ACTA SCIENTIARUM POLONORUM *Acta Sci. Pol., Technol. Aliment. 6(3) 2007, 37-49*

THE EFFECT OF SELECTED COMPOUNDS AS INHIBITORS OF ENZYMATIC BROWNING AND SOFTENING OF MINIMALLY PROCESSED APPLES

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Abstract. In the study the effect was assessed of sample processing with solutions containing inhibitors of enzymatic browning and tissue softening and sucrose on the quality of minimally processed apples. Ascorbic acid, citric acid, 4-hexylresorcinol, sodium chloride, calcium chloride, sodium lactate, calcium lactate and sucrose were used as inhibitors. The application in apple slice processing of a solution containing 1% ascorbic acid, 0.005% 4-hexylresorcinol, 0.5% calcium chloride, 20% sucrose effectively inhibited the browning and softening of apple slices during storage. Moreover, it had an advantageous effect on the other sensory attributes, resulting in a product of very high quality. A good quality product is obtained using a solution of citric acid and sucrose.

Key words: enzymatic browning, softening, inhibitors, apples, minimal processing

INTRODUCTION

Prompt browning of numerous fruits and vegetables, such as bananas, potatoes, peaches and apples, is a serious problem in the production of minimally processed vegetables and fruits and may result in the deterioration of the sensory attributes of the obtained products. Browning shortens the shelf-life of a product, lowers its commercial value, and in some cases results in the complete rejection of a product [Sapers and Miller 1992, Watada et al. 1996, Moline et al. 1998].

The most commonly used method to inhibit browning is the application of inhibitory agents. Browning inhibitors are compounds which affect the enzyme or react with the substrates or products, inhibiting the formation of colouring compounds. The application of inhibitors of enzymatic browning is limited by such factors as their toxicity, effect on the taste, aroma and texture of the product and by economic reasons [Iyengar and McEvilly 1992]. The most commonly used inhibition method in food industry has been the addition of sulfur compounds (IV). They are used to inhibit the browning of

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potatoes, mushrooms, apples and other fruits and vegetables, as well as whitening compounds, inhibiting the development of microorganisms, and stabilizing the taste and colour of wines. These compounds, although very effective in the inhibition of both enzymatic and non-enzymatic browning, may cause allergic reactions and have a negative effect on taste.

The harmfulness of sulfites was the direct cause for the development of studies on the application of other, safer browning inhibitors. Numerous reports describe attempts to minimally process fruits and vegetables, consisting in their treatment with compounds inhibiting the processes of enzymatic browning, which at the same time do not lower their culinary value. Various substances are used as inhibitors, e.g. ascorbic acid and its derivatives, citric acid, ethanol, or cysteine [Nicoli et al. 1993, Jiang et al. 1999, Buta and Moline 2000, Lamikanra and Watson 2001, Soliva et al. 2001].

Substances inhibiting browning may be divided in terms of the mechanism of their action into several groups: reducing agents, chelating agents, enzyme inhibitors, acidifying compounds, enzymes and complexing compounds. The mechanism of inhibition varies for individual categories of enzymatic browning inhibitors. Differences in the mechanism of their action make it possible to use several agents simultaneously, which facilitates the utilization of their synergism and enhances their activity in comparison to those in case of inhibitors used individually [McEvilly and Iyengar 1992].

Flesh softening is also one of major problems connected with the extension of shelf-life of minimally processed products, since enzymes causing degradation of cell walls are not inhibited. Calcium plays a significant role in the formation of structures composing cell membranes and walls. It forms bridges connecting polymer anion groups, ensuring in this way appropriate membrane permeability and flesh integrity. The presence of calcium increases flesh resistance to the action of pectinases, produced both by the raw material and microorganisms [Gunes et al. 2001, Gorny et al. 2002, Soliva-Fortuny et al. 2002].

The aim of the study was to determine the effectiveness of selected compounds as inhibitors of enzymatic browning and softening of minimally processed apples used in the form of vacuum impregnation slices.

