Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food Chemistry 93 (2005) 681–687
Food Chemistry
www.elsevier.com/locate/foodchem

Structural changes of potato tissue during French fries production

Grażyna Lisińska *, Grażyna Gołubowska

Department of Food Storage and Technology, Faculty of Food Sciences, Agricultural University of Wrocław ul. C.K. Norwida 25, 50-375 Wrocław, Poland

Received 28 June 2004; received in revised form 20 October 2004; accepted 20 October 2004

Abstract

The purpose of the study was to determine some changes in the structure of potato tissue and the contents of non-starch polysaccharides and lignin in potatoes at particular stages of French fries production. The samples for laboratory studies were taken from potato tubers, strips and French fries collected from six locations of the technological line. Immediately after the samples were collected from the processing line, the texture of potatoes was determined using an Instron 5544. Structural changes in the tissue were determined using a Leo-435VP scanning electron microscope. Dry matter and non-starch polysaccharide contents were determined in the samples of processed potatoes. It was found that the texture of potato was changing during the technological process due to water losses and damages of potato tissue and consequent changes in non-starch polysaccharides and lignin. The greatest changes in potato tissue resulted from thermal processes: blanching, pre-drying and frying. Increases of non-starch polysaccharide and lignin contents were observed during these processes, owing to water losses in potato strips. The ultimate texture of French fries was developed during frying, by penetration of fat primarily into the external layer of strips.

Keywords: Potato tuber; French fries; French fries processing line; Tissue structure; Texture; Non-starch polysaccharides; Lignin

1. Introduction

Processing of plant raw materials causes irreversible changes in the tissues of fruit and vegetables. These changes are particularly visible after heat treatment, and their intensity depends on temperatures during blanching, drying and frying. Turgor of fresh plant tissues depends, among others, on ratios and distribution of chemical constituents in the cell wall and intracellular spaces. These constituents include: cellulose, hemicelluloses and pectins, generally referred to as non-starch polysaccharides (NSP) and lignin (Fennema, 1996). The cellular structure of external tissues of vegetables is partially damaged during blanching, and besides, the content of pectic substances is reduced, proteins are denatured, enzymes are inactivated and chemical constituents soluble in water are partially washed out (Jeremiah, 1996).

Apart from starch, texture-forming components of potatoes are NSP and lignin (Andersson, Gekas, Lind, Oliveira, & Oste, 1994), which account for almost one half the non-starch dry matter of the potato (Lisińska & Leszczyński, 1989). These compounds, not only influence the nutritive value of the product, but also the organoleptic features, especially the texture. The technological parameters used during processing also affect the content and composition of NSP and lignin. Thermal processes (blanching, pre-drying and frying) during French fries manufacturing cause the occurrence of a "skeleton" (consisting of varied proportions of carbohydrate compounds) in potato tissue, which is likely responsible for the texture of the finished

* Corresponding author. Tel.: +48 71 320 5239; fax: +48 71 320 5221.
E-mail address: lisinska@wnoz.ar.wroc.pl (G. Lisińska).

0308-8146/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2004.10.046

product (Gołubowska & Lisińska, 2003). In recent years, extensive studies have been carried out on the microstructure of food products, using electron microscopy for a better knowledge of textural properties of such products. Identification of the basic components of the microstructure of the raw material and half-products obtained at a given stage of French fries production, along with the content of NSP, will expand our knowledge of their texture-forming properties.

The purpose of the present study was to determine some changes in the structure of potato tissue and NSP and lignin contents of potatoes at a given stage of French fries production.

2. Materials and methods

2.1. Samples

The samples collected for laboratory studies consisted of potato tubers, potato strips and French fries (2 kg each) from six locations on the French fries processing line. Sample 1 consisted of potatoes before peeling, sample 2 steam-peeled potatoes, sample 3 potato strips (0.7 cm × 0.7 cm) by hydro-cutting, sample 4 after blanching at 80 °C for 5.0 min, sample 5 pre-dried potato strips at 37 °C for 6.0 min, and sample 6 French fries after frying at 180 °C for 7 min.

2.2. Analysis

Immediately after the samples were collected from the processing line, the texture of potatoes was determined using an Instron 5544 apparatus connected to a computer equipped with a rectangular attachment for cutting. The velocity of the head with the attachment was 250 mm/s. The measurements were taken for determining maximum shear force (F_{max}) necessary to cut the potato strips.

