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EFFECT OF MINIMAL PROCESSING ON CHANGES IN THE TEXTURE OF VACUUM-PACKAGED APPLE SLICES

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Key words: minimal processing, texture, apple, vacuum impregnation

The aim of the study was to determine changes in the texture and tissue microstructure of apples under the influence of minimal processing, consisting in dipping, blanching and vacuum impregnation with a solution containing ascorbic acid, 4-hexylresorcinol, calcium chloride and sucrose. Among the 10 tested apple varieties the best flesh hardness was found for var. *Gala* and *Idared*; these cultivars also exhibited the best texture after the application of vacuum impregnation. The biggest changes both in the texture and tissue microstructure of apples were caused by blanching, while the smallest ones by dipping. The process of vacuum impregnation ensured a greater uniformity in the flesh microstructure of apple slices, whereas the values of firmness for these slices decreased during product's storage.

INTRODUCTION

Minimal processing of fruits and vegetables is a process of transforming raw materials immediately after harvest into storable, safe, convenient, nutritious and attractive products, which would to a high degree preserve freshness as a quality attribute [Powrie & Skura, 1991]. Technology of minimal processing of fruits and vegetables includes various processing methods, excluding conventional preservation methods such as appertizing or freezing [de Daza *et al*., 1996].

Food texture is a combination of physical, chemical and mechanical properties, such as fat content, the presence of cell walls and their composition, the size and shape of molecules or flesh moisture content. In order to precisely determine the product's texture it is necessary to combine both sensory examination and instrumental methods of texture assessment.

Minimally processed products exhibit attributes of both convenience and fresh food. In case of minimally processed fruits and vegetables their freshness is connected with the fact that they have live tissue. During the processing of such products flesh is mechanically damaged and injured, with these injuries causing a series of physiological and mechanical changes. Flesh softening is 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 [Kim *et al.,* 1994].

In order to postpone softening, fresh-cut fruits and vegetables may be subjected to various preservation measures. Calcium plays a significant role in the formation of structures composing cell membranes and walls. It forms bridges connecting polymer anion groups, thus ensuring 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. Numerous studies are being conducted on the simultaneous application of calcium ions and modified atmosphere packaging to preserve natural texture [Rosen & Kader, 1989; Guzman *et al*., 1999]. Texture of minimally processed fruits and vegetables is also maintained thanks to the application of modified atmosphere packaging [Everson *et al*., 1992; Anese *et al*., 1997]. This is connected with the inhibition of physiological processes in the flesh of fruits and vegetables, the inhibition of ripening and overripening, as well as a limitation of growth in case of pectinase-producing microorganisms.

The aim of the conducted experiments was to determine the effect of minimal processing, including blanching, dipping and vacuum impregnation with solutions containing compounds inhibiting browning and flesh softening, on textural and microstructure changes in apple slices.

MATERIAL AND METHODS

Experimental material consisted of apples of 10 varieties: *Cortland*, *Elstar, Gala, Gloster, Golden Delicious, Idared, Jonagold*, *Ligol, Melrose* and *Szampion*, originating from a pomology experimental station of the Agricultural University of Poznań, located in Przybroda near Poznań. Experiments were conducted from October to March in the years 2001–2003. The technological process of minimal processing of apples consisted of the following stages: after washing and core removal apples were cut into 1 cm thick slices, which were subsequently subjected to treatment with a solution containing 10 mg/L ascorbic acid, 0.05 mg/L 4-hexylresorcin-

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ol, 5 mg/L calcium chloride and 200 mg/L sucrose in order to inhibit enzymatic browning and flesh softening. Slice processing consisted in the application of one of the treatments mentioned below: blanching, dipping and vacuum impregnation. Blanching was conducted in the above-mentioned solution for 1 min at a temperature of 60ºC, dipping lasted for 15 min. Deaeration and vacuum impregnation of slices were performed applying the pressure of 80 mbar for 5 min. After processing using one of these methods the slices were dried and vacuum packaged into bags made of laminate (oriented polyamide/polyethylene) and stored at 4°C for 15 days. Analyses were also conducted on non-processed apples and control slices, *i.e*. slices of apples not subjected to processing, which were vacuum-packaged and subsequently stored.