MATERIALS AND METHODS

In the investigations solutions of the following compounds were used: ascorbic acid, citric acid, 4-hexylresorcinol, sodium chloride, calcium chloride, sodium lactate, calcium lactate and sucrose. The experimental material consisted of apples of cultivar *Jonagold* from the pomiculture experimental station, the Agricultural University of Poznań, in Przybroda near Poznań.

Posharvest handling and treatments aplication

Fruits were peeled, cored and sliced into 1-cm thick slices, then deaerated and vacuum impregnated in solutions containing the above mentioned compounds in various combinations and concentrations. Deaeration and vacuum impregnation were performed at the pressure of 70 mbar. After processing slices were placed in the amounts of 100 g each in 15 × 21 cm bags by Multivac made of laminate (oriented polyamide/polyethyl-

ene) with gas permeability in $cm^3/m^2/24$ h: O_2 – 45, CO_2 – 200, N_2 – 8, and vacuum packed using an A 900 vacuum packaging machine by Multivac, at the pressure of 70 mbar. The product was stored at the temperature of 4°C for 15 days.

The first stage of the investigations was to study the effect of various concentrations of ascorbic acid, citric acid and sucrose in solutions used for the quality processing of the product. The investigations consisted of two experiments, the concentrations of the components in the solutions used in processing in experiment 1 are given in Table 1, whereas in experiment 2 the concentrations of 0.1%, 0.5% and 1% of ascorbic and citric acids, and 10%, 20% and 30% sucrose were used in various combinations (Table 2). The sensory examination, measurement of colour parameter and the other physicochemical analyses (pH and refractometric extract) of the product were conducted after 1, 10 and 15 days of storage.

Table 1. Concentrations of sucrose, ascorbic acid and citric acid in solutions used for vacuum impregnation of apple slices and changes in physicochemical properties of apple slices in experiment 1
Tabela 1. Stężenie składników w roztworach stosowanych do nasączania próżniowego oraz zmiany właściwości fizykochemicznych plastrów jabłek w doświadczeniu 1

Sample Próba	Sucrose Sacharoza %	Ascorbic acid Kwas askorbinowy %	Citric acid Kwas cytrynowy %	Increase of weight Przyrost masy %	Refractometric extract Ekstrakt %	Value of pH Wartość pH	
						1 day 1. dzień	15 days 15. dzień
A	10	0	0	25.0	12.4	4.48	3.94
B	10	0.5	0	25.2	12.0	4.05	3.71
C	10	0	1	25.4	12.1	3.46	3.06
D	10	0.5	1	25.1	12.8	3.39	3.01
E	20	0.5	0	23.3	16.4	4.07	3.80
F	30	0.5	0	17.1	19.4	4.01	3.81
G	40	0.5	0	14.0	24.1	4.06	3.0

In the second stage the aim was to evaluate the effectiveness of processing using solutions of ascorbic and citric acids in combination with 4-hexylresorcinol, sodium chloride, calcium chloride, sodium lactate and calcium lactate to maintain the best sensory attributes of the obtained product. The experiments conducted at this stage (experiments 3A, 3B, 3C, 3D) were designed using the response surface method on the basis of a linear centrally folded model (computer program: Design Expert version 4.01). The range of concentrations of the applied compounds is presented in Table 3. The analysis and evaluation of the product (after 1, 10 and 15 days of storage) were conducted: sensory examination, color parameter measurement, texture measurement, pH and refractometric extract measurement.

Table 2. Concentrations of inhibitory agents in solutions used to impregnation of apple slices, sensory examination of colour and value of colour parameter L* of samples in experiment 2
Tabela 2. Stężenia związków inhibujących w roztworach użytych do nasączania plastrów jabłek, ocena sensoryczna i wartości parametru barwy L* prób w doświadczeniu 2