Changes in the structure of potato tissue were determined in potato tubers, strips and French fries, using a Leo-435VP scanning electron microscope. The samples for SEM were fixed immediately after handling, by freezing in liquid nitrogen and spraying with gold. NSP and lignin contents were determined by the Dever, Bandurski, and Kiviliaan (1968) method, modified by Jaswal (1970) and Tajner-Czopek et al. (1997) after freeze–drying of the potato samples.

2.3. Statistical analysis

The data were analyzed statistically using a Statistica 6 programme (2001). For comparison, the results obtained were analyzed using one-way analysis of variance with the application of Duncan's test ($P \leqslant 0.05$).

3. Results and discussion

Table 1 shows that dry matter content of potatoes did not change at the initial stages of processing. Both the raw material and peeled, cut and blanched potatoes contained about 21% of dry matter. The final processes of French fries manufacturing caused partial dehydration of potato strips. A half-product after pre-drying contained 25% of dry matter and French fries ready for consumption contained 55% of dry matter.

During French fries processing, the structure of potato tissue is markedly and irreversibly changed. Figs. 1–8 show some changes in the microstructure of the raw material at consecutive stages of processing. Fig. 1 shows the cross-section of a potato tuber with a thin layer of skin and a group of flesh cells with starch granules. The cells of the skin are compact, have no starch granules and resemble "cork" structure. At the same time, the contents of NSP and lignin were changing in potato tubers, half-products and French fries (Table 1) as also was the texture of the processed potatoes (Fig. 9). There are few literature reports on changes on non-starch polysaccharide and lignin contents of potatoes, half- and finished potato products resulting from technological processing. In general, the authors study the changes occurring during one stage of processing, e.g. peeling or blanching. Lisińska and Leszczyński (1989) report that the sum of NSP and lignin makes up almost half the non-starch dry matter content of the potato. Total content of these compounds in potato dry matter is varied and amounts to 8.58% (Anderson & Bridges, 1988), 6.70% (Englyst & Hudson, 1996) and from 6.16% to 7.28%, depending on potato cultivar (Tajner-Czopek, Kita, Rytel, & Gołubowska, 2002). In the present study, NSP and lignin content of dry matter of the raw material before peeling was about 10.9%.

One of the first stages of potato processing is peeling. Kita (2002) and Garrote et al. (2000) report that the compounds present in NSP and lignin content are subject to quantitative changes during peeling. Kita (2002) reports that the quantity of NSP and lignin decreased by 30% after peeling by a carboround method and greatest losses were observed in the cellulose fraction (from 70% to 40%) and lignin (about 30%). In the present

Table 1
Content of dry matter and non-starch polysaccharides (NSP) and lignin in potato tubers during French fries processing

Samples	Dry matter (%)	NSP and lignin (% d.m.)
Potato not peeled	21.0a	10.9a
Potato after peeling	22.0a	11.1a
Potato after cutting	20.7a	10.8a
Strips after blanching	21.2a	15.8b
Strips after pre-drying	24.8b	15.8b
French fries after frying	55.3c	17.1c

a–d, significant differences; $P \leqslant 0{,}05$.

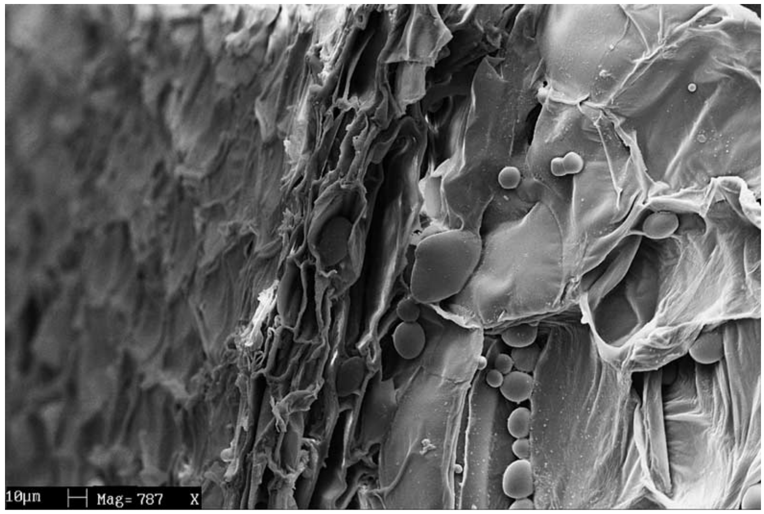

Fig. 1. Cross-section of a potato tuber with a thin layer of skin and a group of flesh cells with starch granules.