In the first stage of the study, texture of 10 varieties of non-processed apples was compared, while these varieties were subjected to one processing method: deaeration and vacuum impregnation with a solution. After processing texture of the products obtained was subjected to instrumental measurements and sensory assessment.

In the second stage of the study, textural changes were analysed in one apple variety (var. *Jonagold*), subjected to all the above-mentioned processing methods, *i.e*. blanching, dipping and vacuum impregnation with the above-mentioned solution.

For the purpose of texture measurements the 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% of their original height with the use of an apparatus for texture measurements TA-XT2 (Stable Micro System Ltd., UK). 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, as well as work of the 1st and 2nd cycle.

Sensory examination was conducted using a 5-point scale, evaluating flesh firmness and tenderness in comparison to fresh apples. Measurements and sensory examination of minimally-processed apples were conducted after 1, 10 and 15 days of packaged product storage at 4°C.

The third stage of the study included analyses of microstructure in raw apples and slices of minimally-processed apples. Tissue microstructure analyses of apple variety *Jonagold* were conducted on the basis of images under a scanning electron microscope JSM-35 at 50× and 100× magnification, using computer software Zeiss KS 300 3.0 for calculations. The area and shape factor (the value of the smallest cell diameter/the value of the biggest cell diameter) of apple tissue cells were determined. Samples for observations of apple flesh were collected after 1 day of product storage. Samples were composed of slice sectors being sections of their central part.

RESULTS AND DISCUSSION

While subjecting 10 apple varieties to compression tests it was found that both hardness and work during sample compression depended on apple variety. Values of hardness for apple samples fell within the range from 51 N for var. Cortland to 109 N for var. Gala and Idared (Figure 1). Values of work during compression were directly proportional to hardness of apple samples of individual varieties and ranged from 227 N·mm (var. *Gala*) to 531 N·mm (var. *Idared*).

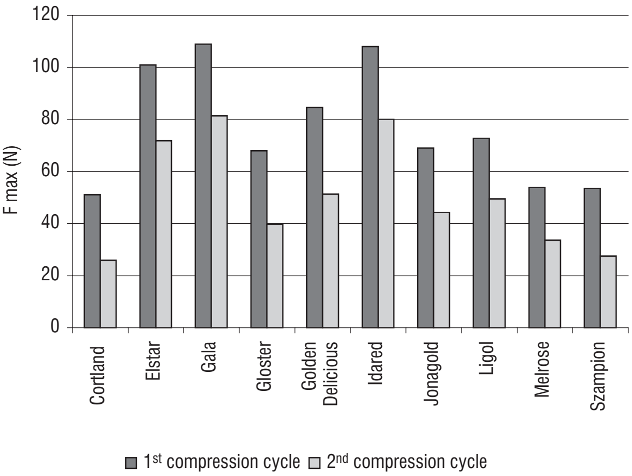


FIGURE 1. Values of maximum force of 1st and 2nd compression cycles of raw apple samples obtained using the TPA test.

After the vacuum impregnation of apple slices with a solution, values of the parameters analysed increased (Figure 2). The increase in the value of hardness and work after the application of apple slice processing was dependent on the variety used. However, during the 15-day product storage a decrease was observed in the discussed values for all the varieties. Soliva-Fortuny *et al.* [2002], when dipping *Golden Delicious* apples in a solution of ascorbic acid and calcium chloride, observed a deterioration of texture attributes of apple slices by 33% during 60-day storage. Moreover, they found a considerable deterioration of texture in control slices, at the same time indicating an advantageous effect of calcium chloride in processed slices. Lurie & Nussinovitch [1996], when measuring the texture of apple varieties *Golden Delicious* and *Granny Smith* subjected to heating and unheated ones, showed that firmness, strength and stiffness were correlated with apple crispness and observed higher values for