Sample Próba	Concentration, % Stężenie, %			Sensory examination Ocena sensoryczna		Value L* Wartość L*	
	sucrose sacharoza	ascorbic acid kwas askorbinowy	citric acid kwas cytrynowy	color – tone barwa – ton	color – uniformity barwa – wyrównanie	0 h*	4 h*
1	10	0.1	0.1	2.1	2.0	61.9	47.3
2	10	0.1	1.0	2.6	2.5	54.8	55.7
3	10	1.0	0.1	3.0	3.1	59.9	61.8
4	10	1.0	1.0	3.4	4.0	63.0	63.4
5	30	0.1	0.1	2.2	2.0	55.2	47.0
6	30	0.1	1.0	2.9	2.5	56.4	57.4
7	30	1.0	0.1	3.2	3.2	52.1	52.7
8	30	1.0	1.0	4.0	4.2	52.3	51.9
9	20	0.55	0.55	3.9	4.2	57.6	58.2
1	20	0.55	0.1	3.8	3.7	56.8	54.8
11	20	0.55	1.0	4.3	4.5	61.7	60.01
12	20	0.1	0.55	3.8	3.8	56.6	53.3
13	20	1.0	0.55	4.5	4.9	58.1	60.6
14	10	0.55	0.55	3.5	3.9	62.0	59.0
15	20	0.55	0.55	4.1	4.5	58.1	58.7
16	30	0.55	0.55	3.8	3.8	50.5	51.2

*After opening the packaging.
*Po otwarciu opakowania.

Colour parameters measurement

Measurements of colour parameters were conducted in homogenized apple slices (homogeniser IKA T25). Measurement were performed in the CIE L*a*b* system, in reflected light (a U-3000 Hitachi spectrophotometer). Measurements were taken immediately after bags with the product were opened and 4, 8 and 24 hours later, after the slices were left at room temperature.

Table 3. Concentrations of inhibitory agents in solutions used to impregnation of apple slices in experiment 3
Tabela 3. Stężenia związków inhibujących w roztworach użytych do nasączania plastrów jabłek w doświadczeniu 3

Experiment Doświadczenie	Concentration of compounds, % min.-max. Stężenie związków, % min.-maks.						
	ascorbic acid kwas askorbinowy	citric acid kwas cytrynowy	4-hexylresorcinol 4-heksylrezorcynol	sodium chloride chlorek sodu	calcium chloride chlorek wapnia	sodium lactate mleczan sodu	calcium lactate mleczan wapnia
3A	0.8-1.2	0.3–0.5	–	0.05-0.1	–	1-1.5	1-1.5
3B	0.8-2	0.5-1.5	–	0.1-0.2	–	–	1.5-4.5
3C	1-2	–	–	–	–	–	1-2
3D	0.5-1.5	–	0.003-0.01	–	0.1-0.5	–	–

The concentration of sucrose in all experiments was 20%.
Stężenie sacharozy we wszystkich doświadczeniach wynosiło 20%.

Texture measurement

For the purpose of texture measurements apple slices (after 1, 10 and 15 days of storage) were used to prepare cylinder-shaped samples with the height of 1 cm and diameter of 2 cm, which were subsequently subjected to the TPA test, being compressed twice to 75% their original height with the use of an TA-XT2 texturometer. Compression was conducted with the velocity of 1.67×10^{-3} $m \cdot s^{-1}$, causing permanent sample deformation. On this basis values were determined for Fmax (maximum force) of the 1st compression cycle (hardness [N]) and the 2nd compression cycle.

Sensory evaluation

Sensory analysis was conducted in a 5-point hedonic scale. The colour (tone, equalization, desirability), texture (type, tenderness), taste (typicality, intensity) and aroma (typicality) were assessed. Sensory examination of minimally processed apples were conducted after 1, 10 and 15 days of packaged product storage at 4°C.

Moreover, the gain in the slice weight during vacuum impregnation was measured along with pH values and contents of the refractometric extract.

RESULTS AND DISCUSSION

The effect of sucrose, ascorbic and citric acid concentrations in the solutions used in the processing of slices on their quality

At the increase in sucrose concentration in the impregnation solution from 10 to 40%, the degree of solution saturation of slices decreased considerably (Table 1). The highest values of parameter L* (lightness) were obtained for sample C, as well as samples B and D, impregnated with the solution containing 10% sucrose and citric and ascorbic acids. At higher sucrose concentrations (20-40%), even in the presence of acids, the L* value dropped considerably. Changes in the slice colour parameters L*, a* and b* are presented in Figure 1.

