal V., Siddiqui M.W., Rahma, M.S. (2015). Minimally Processed Foods. Overview. In: Siddiqui M., Rahman M. (eds.). Minimally Processed Foods. (Food Engineering Series). Springer, Cham, Germany. DOI: 10.1007/978-3-319-10677-9_1.

[19] Clydesdale F.M. (1993). Color as a factor in food choice. Critical Reviews in Food Science and Nutrition 33 (1), 83-101, DOI: 10.1080/10408399309527614.

[20] Garcia E., Barrett D. M. (2002). Preservative treatments for fresh cut fruits and vegetables. In: Lamikanra, O. (ed.). Fresh-cut Fruits and Vegetables. Science, Technology, and Market. CRC Press, Boca Raton, Florida, USA, pp. 267-304, DOI: 10.1201/9781420031874.

[21] Wibowo C., Haryanti P., Wicaksono R. (2021). Effect of Edible Coating Application by Spraying Method on the Quality of Red Chili during Storage. In: IOP Conference Series. Earth and Environmental Science. Vol. 746. Proceedings oft the 3rd International Conference on Life and Applied Sciences for Sustainable Rural Development (ICLAS-SURE 2020), Central Java, Indonesia, November 18-19, 2020. IOP Publishing Ltd, Bristol, United Kingdom, DOI: 10.1088/1755-1315/746/1/012004.

[22] Qi H., Hu W., Jiang A. (2011). Extending shelf-life of Fresh-cut ‘Fuji’ apples with chitosan-coatings. Innovative Food Science & Emerging Technologies 12 (1), 62-66, DOI: 10.1016/j.ifset.2010.11.001.

[23] Bianchi F., Pünsch M., Venir E. (2021). Effect of Processing and Storage on the Quality of Beetroot and Apple Mixed Juice. Foods 10 (5), 1052, DOI: 10.3390/foods10051052.

[24] Aguayo E., Requejo-Jackman C., Stanley R. et al. (2010). Effects of Calcium Ascorbate Treatments and Storage Atmosphere on Antioxidant Activity and Quality of Fresh-Cut Apple Slices. Postharvest Biology and Technology 57 (1), 52-60, DOI: 10.1016/j.postharvbio.2010.03.001.

[25] Lozano-De-Gonzalez P.G., Barrett D.M., Wrolstad R.E. et al. (1993) Enzymatic Browning Inhibited in Fresh and Dried Apple Rings by Pineapple Juice. Journal of Food Science 58 (2), 399-404, DOI: 10.1111/j.1365-2621.1993.tb04284.x.

[26] Kamrul Hasan S.M., Manzocco L., Morozova K. (2017). Effects of Ascorbic Acid and Light on Reactions in Fresh-Cut Apples by Microcalorimetry. Thermochimica Acta 649, 63-68, DOI: 10.1016/j.tca.2017.01.008.

[27] Mauro M.A., Dellarosa N., Tylewicz U. et al. (2016). Calcium and ascorbic acid affect cellular structure and water mobility in apple tissue during osmotic dehydration in sucrose solutions. Food Chemistry 195, 19-28, DOI: 10.1016/j.foodchem.2015.04.096.

[28] Perez-Gago M.B., Serra M., Río M.A.D. (2006). Color Change of Fresh-Cut Apples Coated with Whey Protein Concentrate-Based Edible Coatings. Postharvest Biology and Technology 39 (1), 84-92, DOI: 10.1016/j.postharvbio.2005.08.002.

[29] Rodríguez-Arzuaga M., Piagentini A.M. (2018). New Antioxidant Treatment with Yerba Mate (Ilex Paraguariensis) Infusion for Fresh-Cut Apples. Modeling, Optimization, and Acceptability. Food Science and Technology International 24 (3), 223-231, DOI: 10.1177/1082013217744424.

[30] Rößle C., Gormley T., Butler F. (2009). Efficacy of Natureseal® AS1 browning inhibitor in fresh-cut fruit salads applications with emphasis on apple wedges. Journal of Horticultural Science and Biotechnology 84 (6), 62-67, DOI: 10.1080/14620316.2009.11512597.

[31] Tappi S., Mauro M.A., Tylewicz U. et al. (2017). Effects of calcium lactate and ascorbic acid on osmotic dehydration kinetics and metabolic profile of apples. Food and Bioproducts Processing 103, 1-9, DOI: 10.1016/j.fbp.2017.01.010.

[32] Toivonen P.M.A., Delaquis P. (2006). Low-Volume Sprays to Treat Fresh-Sliced Apples with Anti-Browning Solution. HortTechnology 16 (2), 257-261, DOI: 10.13140/2.1.4289.6008.