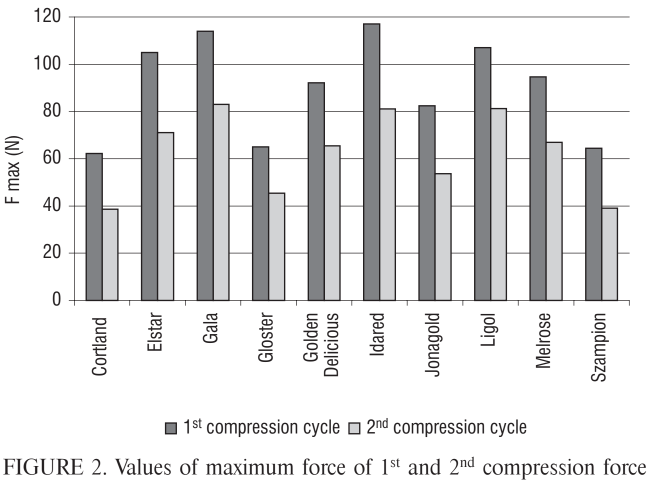


FIGURE 2. Values of maximum force of 1st and 2nd compression force cycles of vacuum impregnated apple samples obtained using the TPA test. Impregnation solution: 1% ascorbic acid, 0.005% 4-hexylresorcinol, 0.5% calcium chloride, 20% sucrose.

the unheated apples. Those authors also found that dependencies between values of the above-mentioned parameters describing texture were dependent on the apple variety analysed.

A statistical analysis showed a significant effect of a variety and product storage time on values of sample hardness and work (Table 1).

TABLE 1. A two-way analysis of variance determining the effect of variety and storage time of apple slices on changes in texture parameters.

Variable	Degrees of freedom	Mean of square	Value F	Value p
		F MAX I		
A	9	21981.39	97.62008	<0.001
B	3	20377.58	90.49748	<0.001
AB	27	3642.48	16.17638	<0.001
		WORK I		
A	9	421932.9	97.8917	<0.001
B	3	450762.2	104.5803	<0.001
AB	27	77528.8	17.9873	<0.001
		F MAX II		
A	9	17636.36	118.7201	<0.001
B	3	16848.91	113.4193	<0.001
AB	27	3183.59	21.4305	<0.001
		WORK II		
A	9	15009.42	130.2592	<0.001
B	3	13997.84	121.4802	<0.001
AB	27	3681.15	33.5090	<0.001

* – the effect of the factor is statistically non-significant ($p>0.05$); A – variety; B – duration of storage of apple slices; AB – interactions between variables

A difference was observed in the decrease in sample hardness in the 2nd compression cycle in comparison to the 1st cycle depending on the variety, which ranged from 30 to 50%. In turn, the difference in the value of work for identical samples during the 2nd compression cycle in comparison to the 1st cycle ranged from 80 to 95%, respectively.

Notes of sensory examination for the texture of vacuum impregnated apple slices ranged from 3 to 5, in a 5-point scale. Varieties with flesh exhibiting higher hardness values (*Gala, Idared*) showed a uniform firm texture throughout the whole slice subjected to analysis. In contrast, varieties with a looser flesh (*Cortland, Szampion*) exhibited a trend towards flesh deliquescence, especially in the outer layers of slices.

In the second stage of the study one apple variety was used, that was characterised by average values of flesh hardness, *i.e. Jonagold*. After the application of blanching, dipping and vacuum impregnation the product obtained received uniform notes in sensory examination of texture, ranging from 4 to 5. Similar notes were also given to control samples. These notes deteriorated during 15 days of storage, both in the case of slices subjected to processing and controls (Figure 3).

On the basis of instrumental texture measurements after 1 day of storage in apple var. *Jonagold* slices subjected to 3 types of processing a decrease was found in the measured values of texture only in the case of blanched samples. Dipped and vacuum impregnated samples showed hardness values similar to those of the control samples (Figure 4). During storage of apple slices values of hardness dropped

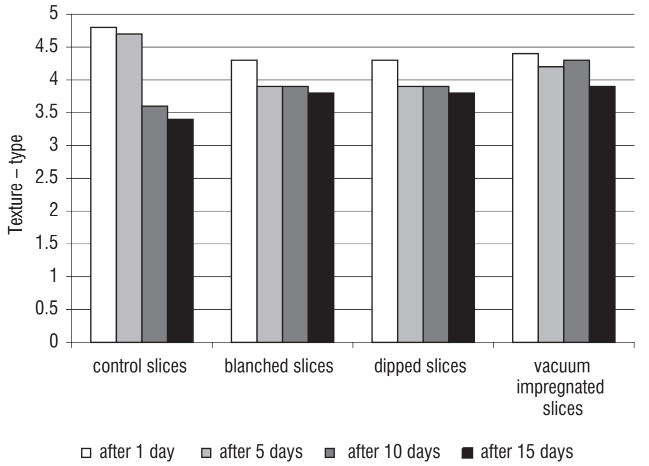


FIGURE 3. Sensory examination of texture in apple var. *Jonagold* samples subjected to 3 processing methods with a solution containing 1% ascorbic acid, 0.005% 4-hexylresorcinol, 0.5% calcium chloride, 20% sucrose.