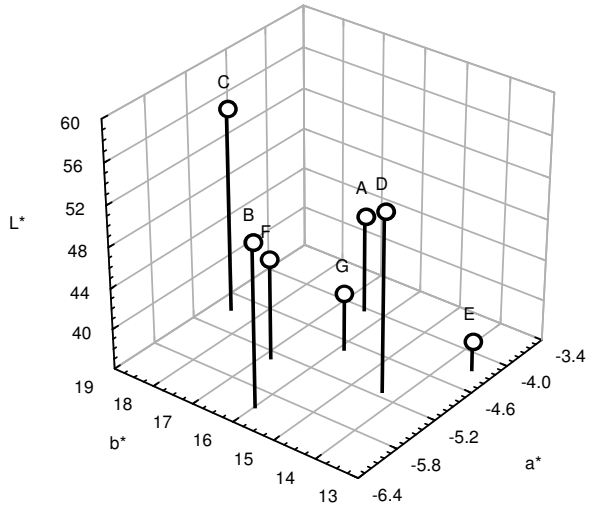

Fig. 1. A comparison of colour parameters of vacuum impregnated slices with solutions with different concentrations of sucrose, ascorbic and citric acids in experiment 1 (sample description – Table 1)
Rys. 1. Porównanie parametrów barwy plastrów nasączanych próżniowo roztworami o różnym stężeniu sacharozy, kwasu askorbinowego i kwasu cytrynowego w doświadczeniu 1 (opis prób – tabela 1)

The extract contents in slices increased along with the increase in sucrose content in the impregnation solution (Table 1). The addition of acids (0.5, 1.0 and 1.5%) resulted in a considerable decrease in the pH value of vacuum impregnated apple slices. It was highest in samples C and D, where the addition of citric acid was 1% (Table 1).

The highest notes in sensory examination were given to samples impregnated with solutions containing 20, 30 and 40% sucrose and 0.5% ascorbic acid (samples E, F, G). They were characterized by the yellow colour, no brown discolouration was observed at

the core. The L* values for these samples were low, which was caused by the high saturation of the yellow colour tone as a result of impregnation them in the solution with a high sucrose content (20-40%), and the absence of brown spots indicating enzymatic browning of the tissue (Fig. 1). It is confirmed by the values of parameter b* of these samples, which increase along with the increase in the sucrose concentration in the solution. The texture of samples E, F and G was evaluated as very firm and the taste as sweet.

The lowest notes in sensory examination were given to the samples impregnated with a 10% solution of sucrose (sample A). It showed brown discolourations in the core area, which was also confirmed in the measurement of colour parameters. These slices showed the highest value of parameter a* observed for all the samples, which indicates the presence of the brown tone in their colour. Moreover, sample A had low values of color parameter L*, sour taste and medium-firm texture.

Differences between samples impregnated with solutions of varying concentrations of ascorbic and citric acids and sucrose were similar also in experiment 2 (Table 2). They were distinctly visible after samples were taken out of the packaging and left at room temperature. Already after 4 hours of such storage samples treated with solutions of the lowest acid concentrations showed a considerable decrease in the L* value (Table 2). In these samples an immediate appearance of brown discolouration of the flesh was observed, especially in the core area. The values of parameters a* and b* were decreasing along with the increase in the concentrations of acids in the impregnation solution. It reflects the changes in the colour tone in slices treated with a solution with a lower acid concentration and the appearance of brown tissue discolouration. It is confirmed by the sensory examination of the colour, where samples treated with solutions with a low acid concentration received lower notes for colour, especially its tone and uniformity (Table 2).

