A first approach of using ultrasound as an alternative for blanching in vacuum-packaged potato strips

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ABSTRACT: The effect of ultrasound (US) (40 kHz, 200 W, 3 min), blanching (85 ˚C, 3.5 min) and the combination of both methods was evaluated on the quality of vacuum packaged potato strips stored at 3±1 ˚C for up to 10 days. For this study two cultivars of potatoes were assessed. For blanched Agata samples, the lightness (L*) decreased over 12 % (p < 0.05). Moreover, their hue increased up to 100, obtaining lesser yellow potato strips. In contrast, US did not affect the hue values. The losses of firmness of blanched potato strips were notable (35 % for Agata and 51 % for Agria), whereas US did not change this property (p < 0.05). Nevertheless, no significant differences were found in the total starch content at 10 days. Agata and Agria showed different metabolic behavior of sucrose in the refrigerated storage. Therefore Agria cultivar retained better colour after frying. These results suggest that US had less impact in colour and improve the firmness in vacuum-packaged potato strips with no added chemicals.

Keywords: Colour, firmness, starch content, reducing sugars, vacuum packaging

Introduction

Minimal processing operations of vegetables and tubers can induce undesirable changes in the colour and appearance during storage, caused mainly by enzymatic browning. This can accelerate the loss of quality and reduce the product's shelf life (Tomás-Barberán and Espín 2001; Cantos et al. 2002).

Blanching is a method commonly used in minimally processed potatoes to prevent enzymatic browning by inactivating polyphenol oxidase. Blanching promoted in potato slices more uniform colour after frying and the layer of gelatinized starch formed, limited oil absorption and improved texture Moreira et al. (1999). Severini et al. (2003) achieved the inactivation of polyphenol oxidase in potatoes through blanching treatments and the combination with calcium chloride, which promoted increased lightness (L*), probably due to its chelating properties. Meanwhile, Alvarez et al. (2000) observed that blanching led to a loss of firmness and of other quality attributes of the product, such as nutrients, flavor and colour.

To prevent the undesirable effects of blanching, ultrasound may be a viable method for non-thermal processing. Acoustic cavitation of ultrasound can accelerate chemical reactions, increase diffusion rates, disperse aggregates, inhibit enzymes and destroy microorganisms (Sala et al. 1995; Knorr et al. 2002). Zuo et al. (2012) studied the behavior of high intensity low-frequency ultrasound (20 kHz) on potato starch granules and observed that treatment by ultrasound resulted in the damage to the starch surface and in some cases in the shattering of the granules. Furthermore, the increase in the number of defect was found to be linear with the sonication power. Comandini et al. (2013) studied the application of ultrasound produced through a 35 kHz sonotrode during immersion freezing of potatoes and concluded that the treatment affected important freezing parameters, like the anticipation of nucleation and the reduction of freezing time. Karizaki et al. (2013) investigated the possibility of using ultrasound-assisted osmotic dehydration as a pretreatment prior to frying and its effects on the quality of fried potatoes. The authors concluded that the association with ultrasound reached the goal by reducing oil and moisture content as compared to that of untreated ones.

For the authors' knowledge, few applications have been described of the use of ultrasound in the fresh vegetable industry to retain food quality. Color and texture changes have to be taken into account regarding the quality of potato strips as they are the two parameters that define their appearance. Furthermore, the effects of ultrasound on some specific food components have not been sufficiently studied, so the actual effect of degradation due to the use of this treatment is not yet fully understood (Mizrach 2008). For this purpose, this study aimed to evaluate the effect of ultrasound compared to conventional blanching on the colour, pH, firmness, sugars and starch content of vacuum-packed potato strips stored at 3±1 °C for up to 10 days. Colour and firmness of the fried potato strips were also assessed.

Materials and Methods

Materials

Potatoes (*Solanum tuberosum* L.) of the Agata and Agria cultivars were acquired from Mercabarna (Mercados de Abastecimientos de Barcelona SA), selected, washed in tap water to remove surface dirt, dried and stored in the dark at 18 ± 2 ºC overnight prior to processing. Agata presented values of dry matter of 18.40 ± 1.20 $g\cdot 100g^{-1}$ and Agria 20.95 ± 0.25 $g\cdot 100g^{-1}$.