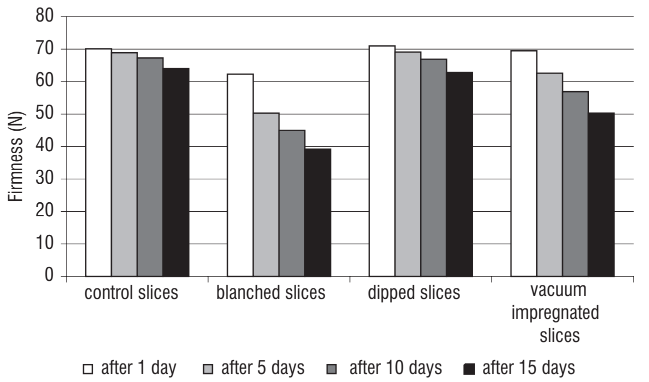


FIGURE 4. Values of sample firmness (values Fmax of 1st compression cycle) in apple var. *Jonagold* subjected to 3 processing methods with a solution containing 1% ascorbic acid, 0.005% 4-hexylresorcinol, 0.5% calcium chloride, 20% sucrose.

the fastest for the blanched samples, followed by vacuum impregnated samples, whereas the dipped samples retained the level of hardness of the control apples throughout the whole period of product storage. Figure 5 presents examples of double compression curves for samples of var. *Jonagold*, both processed and controls.

Similarly as in this study, del Valle *et al.* [1998] observed softening of apples subjected to mild blanching (temperature of 50°C) and an advantageous effect of vacuum impregnation with a calcium solution on texture. In contrast, Beveridge & Weintraub [1995] found that apple slices subjected to blanching and dipping in a solution containing SO_2, retain a similar texture to that of unprocessed samples at water activity of 0.7–0.77. Only the lowering of water activity by drying results in a definite deterioration of texture in sulfite slices, while the effect of blanching is in that case advantageous. At water activity of 0.29 the blanched samples were 2.5 times harder than the sulfite and control samples.

A large number of factors affecting texture of plant origin products is the reason for frequent decisions to undertake studies on the effect of the application of various processing and storage parameters, as well as various chemical com-

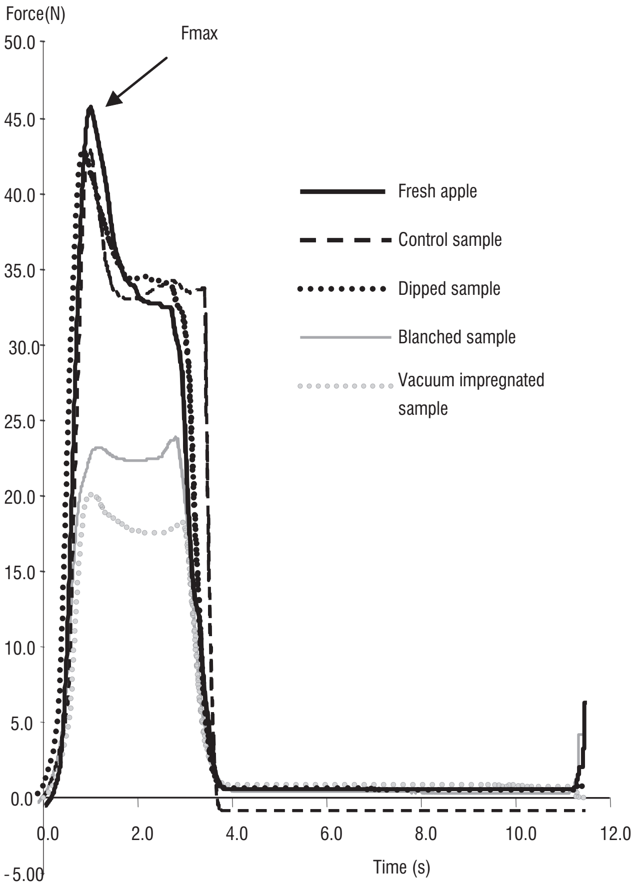


FIGURE 5. Examples of double compression curves for samples of var. *Jonagold*, both processed and controls (after 15 days of storage).