The contents of ascorbic and citric acids and sucrose in impregnation solutions had an advantageous effect on the sensory attributes of apples, especially in terms of the improved colour and taste of the product. An increase in sucrose concentration in the impregnation solution lowered the saturation of slices with the solution and resulted in their decreased brightness and increased saturation of the yellow colour. The effectiveness of the combination of ascorbic and citric acids in the inhibition of enzymatic browning in minimally processed fruits and vegetables is confirmed in the studies by e.g. Pizzacaro et al. [1993], Nicoli et al. [1993].

On the basis of the conducted experiments at a later stage of the investigations it was decided to apply the 20% concentration of sucrose in the impregnation solution, which had an advantageous effect on the product taste, facilitated good solution saturation of slices and did not result in such high drops in sample brightness as in case of 30% and 40% concentrations. It was also observed that acid concentrations of 0.1% do not effectively inhibit enzymatic browning of apple slices.

The assessment of effective action of solutions containing ascorbic and citric acids, and sucrose in combination with 4-hexylresorcinol, sodium chloride, calcium chloride, sodium lactate and calcium lactate

The application of ascorbic and citric acids in combination with calcium and sodium lactates, sodium chloride and sucrose (experiment 3A; Table 3) resulted in a product with light yellow colour with small spots in the core area, observed after 10 and 15 days of storage. The taste of the product was defined as sweet-sour and the texture as medium-firm.

Brightness L* in experiments 3A and 3B was advantageously affected by the concentration of citric acid in the impregnation solution (Table 4). However, this acid in both experiments had a disadvantageous effect on slice texture, which was observed during sensory examination of the product (Fig. 2). Ascorbic acid in experiments 3A and 3B had a more advantageous effect on the notes given in sensory examination than citric acid, especially in terms of slice colour and taste (Table 5). The addition of calcium lactate to the impregnation solution had an advantageous effect on the texture of apple slices (Fig. 2) and the advantageous effect of the action in case of this compound increased along with the prolonged storage of the product. However, high concentrations of this agent had a negative effect of product taste. The application of sodium lactate had an advantageous effect on the investigated quality factors of the product only after 1 day of storage, whereas after 10 and 15 days of storage a disadvantageous effect of this agent was observed, especially on the taste and colour of apple slices. The addition of sodium chloride to the impregnation solution did not have a significant effect on the quality of apple slices.

The values of colour parameters L*, a* and b* of apple slices in experiments 3C and 3D during 15 days of storage varied only slightly and ranged from 55 to 61 for value L*, from –4 to –6 for a*, and from 24 to 29 for b*.

The application of sodium lactate (experiment 3C; Table 3) and 4-hexylresorcinol and sodium chloride (experiment 3D; Table 3) in combination with ascorbic acid effectively inhibited enzymatic browning of apple slices, having a positive effect on both colour and texture parameters, and the sensory examination results. Apple slices in these experiments during the 15-day storage were characterized by light yellow colour and firm texture.

Table 4. Equation parameters for the dependency of brightness values L* and sensory examination notes on the concentration of inhibitory agents in the impregnation solution in experiment 3A
Tabela 4. Parametry równania określające zależność wartości jasności L* i not oceny sensorycznej barwy od stężenia substancji inhibujących w roztworze nasączającym w doświadczeniu 3A

Days of storage Dni przechowywania	Intercept Wyraz wolny	Independent variables, concentration, % Zmienne niezależne, stężenie, %					Significance of F-test Istotność testu F	Fitting Stopień dopasowania
		ascorbic acid kwas askorbinowy	citric acid kwas cytrynowy	calcium lactate mleczan wapnia	sodium lactate mleczan sodu	sodium chloride chlorek sodu		
L* (brightness) – L* (jasność)								
1	55.60	x	+0.82	+1.05	x	x	< 0.001	0.54
10	61.10	x	+0.89	+0.91	x	x	0.007	0.21
15	44.24	x	x	+0.63	x	+1.13	< 0.001	0.93
Color – sensory examination – Barwa – ocena sensoryczna								
1	4.29	+0.06	x	x	x	x	0.05	0.67
10	3.96	+0.27	x	–0.17	–0.16	x	< 0.001	0.57
15	3.71	+0.13	x	–0.22	x	x	< 0.001	0.64

x – non-significant values rejected for stepwise regression at $\alpha = 0.1$.
x – wartości nieistotne odrzucone przy regresji krokowej na poziomie $\alpha = 0,1$.