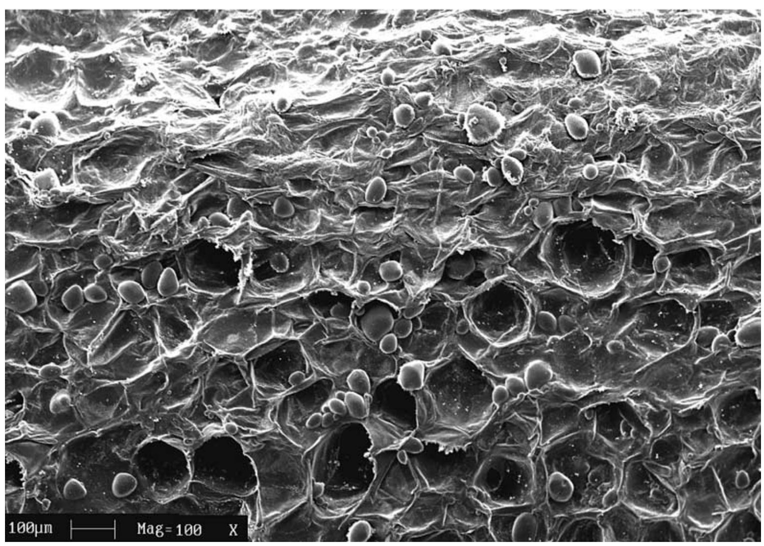

Fig. 2. Cross-section of the potato after steam-peeling.

study, the potatoes were steam-peeled and no significant changes were observed in polysaccharides and lignin contents of the raw material before and after peeling. Fig. 2 shows a cross-section of the potato after steam-peeling. Starch present in the outer layer of the tuber is pasted and forms an impermeable layer, which probably inhibits transport of soluble constituents of potato tubers to water. Camire, Violette, Dougherty, and McLaughlin (1997) compared the contents of some potato constituents, depending on peeling method, and found higher contents of carbohydrates and insoluble substances in steam-peeled than in mechanically-peeled potatoes.

The next technological process, "hydro-cutting" of potatoes into strips, caused mechanical damage of cells on the outer surface of the strips. The deeper layers of the strips contain non-deformed flesh cells with starch granules (Fig. 3). After the process, the strips exhibited lower hardness (31 N) than did potatoes after peeling (35.5 N). The changes in texture were likely due to partial washing out of insoluble constituents (e.g. starch, protein) which fell out from the damaged (open) cells of the outer layer of strips.

After blanching, starch swelling occurred in the outer layers of strips, along with an enormous increase in their volume (Fig. 4.). Pre-drying of potato strips resulted in further destruction of potato tissue. Fig. 5 shows swollen starch granules, also in the inner layers of strips. After blanching and pre-drying (Fig. 9), the texture of potato strips was softer (24.8 N) than that of potatoes after blanching (31 N). The reduction in hardness of the potato strips was likely due to partial pasting of starch. According to Mate, Quartaert, Meerdink, and van't Riet (1998), it is in the first 2 min of blanching

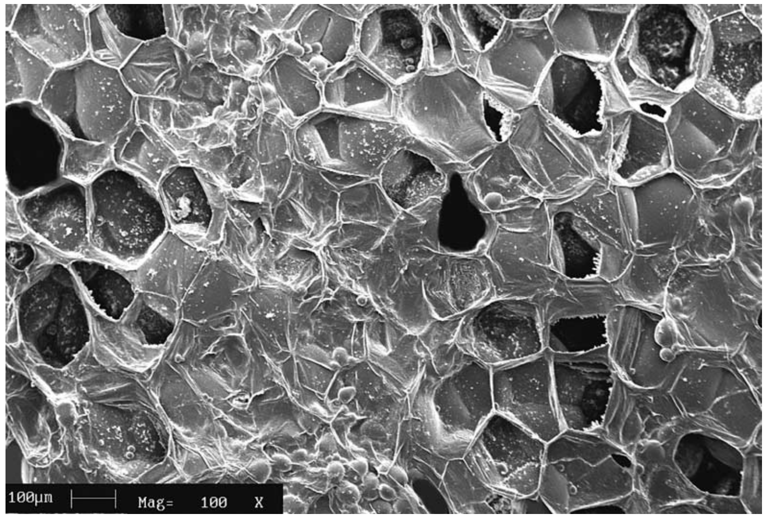

Fig. 3. Outer surface of the strips after "hydro-cutting". The deeper layers of the strips contain un-deformed flesh cells with starch granules.