[33] Tortoe C., Orchard J., Beezer A. (2007). Prevention of Enzymatic Browning of Apple Cylinders Using Different Solutions. International Journal of Food Science and Technology 42 (12), 1475-1481, DOI: 10.1111/j.1365-2621.2006.01367.x.

[34] Ioannou I., Ghoul M. (2013). Prevention of Enymatic Browning in Fruit and Vegetables. European Scientific Journal 9 (30), 310-341, DOI: 10.19044/ESJ.2013.V9N30P%P.

[35] Chiabrando V., Giacalone G. (2012). Effect of Antibrowning Agents on Color and Related Enzymes in Fresh-Cut Apples during Cold Storage. Journal of Food Processing and Preservation 36 (2), 133-140, DOI: 10.1111/j.1745-4549.2011.00561.x.

[36] Rojas-Graü M., Soliva-Fortuny R., Martin-Belloso O. (2009). Edible coatings to incorporate active ingredients to fresh-cut fruits. A review. Trends in Food Science & Technology 20 (10), 438-447, DOI: 10.1016/j.tifs.2009.05.002.

[37] Toivonen P.M.A. (2006). Fresh-cut apples. Challenges and opportunities for multi-disciplinary research. Canadian Journal of Plant Science 86 (special), 1361-1368, DOI: 10.4141/P06-147.

[38] Andrade R.D., Skurtys O., Osorio F.A. (2012). Atomizing Spray Systems for Application of Edible Coatings. Comprehensive Reviews in Food Science and Food Safety 11 (3), 323-337, DOI: 10.1111/j.1541-4337.2012.00186.x.

[39] Martín-Belloso O., Soliva-Fortuny R., Oms-Oliu G. (2006). Fresh-Cut Fruits. In: Hui, Y.H. (ed.). Handbook of Fruits and Fruit Processing. Blackwell Publishing Professional, Ames, Iowa, USA, hier pp. 129-144, DOI: 10.1002/9780470277737.

[40] Baldwin E.A., Nisperos M.O., Chen X. et al. (1996). Improving storage life of cut apple and potato with edible coating. Postharvest Biology and Technology 9 (2), 151-163, DOI: 10.1016/S0925-5214(96)00044-0.

[41] Luo Y., Barbosa-Cánovas G.V. (1996). Preservation of Apple Slices Using Ascorbic Acid and 4-Hexylresorcinol. Food Science and Technology International 2 (5), 315-321, DOI: 10.1177/108201329600200505.

[42] Eissa H.A., Fadel H.H.M., Ibrahim G.E. (2006). Thiol Containing Compounds as Controlling Agents of Enzymatic Browning in Some Apple Products. Food Research International 39 (8), 855-863, DOI: 10.1016/j.foodres.2006.04.004.

[43] Rico D., Martín-Diana A.B., Barat J.M. (2007). Extending and Measuring the Quality of Fresh-Cut Fruit and Vegetables. A review. Trends in Food Science & Technology, 18 (7), 373-386, DOI: 10.1016/j.tifs.2007.03.011.

[44] Rodríguez-Bernaldo de Quirós A., Fernández-Arias M., López-Hernández J. (2009). A Screening Method for the Determination of Ascorbic Acid in Fruit Juices and Soft Drinks. Food Chemistry 116 (2), 509-512, DOI: 10.1016/j.foodchem.2009.03.013.

[45] Son S.M., Moon K.D., Lee C.Y. (2001). Inhibitory Effects of Various Antibrowning Agents on Apple Slices. Food Chemistry 73 (1), 23-30, DOI: 10.1016/S0308-8146(00)00274-0.

[46] Ribeiro C., Vicente A.A., Teixeira J.A. et al. (2007). Optimization of Edible Coating Composition to Retard Strawberry Fruit Senescence. Postharvest Biology and Technology 44 (1), 63-70, DOI: 10.1016/j.postharvbio.2006.11.015.

[47] Toivonen P.M.A. (2008). Influence of Harvest Maturity on Cut-Edge Browning of “Granny Smith” Fresh Apple Slices Treated with Anti-Browning Solution after Cutting. LWT - Food Science and Technology 41 (9), 1607-1609, DOI: 10.1016/j.lwt.2007.10.005.

[48] Seal T., Chaudhuri K. (2017). High Performance Liquid Chromatography Method for the Estimation of Water Soluble Vitamin in Five Wild Edible Fruits Consumed by the Tribal People of North-Eastern Region in India. International Journal of Current Microbiology and Applied Sciences 6 (10), 2900-2913, DOI: 10.20546/ijcmas.2017.610.343.