pounds in order to preserve or improve their texture. Studies have been initiated – among other things – on the determination of the effect of such processes as gamma irradiation, flesh acidification through vacuum impregnation with organic and mineral acids, or blanching and calcium impregnation in osmotically dehydrated fruits on the texture of fruits and vegetables [del Valle *et al*., 1988; Gunes *et al.*, 2001].

Dipping in calcium salt solutions inhibited softening, and partly also enzymatic browning of flesh in the case of apples, pears, strawberries, potatoes and zucchini [Izumi & Watada, 1996; Rosen & Kader, 1989]. Mc Feeters *et al*. [1985] showed an advantageous effect of hot air (50-80°C) treatment on the improvement of texture in the case of fresh-cut fruits and vegetables. Similar studies on whole apples were conducted by Lurie *et al*. [1996]. Obenland & Carrol [2000] showed the effect of mild, long-term heating of peaches and nectarines on a decrease in pectinase activity; however, they also observed an increase in mealiness of these fruits.

Microscopic analysis of apple tissue

On the basis of a microscopic image obtained in this study the tissue of fresh apples was characterised by large, elongated cells (Figure 6), with the shape factor amounting to approx. 0.77 and mean cell area of 0.029 mm^2 (29 000 μm^2) (Table 2). Numerous irregularly distributed intercellular spaces were observed as well. In control apple slices, *i.e.* not subjected to processing, no differences were observed in comparison to the fresh apples (Figure 6). Both these samples had cells with full turgor and regular shapes.

The structure of apple slices subjected to blanching differed from the structure of fresh apples and the control (Figure 6). A decreased cell turgor was observed; moreover, cells had less regular shapes. Partial depression of cell walls could also be observed. Moreover, a slight decrease was found in the value of the shape factor in the case of cells subjected to blanching in comparison to those of the fresh apples (Table 2). The values of both the smallest and biggest cell diameters decreased slightly as well.

In dipped slices no definite differences were observed in tissue structure in relation to that in the fresh apples, although the shape of cell walls was less symmetrical and distinct (Figure 6). Moreover, in this sample no significant changes were found in values of measured cell size parameters in comparison to those of the fresh apples (Table 2).

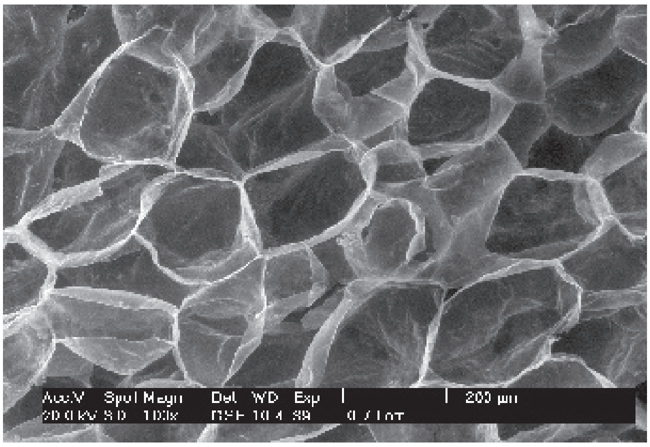
The process of deaeration and vacuum impregnation of slices resulted in a better uniformity of apple tissue structure. The size and shape of all cells within the observed flesh sectors were more uniform in comparison to those in the fresh apple and controls (Figure 6). Cells were rounder in shape than in the case of the fresh apples and an increase was observed in the values of the shape factor – from 0.77 to 0.91 (Table 2). The biggest cell diameter did not change, whereas the smallest diameter increased considerably. As a consequence, the mean value of cell area increased as well in comparison to that in the fresh apples, while the size of intercellular spaces decreased.