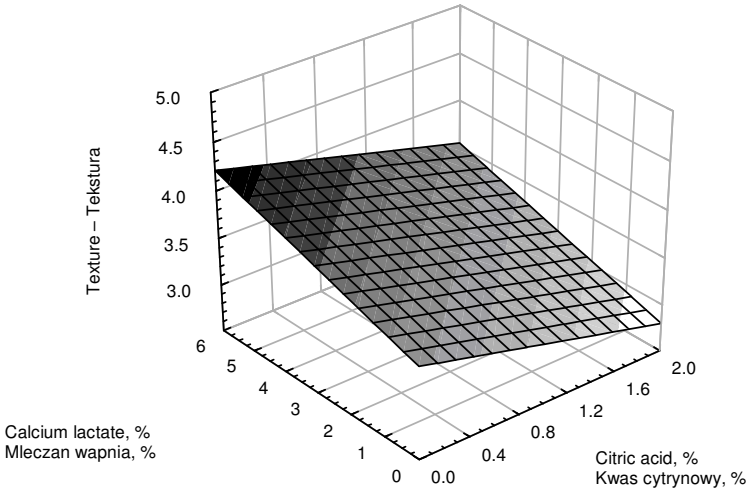

Fig. 2. Plane graph of dependency of texture sensory examination notes on the concentration of calcium lactate and citric acid in the solution used in vacuum impregnation of apple slices in experiment 3A
Rys. 2. Wykres powierzchniowy zależności not oceny sensorycznej tekstury od stężenia mleczanu wapnia i kwasu cytrynowego w roztworze stosowanym do próżniowego nasączania plastrów jabłek w doświadczeniu 3A

Table 5. Equation parameters for the dependency of the color sensory examination values on the concentration of inhibitory agents in the impregnation solution in experiment 3D
Tabela 5. Parametry równania określające zależność wartości oceny sensorycznej barwy od stężenia substancji inhibujących w roztworze nasączającym w doświadczeniu 3D

Days of storage Dni przechowywania	Intercept Wyraz wolny	Independent variables, concentration, % Zmienne niezależne, stężenie, %			Significance of F-test Istotność testu F	Fitting Stopień dopasowania
		ascorbic acid kwas askorbinowy	4-hexyl resorcinol 4-heksylrezorcynol	calcium chloride chlorek wapnia		
1	2	3	4	5	6	7
Color – tone – Barwa – ton						
1	4.506	x	x	x	x	0.490
10	4.209	+0.358	x	x	0.091	0.499
15	4.649	+0.778	+0.203	–0.106	0.007	0.807
Color – equalization – Barwa – wyrównanie						
1	4.242	+0.077	+0.050	x	0.085	0.100
10	4.171	+0.272	x	x	0.068	0.168
15	4.240	+0.424	+0.131	+0.018	0.002	0.548

Table 5 – cont.

1	2	3	4	5	6	7
Color – desirability – Barwa – pożądalność						
1	4.273	x	x	+0.196	0.050	0.401
10	4.181	x	x	x	x	0.522
15	4.190	+0.778	+0.288	+0.113	0.131	0.924

x – non-significant values rejected at stepwise regression at $\alpha = 0.1$.
x – wartości nieistotne odrzucone przy regresji krokowej na poziomie $\alpha = 0,1$.

In contrast, only slight lowering of value L* for fruit flesh was observed after 15 and 30 minutes since homogenization; these changes were lower in case of impregnation with a mixture of ascorbic acid, 4-hexylresorcinol and calcium chloride than in case of a combination of ascorbic acid and calcium lactate. It indicates high efficiency of browning inhibitory action by 4-hexylresorcinol (Fig. 3). Small changes in colour parameters in the course of 15 days of storage indicate an effective inhibition of enzymatic browning by both applied combinations of inhibitory agents.