Ultrasound equipment

An ultrasound bath with 40 kHz of frequency and 200 W of generation power (JP-SELECTA 3000617, Barcelona, Spain) was used to sonicate the potatoes. The machine was made of welded aluminum sheet, with a capacity of 9 L, the dimensions were 12 cm x 46 cm x 12 cm (height x width x depth). The ultrasound bath had four steel cone-shape transductors (45 mm/38 mm of diameter; 47 mm length). The experiment was conducted in batch mode in non-refrigerated equipment. The operating conditions had previously been optimized and the distribution of the ultrasound in the bath was uniform (Amaral et al. 2015). The specific heat and power of dissipation were calculated and were 47234 $kJ\cdot kg^{-1}$ and 157.45 W, respectively. The increase of the temperature in the water was lesser than 1.5ºC after 3 min of treatment.

Experimental procedure

Potato tubers, free of defects, were hand-peeled, cut into rectangular strips with a cross-section of 10 x 10 mm with a manual vegetable slicer and immediately rinsed in distilled water (1:4 w/w; potato:distilled water ratio). The strips were then centrifuged in a manual centrifuge to eliminate excess water. For the treatment phase, potato strips of each variety were separated into two portions: from the first portion, packs of 100 ± 5 g were selected at random from the whole bunch and vacuum packed (-98 kPa, in a vacuum sealer VM-18 ORVED S.p.A., Italy) in coextruted polyamide/high density polystyrene (Coex. PA/PEHD-70/150; thickness: 22 µm; O_2 transmission rate: 8 cm^3/m^2 dbar at 25 °C) bags. The bags were then separated to receive either no further treatment (control samples) or a 3-minute ultrasound treatment at 40 kHz. The second portion of the potato strips was blanched in a non-agitated system (85 °C for 3.5 min, Pedreschi and Moyano 2005), samples were manually shaken during blanching and the potato:water ratio was 1:4 (w/w). Blanched samples were cooled, for five minutes at 22 ± 2 ºC and centrifuged. They were also vacuum packed (-98 kPa) in PA/PEHD bags. Then, the packages were divided into another two portions: one portion was subjected to sonication and the other refrigerated. All samples were stored at 3 ± 1 ˚C for up to 10 days. Two replicates of 100 ± 5 g of vacuum-packaged potatoes were assessed for each treatment and sampling date. For total starch content and total sugars, samples were collected, immediately frozen at -20 ˚C and subsequently freeze-dried at -54 ˚C and 0.07 mbar vacuums for 40 h by Telstar Cryodos -50 freeze dryer (1 KVA of potency, model 2G-6, Telstar, Barcelona, Spain). Prior to frying, 1 L of olive oil (0.5º) was pre-heated in a deep-fat fryer. Samples were kept at 3 ± 1 ˚C before frying. Then, 200 ± 10 g of each treatment of potato strips were fried at 180 ˚C (Taurus Professional Compac2 fryer, Spain) for 5 minutes for Agata potatoes and 7 minutes for Agria potatoes. Frying times were previously fixed according to the palatability of the fried strips. After frying, the strips were removed from the oil, drained for one minute and then air-dried at 22± 2 ºC for 10 minutes. The colour and firmness of the samples were then assessed.