According to literature data the edible, fleshy part of ripe apples is composed of very large cells, which are loosely arranged and have a thin parietal cytoplasm layer and very large vacuoles filled with cell sap. In ripe apples there are very large intercellular spaces, constituting on average 25% of the volume, while in some varieties, *e.g.* Malinowa Oberlandzka, even more [Esau, 1973; Gorczyński, 1975].

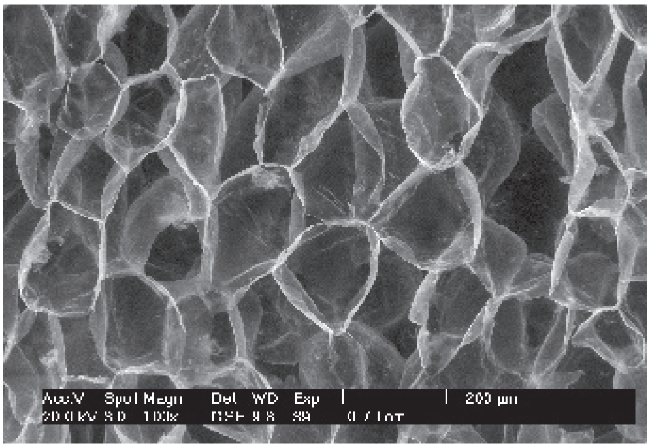
The size of cells and their area in the samples analysed in this study are consistent with literature data [Witrowa-

TABLE 2. Characteristics of the obtained images of flesh structure in fresh apples, control samples and slices subjected to minimal processing.

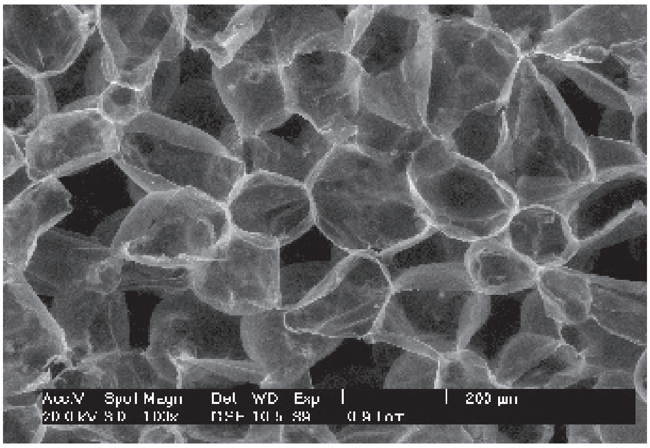
	Fresh apple	Control sample	Blanched sample	Immersed sample	Vacuum impregnated sample
The smallest cell diameter (μm)	160.3±25.8	154.0±20.9	141.8±34.0	157.0±24.4	182.3±23.6
The biggest cell diameter (μm)	209.6±37.2	203.0±29.9	193.0±37.3	201.8±33.9	203.0±30.4
Coefficient of cell shape	0.77±0.15	0.77±0.12	0.74±0.16	0.78±0.13	0.91±0.07
Cell surface area (mm^2)	0.029±0.004	0.028±0.004	0.025±0.006	0.026±0.008	0.035±0.009
Intercellular spaces (the biggest diameter) (μm)	144.4±21.4	149.4±35.0	147.2±29.1	189.6±25.0	137.5±46.5