The results of sensory examination indicate an advantageous effect of ascorbic acid and a negative effect of calcium lactate on colour, especially its tone and desirability in

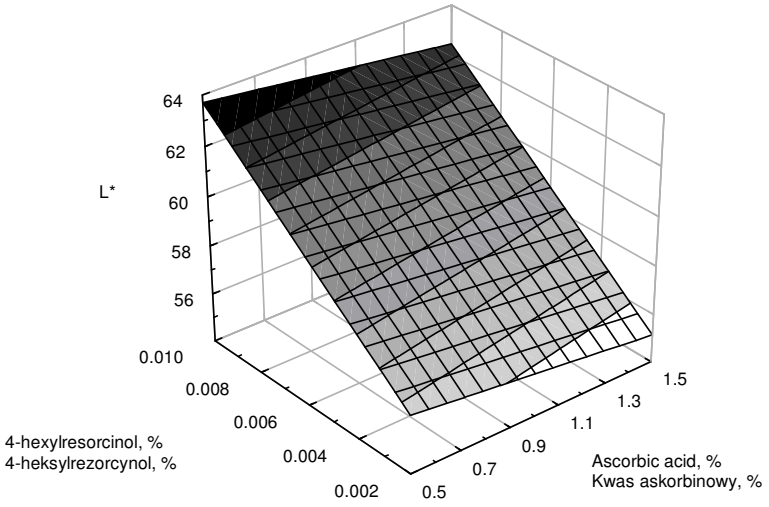

Fig. 3. Plane graph of dependency of colour brightness L* on the concentration of 4-hexylresorcinol and ascorbic acid in the impregnation solution for the processing of apple slices in experiment 3D
Rys. 3. Wykres powierzchniowy zależności jasności barwy L* od stężenia 4-heksylrezorcynolu i kwasu askorbinowego w roztworze nasączającym stosowanym do obróbki plastrów jabłek w doświadczeniu 3D

experiment 3C. The effect of ascorbic acid on the overall sensory examination in this experiment was clearly manifested after 15 days of storage. In experiment 3D, with the application of 4-hexylresorcinol, an increasing advantageous effect of both ascorbic acid and 4-hexylresorcinol was observed on the indexes of slice colour, i.e. tone, uniformity and desirability (Table 5).

Fruit slice texture, both measured instrumentally and in sensory examination , was positively affected by the addition of calcium chloride and calcium lactate to the impregnation solution; however, it was diminishing with the duration of storage time (Table 6). A high concentration of calcium lactate (1.5-4.5%) in the solution used for slice processing resulted in a deterioration of product taste. Calcium chloride, which was used in a 7-fold smaller concentration than that for calcium lactate, had a stronger action and did not cause a deterioration of notes for the taste of apple slices.

Table 6. Equation parameters for the dependency of texture instrumental measurement and sensory examination values on the concentration of calcium lactate and calcium chloride in the impregnation solution
Tabela 6. Parametry równania określające zależność wartości pomiaru instrumentalnego i oceny sensorycznej tekstury od stężenia mleczanu wapnia i chlorku wapnia w roztworze nasączającym

Day of storage Dni przechowywania	Experiment 3C – Doświadczenie 3C			Experiment 3D – Doświadczenie 3D		
	intercept wyraz wolny	calcium lactate mleczan wapnia	fitting stopień dopasowania	intercept wyraz wolny	calcium chloride chlorek wapnia	fitting stopień dopasowania
Texture – values F_{max}, N – Tekstura – wartości $F_{maks.}$, N						
1	16.714	x	0.985	16.740	+4.000	0.379
10	12.000	x	0.540	13.520	–0.330	0.624
15	8.500	+1.634	0.097	13.200	x	0.098
Texture – sensory examination – Tekstura – ocena sensoryczna						
1	4.350	x	0.539	4.232	+0.636	0.150
10	4.430	x	0.423	4.011	+0.216	0.249
15	4.070	x	0.244	4.059	x	0.699

x – non-significant values rejected at stepwise regression at $\alpha = 0.1$.
x – wartości nieistotne odrzucone przy regresji krokowej na poziomie $\alpha = 0,1$.