[49] Bastos C., Barros L., Dueñas M. (2015). Chemical Characterisation and Bioactive Properties of Prunus Avium L.. The Widely Studied Fruits and the Unexplored Stems. Food Chemistry 173, 1045-1053, DOI: 10.1016/j.foodchem.2014.10.145.

[50] Dimitri G., Piva A., Arfelli G. et al. (2013). Metodo Rapido per La Determinazione Di Acido Ascorbico. Infowine - Rivista internet di viticoltura ed enologia 7/2. Retrieved February 7, 2022, from https://www.infowine.com/intranet/libretti/libretto10830-01-1.pdf.

[51] Smith S. (2014). Quantifying Color Variation. Improved Formulas for Calculating Hue with Segment Classification. Applications in plant sciences 2 (3), DOI: 10.3732/apps.1300088.

[52] Leceta I., Molinaro S., Guerrero P. et al. (2015). Quality Attributes of Map Packaged Ready-to-Eat Baby Carrots by Using Chitosan-Based Coatings. Postharvest Biology and Technology 100, 142-150, DOI: 10.1016/j.postharvbio.2014.09.022.

[53] Putnik P., Bursać Kovačević D., Herceg K. (2016). Influence of Cultivar, Anti-Browning Solutions, Packaging Gasses, and Advanced Technology on Browning in Fresh-Cut Apples During Storage. Journal of Food Process Engineering 40 (2), e12400, DOI: 10.1111/jfpe.12400.

[54] Toivonen P.M., Wiersma P.A., Hampson C. et al. (2010). Effect of Short-Term Air Storage after Removal from Controlled-Atmosphere Storage on Apple and Fresh-Cut Apple Quality. Journal of the Science of Food and Agriculture 90 (4), 580-585, DOI: 10.1002/jsfa.3851.

[55] Shrestha L., Kulig B., Moscetti R. et al. (2020). Optimisation of Physical and Chemical Treatments to Control Browning Development and Enzymatic Activity on Fresh-cut Apple Slices. Foods 9 (1), 76, DOI: 10.3390/foods9010076.

[56] Rojas-Graü M.A., Sobrino-López A., Tapia M.S. (2006). Inhibition in Fresh-Cut “Fuji” Apple Slices by Natural Antibrowning Agents. Journal of Food Science 71, 59-65, DOI: 10.1111/j.1365-2621.2006.tb12407.x.

[57] Hernández-Muñoz P., Almenar E., Ocio M.J. (2006). Effect of Calcium Dips and Chitosan Coatings on Postharvest Life of Strawberries (Fragaria x Ananassa). Postharvest Biology and Technology 39 (3), 247-253, DOI: 10.1016/j.postharvbio.2005.11.006.

[58] Tiznado-Hernández M.E., Ojeda-Contreras A.J., Sánchez-Estrada A. et al. (2004). A model to predict the developmental stage of Stenocereus thurberi (Cactaceae) fruit from pulp and skin color. Bradleya 22 (22), 77-84, DOI: 10.25223/brad.n22.2004.a8.

[59] Ernesto T.H.M., Moreno D.V., Ojeda A.J.C. (2013). Prediction of Days after Anthesis of Developing Tomato (Solanum Lycopersicum) Fruit from Blossom-End Changes in Color. American Journal of Agricultural and Biological Science 8 (3), 191-198, DOI: 10.3844/ajabssp.2013.191.198.

[60] Commission Internationale de l´Eclairage (ed.) (2020). ILV. International Lighting Vocabulary. CIE S 017/E:2020, DOI: 10.25039/S017.2020.

[61] Lombardi A.M., Zaritzky N.E. (1996). Simultaneous Diffusion of Citric Acid and Ascorbic Acid in Prepeeled Potatoes. Journal of Food Process Engineering 19 (1), 27-48, DOI: 10.1111/j.1745-4530.1996.tb00379.x.

[62] Radziejewska-Kubzdela E., Biegańska-Marecik R., Kidoń M. (2014). Applicability of Vacuum Impregnation to Modify Physico-Chemical, Sensory and Nutritive Characteristics of Plant Origin Products. A Review. International Journal of Molecular Sciences 15 (9), 16577-16610, DOI: 10.3390/ijms150916577.

[63] Neri L., Santarelli V., Di Mattia C.D. et al. (2019). Effect of Dipping and Vacuum Impregnation Pretreatments on the Quality of Frozen Apples. A Comparative Study on Organic and Conventional Fruits. Journal of Food Science 84 (4), 798-806, DOI: 10.1111/1750-3841.14489.

[64] Riva M. (n.d.). Approfondimenti: Il colore degli alimenti e la sua misurazione. Retrieved February 7, 2022, from https://docplayer.it/289593-Approfondimenti-il-colore-degli-alimenti-e-la-sua-misurazione.html.