Physicochemical analysis

Analyses were carried out on days 1, 6 and 10 for the vacuum-packaged and fried potatoes. *pH* was measured in triplicate according to AOAC 981.12. *Colour* was determined with a colorimeter (Konica Minolta CR-400, Japan), measuring L*a*b* parameters in the CIE Lab scale using a D_{65} light source and 10° as the observed standard; results are expressed in L*, Chroma ($C^*=((a^*)^2+(b^*)^2)^{1/2}$ and hue ($H^* = \tan^{-1}(a^*/b^*)$). Ten readings were taken on two sites on the surface of the potato strips for each treatment (Oner and Walker 2011). *Firmness* was measured using the texture analyzer (TA.XT Plus, Stable Micro Systems Co. Ltd., UK) equipped with a 30 kg load cell and connected with a Warner-Bratzler blade set with a speed of 1 $mm{\cdot}s^{-1}$. Twenty potato strips of each treatment and day were analysed (Yang et al. 2016). Firmness was measured as the maximum shear strength values and expressed as maximum force (N). *Total starch* analyses were conducted using 100±0.1 mg of lyophilized sample according to AOAC 996.11 (amyloglucosidase/α-amylase method) and AACC 76.13 procedures. D-glucose was oxidised to D-gluconate, which was quantitatively measured from the absorbance at 510 nm of a colorimetric reactant. The results were expressed by $g{\cdot}100\ g^{-1}$ of lyophilized weight (LW). These determinations were made in triplicate. *Sugars* were extracted and measured as described by (López-Hernández et al. 1998) with slight modifications. 2g of lyophilized sample were extracted by refluxing for 30 min with 70% ethanol. The extract was vacuum-filtered and filled to 25 mL with 70 % ethanol. A 5 mL aliquot of the solution was passed through a Waters Sep-Pak C column, filtered (0.45 μm pore size membrane), and injected into the HPLC Hewlett Packard series 1100, equipped with a Beckman 110B injector and a Beckman Refraction Index Detector (RID). The fructose, glucose and sucrose separation was performed using a Phenomenex Luna column at 28 °C using acetonitrile-water (78:22 v/v). The average of the results of three replications were expressed by $g \cdot 100g^{-1}$ of LW.

Statistical analysis

The statistical study of variations after application of treatments and during storage was carried out using two-way ANOVA using Minitab (v.16, MINITAB Inc, State College, PA) at a 95% confidence level. ANOVA was carried out for each cultivar independently. The differences between samples were determined using Tukey´s least significant difference test.

Results and Discussion

Effect of the treatments on pH of the potato strips

For Agata and Agria, the interaction between both factors (treatment and storage day) was significant for pH values (data not shown). Both heat-treated Agata and Agria samples (blanched and blanched+US) had significantly higher pH values (6.09-6.11 and 6.48-6.10, respectively) than the control (5.77-5.88) and US samples (5.72 -5.89) at the beginning of the experiment ($p < 0.05$).In general, a statistically significant decrease of pH (≤0.2 pH units) was observed in both cultivars and treatments at the end of 10 storage days at 3 ± 1 ˚C. Only, the pH of the blanched treatment for Agata was not significant different than samples analysed at the beginning of the experiment. Our previous study about the effect of different times of application of ultrasound (40 kHz, 200 W) only observed alterations in pH after 5 minutes of sonication (Amaral et al. 2015).

Effect of treatment on carbohydrates: sugars and starch content of potato strips

Total starch

The content of total starch was 60.65 ± 2.77 $g \cdot 100g^{-1}$ LW and 65.46 ± 1.60 $g \cdot 100g^{-1}$ LW for Agata and Agria cultivar, respectively. No significant differences were observed in the total starch content in either blanched or control samples ($p > 0.05$) after one day of storage at 3±1 ˚C in the two cultivars studied (data not shown). Wang, Zhang and Mujumdar (2010) did not find significant differences either between unprocessed and blanched potatoes (in boiling water for 5 min); although a slight decrease was noticed due to leaching losses. Ultrasound affected the total starch content of the potato strips and promoted its reduction, but no significant differences were found compared to the control and blanched samples at the end of storage. According to Jambrak et al. (2010), ultrasound causes changes in the starch granule, such as a decrease in size and, consequently, alterations in the physical-chemical properties of starch. Ultrasound treatment fosters the damage and ruptures of the starch granules and distorts the crystalline region prior to a reversible hydration of the amorphous phase. The samples treated with the combination of blanching and ultrasound had a slightly higher content of total starch, but no significant differences were detected with the control and blanched potato strips ($p>0.05$). At 10 days, for both of the cultivars assessed, the potato strips did not show changes in their major nutrient.