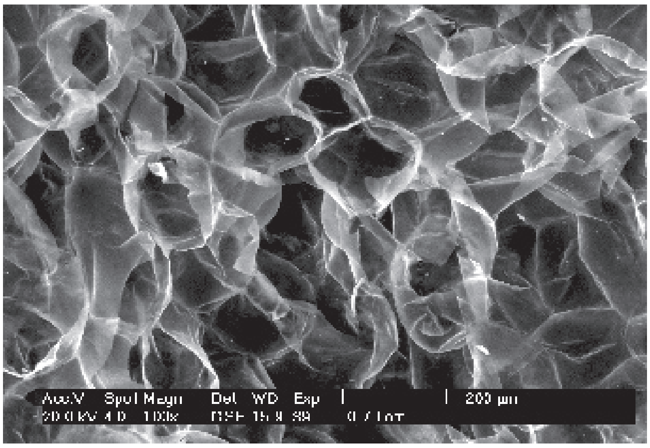
Fresh apple



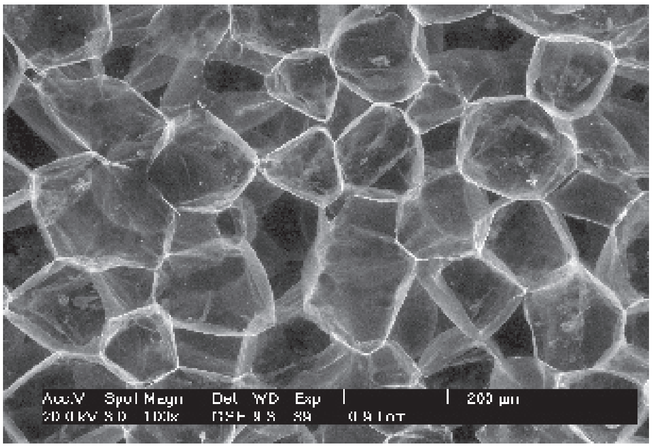
Control sample



Dipped sample



Blanched sample



Vacuum impregnated sample

FIGURE 6. The microscopic images of flesh structure in fresh apples, control samples and slices subjected to minimal processing.

-Rajchert, 1999; Erle & Schubert, 2001]. Martinez-Monzo *et al.* [1998] and Fito *et al.* [2001a, b] also observed changes in the tissue structure of apples during blanching and vacuum impregnation. Del Valle *et al.* [1998] reported that HTST and LTLT blanching resulted in cellular collapse and increased separation of cells in comparison to control samples with full turgor. Moreover, they found that HTST blanching caused bigger changes in the structure of apple flesh that prolonged mild blanching. Those authors also reported that vacuum treatment resulted in a modification of microstructure consisting in increased intercellular spaces. At vacuum treatment with a 2% calcium chloride changes in tissue structure were smaller than in the case of water infiltration.

CONCLUSIONS

Among the 10 apple varieties constituting experimental material in this study the highest values of tissue firmness were found for var. *Gala* and *Idared*, while the lowest for *Cortland* and *Szampion*. The values of hardness in apples ranged from approx. 50 to 110 N. After the application of vacuum impregnation with a solution these values increased slightly and ranged from 60 to 120 N, respectively.

After the application of 3 processing methods in apple variety *Jonagold* a deterioration of texture was found only in samples subjected to blanching. Dipped and vacuum impregnated samples exhibited hardness similar to that of control samples.

During storage of apple slices values of hardness dropped the fastest in blanched samples, followed by vacuum impregnated samples, while dipped samples retained the level of hardness of control apples throughout the whole storage period.

Blanching apple slices resulted in more distinct, disadvantageous changes in the structure of apple tissue than it was the case in the other applied processing methods. The introduction of a solution to apple flesh during vacuum impregnation resulted in the uniformity of the tissue structure.