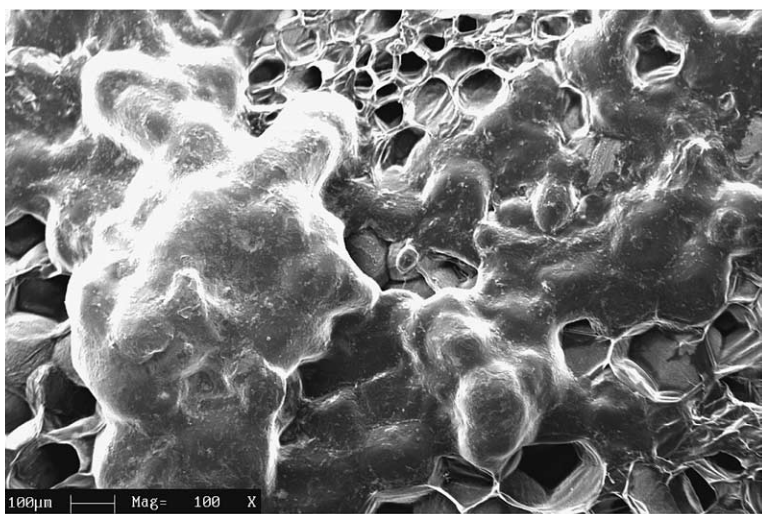

Fig. 4. The strips after blanching; starch swelling occurred in the outer layer of strips, along with enormous increase in their volume.

when the structure of potato tissue is loosened and the changes are significant compared to those observed during further minutes of heating. The technological parameters used for blanching significantly affect the texture of plant tissue and, consequently the texture of French fries (Alvarez & Canet, 1999).

NSP and lignin contents of potato strips after blanching and pre-drying (Table 1) were about 16% higher in dry matter, while their contents in dry matter of French fries were 17% higher. Similar changes in non-polysaccharides and lignin contents of potatoes after heat-treatment were observed by Johnston and Oliver (1982); Varo, Veijalaainen, and Koivistoinen (1984); Thed and Phillips (1995); Herranz, Vidal-Valverde, and Rojas-Hidalgo (1983); Gołubowska and Lisińska (2003). According to Asp (1996), the increases in the sum of NSP in potatoes during heat treatment are likely due to the losses of non-fibre substances. Thed and Phillips (1995) report that microwave cooking of potatoes in frying oil increases the content of NSP constituents insoluble in water and lignin, while cooking and baking decrease the contents of these constituents in potato tubers.

Consumers like French fries with crispy, delicate surface, golden colour and free of oily taste (Lisińska & Leszczyński, 1989). According to the requirements of fast-food restaurants, French fries, after frying in oil, should maintain crispiness for 5–10 min (Anonym, 2002). According to Aguilera and Gloria (2000), the development of crispy structure begins with pre-drying, and next for the first 60 s of frying. Crispy surface is developed due to the migration of oil to intracellular spaces formed during frying as a result of cell wall shrinkage and water evaporation (Costa Rui, Oliveira Fernanda, & Boutcheva, 2001). Aguilera, Cadoche, Lopez, and Gutierrez (2001) report that starch granules are subject to rapid pasting during frying, so that they fill

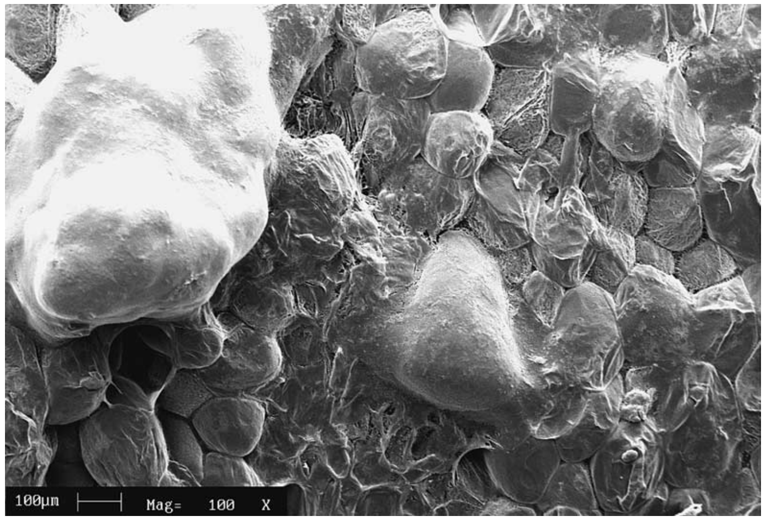

Fig. 5. The strips after pre-drying – further destruction of potato tissue.