Sugars

Agata showed higher concentrations of fructose, glucose and sucrose (Figure 1) compared with Agria. This information differs than that found by Uri et al. (2014) that observed the French fry cultivars have greater amounts of fructose and glucose. In the refrigerated storage the results suggest a different metabolic behaviour of sucrose for each cultivar, since Agata accumulates sucrose while the two monosaccharide from which it is composed, reduced their quantities in contrast to Agria that presented reduction of the content of sucrose. Folgado et al. (2014) pointed that the different behaviour of sucrose metabolism is due to the cold-acclimation of each species of tuber. Although Park et al. (2009) stated that sucrose is a substrate for starch formation; in this work there was no connection with the accumulation of this sugar and the total starch content.

The application of treatments decreased significantly ($p < 0.05$) the content of fructose and glucose of Agata potato strips the first day of storage (Figure 1a and 1b). After 10 days, there was a decrease of the content of the three sugars analysed for blanched samples ($p < 0.05$). In contrast, samples of the other treatments increased significantly the content of glucose and fructose. For Agria samples it was observed a slightly increase of the three sugars analysed ($p < 0.05$) at the beginning of the experiment (Figure 1d, 1e and 1f). Moreover, a negative correlation between sucrose and day of storage ($r = -0.615$; $p < 0.01$; $n=12$) and positive correlation between fructose and glucose ($r = 0.956$; $p < 0.01$; $n=12$) were found.

Effect of the treatments on Colour and firmness on vacuum packaged and fried potato strips

Colour

For Agata vacuum-packaged potato strips, the interaction between both factors (treatment and storage day) was significant for all parameters ($p < 0.05$). On the other hand, for Agria the interaction between treatment and storage day was not significant for Chroma and Hue. In fried strips, the effects of treatment and time of storage were significant for all parameters and the two varieties analysed, excepted for the parameter Chroma (data not shown). For this parameter there were significant differences only for time of storage in Agria ($p < 0.05$).

The treated Agata potato strips showed a significant decrease ($p < 0.05$) in *lightness* (L*), at one day of storage but Agria potato strips were not affected (Figure 2a and 2c) It is important to remember that in potato strips, the higher the L* value, the lighter the colour (Cantos et al. 2002). Furthermore, both blanched samples showed significantly lower values than the ultrasound-treated ones. These results are in agreement with Oner and Walker (2011), who noted that unprocessed potato strips were lighter in colour than blanched and fresh-cut strips. Enzymatic oxidation occurring before the denaturation of the polyphenol oxidase (PPO) in the blanched samples may be the cause of their darker colour. According to our results, at the end of storage the blanching operation leads to increase browning ($p > 0.05$) in potato strips, but in Agria this effect is lesser than Agata. Nevertheless, the blanched Agria potato strips were darker than the ultrasound-treated and control potato strips after 10 days of storage ($p < 0.05$). The control and ultrasound samples had lower *hue* (H*) values for both of the cultivars assessed (Figure 2b and 2d) ($p < 0.05$). The Agata samples had a higher H* value than the Agria samples after one day of storage at 3 ± 1 ˚C (100.12, 97.82, respectively) and this trend is maintained during storage time for blanching treatments. Cabezas-Serrano et al. (2009) also found lower L* values for Agata, but the H* value for this cultivar were higher than in Marabel, Agria and Almera. Our results are consistent with those findings; a higher H* value indicates that the potato flesh is less yellow. The H* values of the blanched Agata samples increased significantly after 10 days of storage, whereas the Agria samples did not change. This may indicate that the colour of the blanched Agata potato became less attractive over time.