REFERENCES

1. Anese M., Manzano M., Nicoli M.C., Quality of minimally processed apple slices using different modified atmosphere conditions. J. Food Qual., 1997, 20, 359–370.
2. De Daza M.S.T., Alzamora S.M., Chanes J.W., Combination of preservation factors applied to minimal processing of foods. Crit. Rev. Food Sci. Nutr., 1996, 36, 629.
3. Del Valle J.M., Aranguiz V., Leon H., Effects of blanching and calcium infiltration on PPO activity, texture, microstructure, and kinetics of osmotic dehydration of apple flesh. Food Res. Int., 1998, 31, 557–569.
4. Erle U., Schubert H., Combined osmotic and microwave-vacuum dehydration of apples and strawberries. J. Food Eng., 2001, 49, 193–199.
5. Esau K., Anatomia roślin. 1973, PWRiL, Warszawa, pp. 730–741 (in Polish).
6. Everson H.P., Waldron K.W., Geeson J.D., Browne K.M., Effects of modified atmospheres on textural and cell wall changes of asparagus during shelf-life. Int. J. Food Sci. Technol., 1992, 27, 187–199.
7. Fito P., Chiraldt A., Betoret N., Gras M., Chafer M., Martinez--Monzo J., Andres A., Vidal D., Vacuum impregnation and osmotic dehydration in matrix engineering application in functional fresh food development. J. Food Eng., 2001a, 49, 175–183.
8. Fito P., Chiralt A., Barat J.M., Andres A., Martinez-Monzo J., Martinez-Navarrete N., Vacuum impregnation for development of new dehydrated products. J. Food Eng., 2001b, 297–302.
9. Gorczyński T., Ćwiczenia z botaniki. 1975, PWN, Warszawa, pp. 227–229 (in Polish).
10. Gunes G., Hotchkiss J.H., Watkins C.B., Effect of gamma irradiation on the texture of minimally processed apple slices. J. Food Sci., 2001, 66, 63–67.
11. Guzman I.L., Cantwell M., Barret D.M., Fresh-cut cantaloupe: effect of $CaCl_2$ dips and heat treatments on firmness and metabolic activity. Posth. Biol. Technol., 1999, 17, 201–213.
12. Izumi H., Watada A.E., Calcium treatment to maintain quality of zucchini squash slices. J. Food Sci., 1996, 60, 789–793.
13. Kim D.M., Smith N.L., Lee C.Y., Apple cultivar variations in response to heat treatment and minimal processing. J. Food Sci., 1994, 58, 1111–1114.
14. Lurie S., Nussinovitch A., Compression characteristics, firmness, and texture perception of heat treated and unheated apples. Int. J. Food Sci. Technol., 1996, 31, 1–5.
15. Martinez-Monzo J., Martinez-Navrrete N., Chiralt A., Fito P., Mechanical and structural changes in apple (var. Granny Smith) due to vacuum impregnation with cryoprotectants. J. Food Sci., 1998, 63, 499–502.
16. McFeeters R.F., Changes in pectin and cellulose during processing. 1985, *in*: Chemical Changes in Food during Processing (eds. T. Richardson), J. W. Finley. AVI Pub. Co., Westport, Conn., pp. 347–372.
17. Obenland D.M., Carrol T.R., Mealiness and pectolytic activity in peaches and nectarines in response to heat treatment and cold storage. J. Amer. Soc. Hort. Sci., 2000, 125, 723–728.
18. Powrie W., Skura B., Modified atmosphere packaging of fruits and vegetables. 1997, *in*: Modified Atmosphere Packaging of Food (eds. B. Ooraikul, B. Stiles). Ellis Horwood, London, p. 167.
19. Rosen J.C., Kader A.A., Postharvest physiology and quality maintenance of sliced pear and strawberry fruits. J. Food Sci., 1989, 57, 656–59.
20. Soliva-Fortuny R.C., Oms-Oliu G., Martin-Belloso O., Effect of ripeness stages on the storage atmosphere, color, and textural properties of minimally processed apple slices. J. Food Sci., 2002, 67, 1958–1963.
21. Witrowa-Rajchert D., Rehydration as an indicator of changes occurring in plant flesh during drying. 1999, Fundacja Rozwój SGGW, Warszawa, pp. 59–71 (in Polish).

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WPŁYW MINIMALNEGO PRZETWARZANIA NA ZMIANY TEKSTURY PLASTRÓW JABŁEK PAKOWANYCH PRÓŻNIOWO

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W pracy określono zmiany tekstury i mikrostruktury tkanki jabłek pod wpływem procesu minimalnego przetwarzania polegającego na zanurzaniu, blanszowaniu oraz nasączaniu próżniowym roztworem zawierającym kwas askorbinowy, 4-heksylrezorcynol, chlorek wapnia i sacharozę. Spośród 10 badanych odmian jabłek świeżych największą twardością tkanki charakteryzowały się odmiany Gala i Idared (rys. 1), odmiany te odznaczały się również najlepszą teksturą po zastosowaniu nasączania próżniowego (rys. 2). Największe zmiany zarówno w teksturze jak i mikrostrukturze tkanki jabłek powodowało blanszowanie w stosowanym roztworze, najmniejsze zanurzanie (rys. 3, 4, 6). Proces nasączania próżniowego nadał większą jednolitość mikrostrukturze tkanki plastrów jabłek (rys. 6), natomiast wartości twardości tych plastrów zmniejszały się w czasie przechowywania produktu.