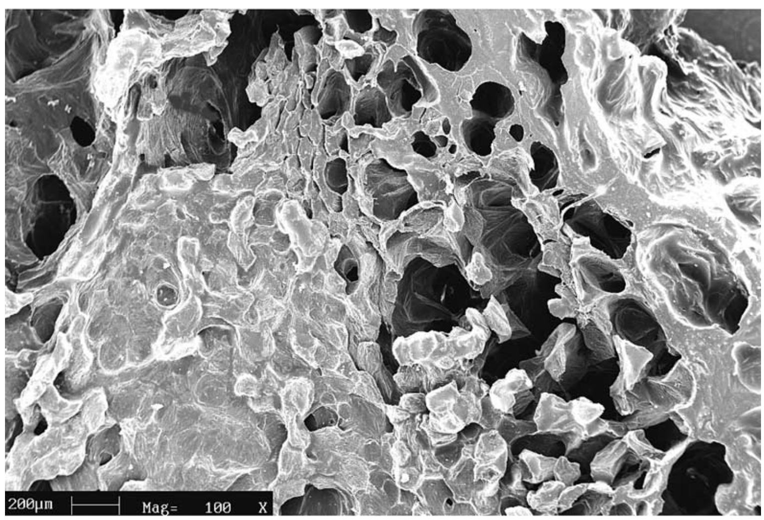

Fig. 6. Cross-section of a fried potato strip with flesh (inner part) and skin (outer part).

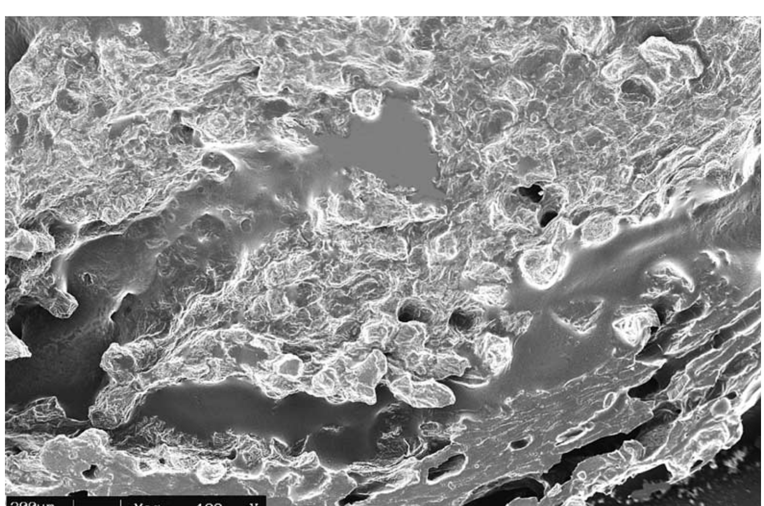

Fig. 7. Outer surface of French fries. Distribution of fat in French fries is not uniform; the largest deposits of fat can be seen close to the outer portion of flesh.

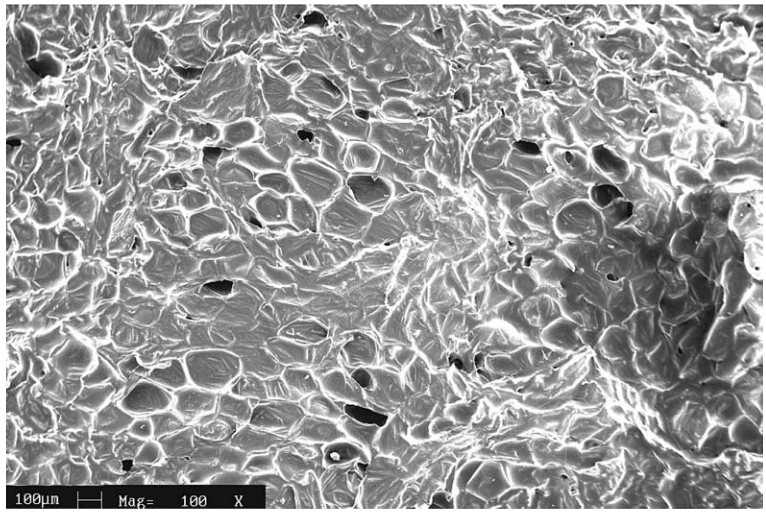

Fig. 8. Outer surface of French fries.