In general, all of the samples of the Agata cultivar displayed a sharper depletion in L* values (47.9% for control potato strips) after frying than the Agria samples (Figures 2e, 2g). Ultrasound-treated Agria potato strips had the highest L* value (71.68), but no significant differences were found between blanched and control samples ($p > 0.05$). For the Agata cultivar, the lightness of the control and ultrasound-treated samples improved over time ($p < 0.05$), whereas blanched samples became slightly darker at the end of storage ($p > 0.05$). Scores under this value indicate a darker, brownish colour for fried potato strips (Oner and Walker 2011). Consequently, the Agata cultivar seems highly suitable for use as a fresh-cut product, but the colour after frying may be considered less attractive to consumers. Its darker colour after frying may be due to the compounds obtained after the Maillard reaction, which is determined by the superficial reducing sugar and amino acid content. However, it is important to note that for the Agata cultivar, the lightness of the control and ultrasound-treated samples improved over time ($p < 0.05$). The H* values follow the same pattern as the lightness values for the Agata cultivar and confirm their brownish colour (Figure 2f). At the end of storage, blanched samples had the lowest value ($p < 0.05$). As is shown in Figure 2h, the treatments did not have an impact on the H* angle of the fried

Agria potato strips at the beginning of the experiment ($p > 0.05$). Despite the H* value of the vacuum-packaged potato strips, after frying, values were around 90˚(yellow) for all the treatments as well as the control.

Firmness

There was a significant decrease in *firmness* in both of the blanched potato strips: 35% for Agata and over 51% for Agria, indicating a remarkable softening of the product due to the heat treatment (Table 1). Starch gelatinization weakens the structure of potato parenchyma which occurs when strips are blanched at high temperatures (over 70 ˚C); meanwhile, the intensity of softening depends on both temperature and time (Liu and Scanlon 2007). Pedreschi and Moyano (2005) reported that blanching induced a reduction of almost 29% in the maximum force of raw slices of potato. Ultrasound treatment did not change the firmness of either the Agata or the Agria potato strips compared to the control over time.

There were no significant differences in maximum force on fried potato strips on day 1 ($p < 0.05$) but, comparing with the vacuum-packaged samples, the control and sonicated potato strips underwent the greatest losses in firmness after frying (>70%). Nevertheless, the Agria fried potato strips were firmer than the Agata ones (Table 1). According to Nourian and Ramaswamy (2003), within five minutes of frying time, potato strips lose more than 80% of their original texture. This is due to the combination effect of cell rupture, solubilisation of the middle lamellae and the gelatinization of starch. Oner and Walker (2011) obtained a greater loss of firmness in unprocessed potato strips (84%) than in blanched ones (35-47%) for the Russet Burbank cultivar. This trend was similar to both potato cultivars assessed in this work. In contrast, Pedreschi et al. (2009) did not find a significant effect on the texture of fried potatoes that had previously been blanched. During refrigerated storage, the control and blanched samples of the Agata cultivar had significantly higher values than the ultrasound-treated and blanched and sonicated samples. The greatest firmness was found on day 10 for the blanched potato strips, which increased significantly over time. In the Agria fried samples, the values were higher for the sonicated potato strips at the end of storage at 3±1 ˚C.

Conclusions

The use of ultrasound indicated that the firmness, colour and pH of sonicated vacuum-packaged potato strips were better than blanched. The combination of both techniques (blanched + US) didn't improve the studied parameters. The colour of the fried Agria potato strips is better than the Agata, however, the use of ultrasound led to the improvement in the lightness of fried Agata potato strips during refrigerated storage. Sugar content showed different results after exposition to ultrasound for both cultivars analysed. Therefore, ultrasound can be considered by the potato industry as an option to reduce the impact in colour and the loss of firmness of vacuum-packaged potato strips with no added chemicals, although further research is needed to understand other important aspects such as the maximum shelf life of this product and the consequences on composition and sensory quality of the fried product.