Ascorbic acid is a frequently used enzymatic browning inhibitor due to its versatile action: it chelates copper ions, reduces *o*-quinones and acts as a competitive PPO inhibitor [Lozano-de-Gonzales et al. 1993]. 4-hexylresorcinol is usually applied as an agent inhibiting enzymatic browning in combination with ascorbic acid and its derivatives [Monsalve-Gonzales et al. 1993, 1995, Dong et al. 2000], and with cysteine and its derivatives [Buta and Moline 2000]. Monsalve-Gonzales et al. [1993] investigated the action of 4-hexylresorcinol as an enzymatic browning inhibitor in cut apples. Sodium sulfate (IV), also used in their study, had to be applied in a 5 times bigger concentration to prevent colour changes as effectively. A considerable effect on sensory attributes of

minimally processed products was also found for calcium. Simultaneous application of calcium salts and ascorbic acid results in a better fruit colour than the use of other components individually. An important advantage of calcium is the improvement of texture of sliced apples thanks to the formation of complexes with pectins inside their tissue [Huxsoll and Bolin 1989]. Citric acid and other acidifying agents are also used as enzymatic browning inhibitors in vegetables and minimally processed fruit in combination with ascorbic acid. Santerre et al. [1988] found that citric acid inhibited enzymatic browning to a similar degree in frozen apple slices as ascorbic acid.

CONCLUSIONS

On the basis of the conducted experiments it was found that the combination of ascorbic acid (1%), 4-hexylresorcinol (0.005%), calcium chloride (0.5%) and sucrose (20%), i.e. the most effective combination out of all used, inhibited the process of enzymatic browning in apple slices, increasing their brightness (L*), as well as improving their sensory attributes. Ascorbic acid had a more advantageous effect on quality factors than citric acid. The addition of citric acid at the concentration of 0.8%, which effectively inhibited enzymatic browning, resulted in the softening of the tissue of the apple slices, and also the appearance of sour taste. However, this agent in combination with sucrose may quite effectively inhibit colour changes in apple slices.

The effectiveness of the action of calcium chloride in comparison to calcium lactate was much higher. No disadvantageous effect of calcium chloride on taste was observed. Calcium lactate at the concentration of 2% caused a deterioration in taste, which resulted in lowered overall notes for sensory examination of slices.

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ZASTOSOWANIE WYBRANYCH ZWIĄZKÓW JAKO INHIBITORÓW ENZYMATYCZNEGO BRĄZOWIENIA I MIĘKNIĘCIA JABŁEK O MAŁYM STOPNIU PRZETWORZENIA

Streszczenie. W pracy określano wpływ obróbki roztworami zawierającymi związki hamujące brązowienie enzymatyczne i mięknięcie tkanki oraz sacharozę na jakość jabłek o małym stopniu przetworzenia. Jako inhibitory zastosowano: kwas askorbinowy, kwas cytrynowy, 4-heksylrezorcynol, chlorek sodu, chlorek wapnia, mleczan sodu, mleczan wapnia oraz sacharozę. Zastosowanie do obróbki plastrów roztworu zawierającego 1% kwasu askorbinowego, 0,005% 4-heksylrezorcynolu, 0,5% chlorku wapnia, 20% sacharozy skutecznie hamowało brązowienie i mięknięcie plastrów jabłek podczas przechowywania, ponadto pozytywnie wpływało na pozostałe cechy sensoryczne, dając produkt o bardzo dobrej jakości. Dobrą jakość produktu uzyskano, stosując roztwór kwasu cytrynowego i sacharozy.

Słowa kluczowe: enzymatyczne brązowienie, mięknięcie, inhibitory, jabłka, minimalne przetwarzanie

Accepted for print – Zaakceptowano do druku: 16.07.2007

For citation – Do cytowania: Biegańska-Marecik R., Czapski J., 2007. The effect of selected compounds as inhibitors of enzymatic browning and softening of minimally processed apples. Acta Sci. Pol., Technol. Aliment. 6(3), 37-49.