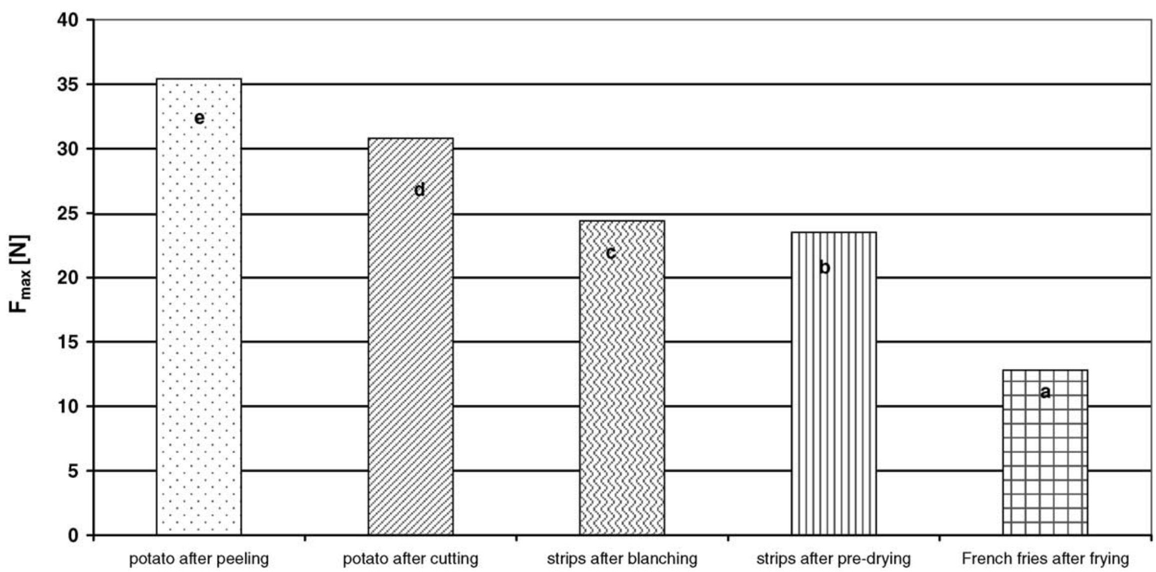

Fig. 9. Changes in potato texture [N] during French fries processing. Different letters indicate significant differences ($P \leqslant 0{,}05$).

the entire surface of the cell without causing any damage.

Fig. 6 shows the cross-section of a fried potato strip with flesh (inner part) and skin (outer part). Frying caused partial separation of cells, which is particularly clear in the areas where flesh is transformed into skin. Distribution of fat in French fries is not uniform; the largest deposits of fat can be seen close to the outer portion of flesh (Fig. 7). Aguilera and Gloria (2000) report that fat content of skin is about 25% higher than that of flesh. According to them, at the initial stage of frying, French fries absorb 70–80% of the oil present in the finished product after frying. When we compare the tissue of fresh potato (Fig.1) with that after frying (Figs. 6–8), irreversible changes can be seen in potato structure. The cells of the skin of French fries (Fig. 8) are much smaller than those of fresh potato, due to water evaporation during thermal processes. This destructive effect of frying on potato tissue, and parallel permeability of fat into the outer layer of potato strips, has a decisive impact on the ultimate texture of French fries. The texture of French fries suitable for consumption, expressed as force N necessary to cut a strip, was 13 N (Fig. 1).

4. Conclusions

It was found that potato texture during French fries production was changing due to water losses, damage of potato tissue and changes in NSP and lignin contents. The greatest changes in potato tissue resulted from thermal processes: blanching, pre-drying and frying. Water losses of potato strips during these processes increased non-starch polysaccharide and lignin contents of the finished product. The ultimate texture of French fries was developed during frying, by penetration of fat primarily into the external layer of strips.

References

Aguilera, J. M., & Gloria, H. (2000). Oil absorption during frying of frozen par fried potatoes. *Journal of Food Science, 65*, 476–479.