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Figure caption

Fig 1 Fructose, Glucose and sacarose contents for vacuum-packaged Agata (a, b and c) and Agria (d, e and f) potato strips stored at 3±1 ˚C. Values are the average ± standard deviation (n=3). Different capital letters in the same parameter and day of storage indicate significant differences. Different lower case letters in the same parameter and treatment indicate significant differences ($p < 0.05$)

( ) control, ( ) blanching, ( ) ultrasound and ( ) blanching + ultrasound

Fig 2 Changes in L* and H* for vacuum-packaged Agata (a, b) and Agria (c, d) and fried Agata (e, f) and Agria (g, h) potato strips stored at 3±1˚C. Values are the average ± standard deviation (n=20). Different capital letters in the same parameter and day of storage indicate significant differences. Different lower case letters in the same parameter and treatment indicate significant differences ($p < 0.05$)

( ) control, ( ) blanching, ( ) ultrasound and ( ) blanching + ultrasound

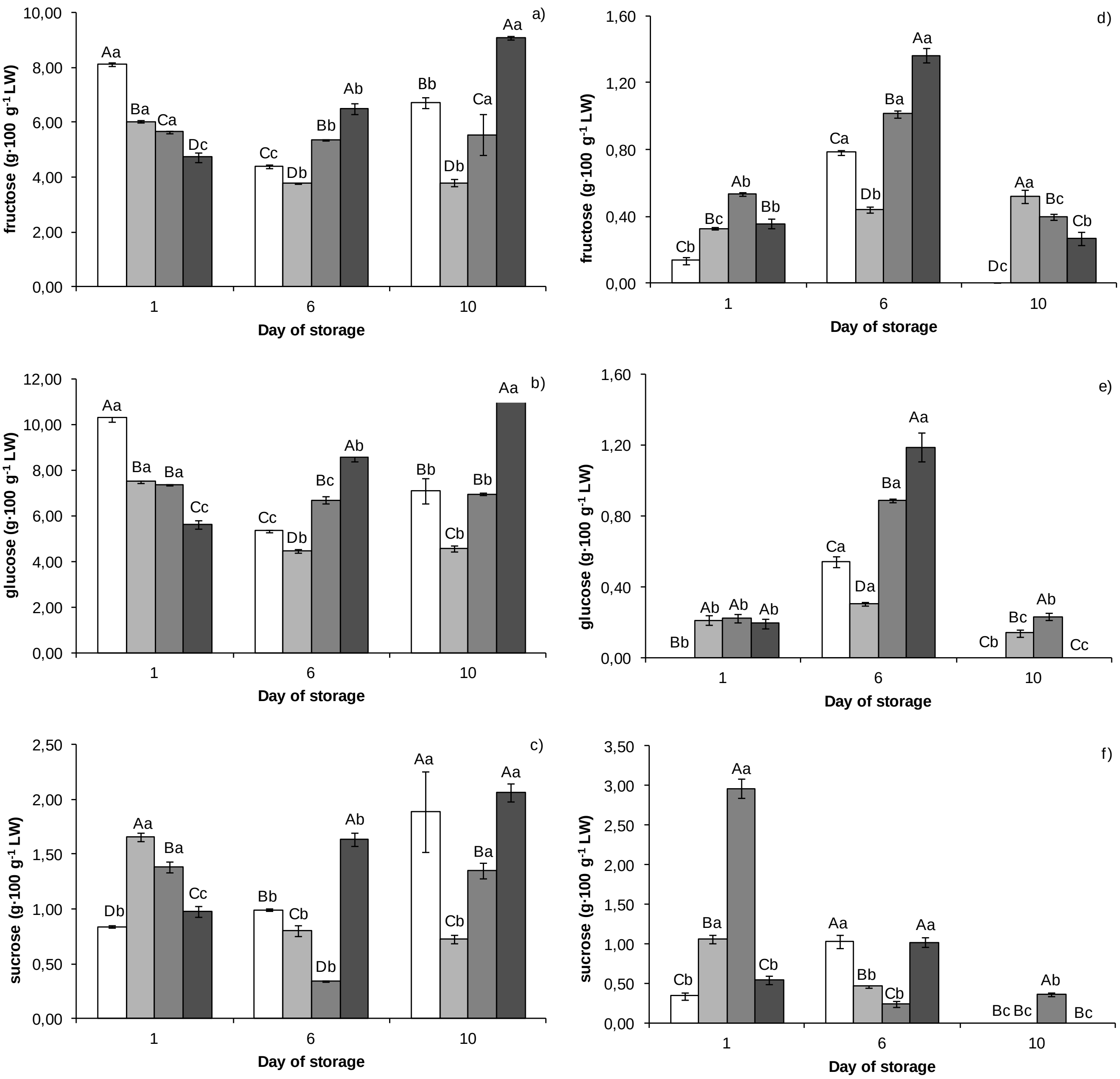
a)
fructose (g·100 g-1 LW)
10,00
8,00
6,00
4,00
2,00
0,00
Aa Ba Ca Dc
Cc Db Bb Ab
Bb Db Ca Aa
1
6
10
Day of storage
d)
fructose (g·100 g-1 LW)
1,60
1,20
0,80
0,40
0,00
Cb Bc Ab Bb
Ca Db Ba Aa
Dc Aa Bc Cb
b)
glucose (g·100 g-1 LW)
12,00
10,00
Aa Ba Ba Cc
Cc Db Bc Ab
Bb Cb Bb Aa
e)
glucose (g·100 g-1 LW)
Bb Ab Ab Ab
Ca Da Ba Aa
Cb Bc Ab Cc
c)
sucrose (g·100 g-1 LW)
2,50
2,00
1,50
1,00
0,50
Db Aa Ba Cc
Bb Cb Db Ab
Aa Cb Ba Aa
f)
sucrose (g·100 g-1 LW)
3,50
3,00
Cb Ba Aa Cb
Aa Bb Cb Aa
Bc Bc Ab Bc

Fig. 1

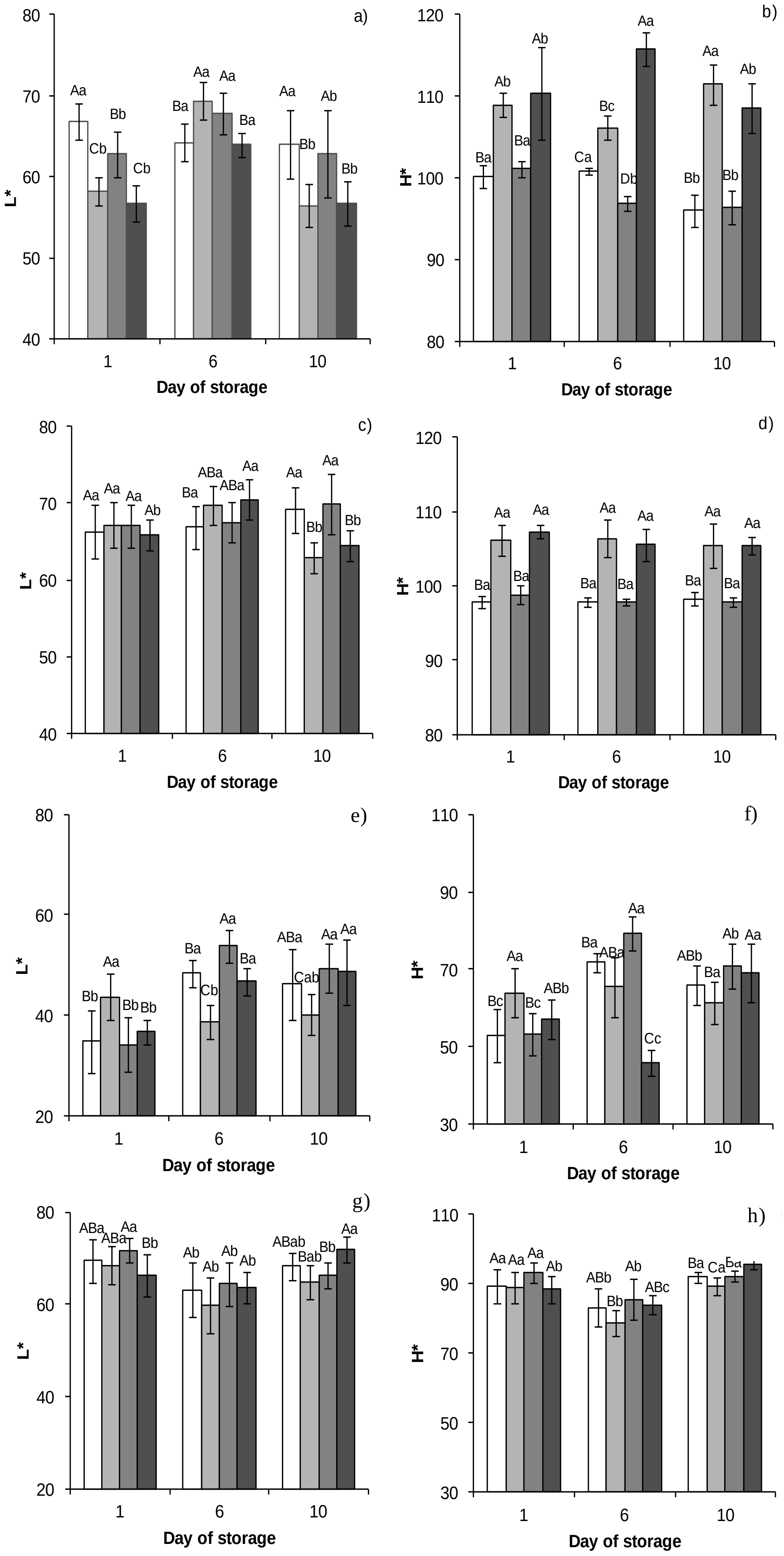

Fig. 2

Table 1. Firmness (N) of vacuum-packaged and fried Agata and Agria potato strips stored at 3 ± 1 °C

Treatment			Storage time (day)		
			1	6	10
Vacuum-packaged	Agata	Control	16.02 ± 2.89 Aa	16.45 ± 1.85 Ba	16.95 ± 1.95 Aa
		Blanching	10.44 ± 2.79 Ba	10.35 ± 2.86 Ca	11.02 ± 3.48 Ba
		US	15.21 ± 2.12 Ab	23.31 ± 5.80 Aa	17.40 ± 1.68 Ab
		Blanching + US	9.26 ± 2.86 Ba	9.20 ± 3.30 Ca	10.44 ± 3.85 Ba
	Agria	Control	21.21 ± 3.37 Aa	23.59 ± 2.18 Aa	20.43 ± 4.73 Aa
		Blanching	10.33 ± 2.31 Ba	12.09 ± 1.94 Ca	10.90 ± 4.20 Ba
		US	23.54 ± 3.88 Aa	20.34 ± 2.43 Bb	22.74 ± 2.29 Aab
		Blanching + US	12.43 ± 4.00 Ba	10.46 ± 1.62 Ca	10.68 ± 2.00 Ba
Fried	Agata	Control	3.67 ± 1.20 Ab	4.95 ± 1.23 Aa	4.99 ± 1.16 ABa
		Blanching	4.13 ± 1.16 Ab	4.72 ± 0.98 Ab	6.55 ± 1.13 Aa
		US	3.82 ± 1.15 Aa	3.50 ± 1.04 Ba	4.68 ± 1.85 Ba
		Blanching + US	3.65 ± 0.99 Ab	3.37 ± 0.88 Bb	4.82 ± 1.20 Ba
	Agria	Control	5.41 ± 1.95 Ab	6.59 ± 1.53 Bab	8.08 ± 2.51 Ba
		Blanching	5.51 ± 0.85 Ab	8.14 ± 2.27 ABa	6.74 ± 1.23 BCab
		US	5.15 ± 1.85 Ab	10.58 ± 4.00 Aa	10.40 ± 3.30 Aa
		Blanching + US	5.91 ± 1.68 Aa	6.39 ± 1.74 Ba	5.31 ± 1.86 Ca

Values are the average ± standard deviation (n=20). Different capital letters in the same parameter and day of storage indicate significant differences. Different lower case letters in the same parameter and treatment indicate significant differences ($p < 0.05$).