Aguilera, J. M., Cadoche, L., Lopez, C., & Gutierrez, G. (2001). Microstructural changes of potato cells and starch granules heated in oil. *Food Research International, 34*, 939–947.

Alvarez, M. D., & Canet, W. (1999). Optimization of stepwise blanching of frozen–thawed potato tissues (cv. Monalisa). *European Food Research Technology, 210*, 102–108.

Anderson, J. W., & Bridges, S. R. (1988). Dietary fiber content of selected foods. *American Journal Clinical Nutrification, 47*, 440–447.

Andersson, A., Gekas, V., Lind, I., Oliveira, F., & Oste, R. (1994). Effect of preheating on potato texture. *Critical Reviews in Food Science and Nutrition, 34*, 229–251.

Anon, (2002). Not just hot air. *Potato Business World* 10, 17–24.

Asp, N. G. (1996). Dietary carbohydrates classification by chemistry and physiology. *Food Chemistry, 57*, 9–14.

Camire, M. E., Violette, D., Dougherty, M. P., & McLaughlin, M. A. (1997). Potato peel dietary fiber composition: effects of peeling and extrusion cooking processes. *Journal of Agricultural and Food Chemistry, 45*, 1404–1408.

Costa Rui, M., Oliveira Fernanda, A. R., & Boutcheva, G. (2001). Structural changes and shrinkage of potato during frying. *International Journal of Food Science and Technology, 36*, 11–23.

Dever, J. E., Bandurski, R. S, & Kiviliaan, A. (1968). Partial chemical characterization of corn root cell walls. *Plant Physiology, 43*, 50–56.

Englyst, H. N., & Hudson, G. J. (1996). The classification and measurement of dietary carbohydrates. *Food Chemistry, 57*(1), 15–21.

Fennema, O. R. (1996). *Food chemistry* (3rd ed.). New York, Basel, Hong Kong: Marcel Dekker Inc..

Garrote, R. L., Silva, R. E., & Bertone, R. A. (2000). Effect of thermal treatment on steam peeled potatoes. *Journal of Food Engineering, 45*, 67–76.

Gołubowska, G., & Lisińska, G. (2003). Changes in contents of non-starch polysaccharides and lignin in potato tubers during the French fries processing (In polish). *Żywność, Nauka, Technologia, Jakość, 1*(34), 91–98.

Herranz, J., Vidal-Valverde, C., & Rojas-Hidalgo, E. (1983). Cellulose, hemicelluloses and lignin content of raw and cooked processed vegetables. *Journal of Food Science, 48*, 274–276.

Jaswal, A. S. (1970). Non-starch polysaccharides and the texture of French fried potato. *American Potato Journal, 47*, 311–316.

Jeremiah, L. E. (1996). *Freezing effects on food quality*. New York, Basel, Hong Kong: Marcel Dekker Inc..

Johnston, D. E., & Oliver, W. T. (1982). The influence of cooking technique on dietary fiber of boiled potato. *Journal of Food Technology, 17*, 99–107.

Kita, A. (2002). The influence of potato chemical composition on crisp texture. *Food Chemistry, 76*, 173–179.

Lisińska, G., & Leszczyński, W. (1989). *Potato science and technology*. London, New York: Elsevier Applied Science.

Mate, J. I., Quartaert, C., Meerdink, G., & van't Riet, K. (1998). Effect of blanching on structural quality of dried potato slices. *Journal of Agricultural and Food Chemistry, 46*, 676–681.

Tajner-Czopek, A., Kita, A., Lisińska, G. (1997). Determination of non-starch polysaccharides in potato tubers. (in polish) *XXVIII scientific session materials "The progress in food technology and chemistry"*, Gdańsk, pp. 270–271.

Tajner-Czopek, A., Kita, A., Rytel, E., & Gołubowska, G. (2002). The content of non-starch polysaccharides and lignin in potato tubers of varieties differing in their lenght of vegetation time (In polish). *Advances of Agricultural Sciences Problem Issues, 489*, 291–301.

Thed, S. T., & Phillips, R. D. (1995). Changes of dietary fiber and starch composition of processed potato products during domestic cooking. *Food Chemistry, 52*, 301–307.

Varo, P., Veijalaainen, K., & Koivistoinen, P. (1984). Effects of heat treatment on the dietary fiber contents of potato and tomato. *Journal Food Technology, 19*, 485–492.