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EFFECT OF THE CONTENT OF POTATO NON-STARCH POLYSACCHARIDES (NSP) AND LIGNIN ON THE MECHANICAL PROPERTIES OF FRENCH FRIES

Agnieszka Tajner-Czopek[1], Adam Figiel[2]*

[1]Department of Food Storage and Technology,
[2]Institute of Agricultural Engineering; Agricultural University, Wrocław, Poland

Key words: Non-starch polysaccharides (NSP), lignin, mechanical properties: shear stress, work, the texture of French fries.

The role of non-starch polysaccharides (NSP) and lignin in shaping the texture of fried products has not been investigated in details yet. These compounds, which accompany dry matter and starch, are a building material of cell walls and can play a crucial role in the texture of French fries. The aim of the work was to determine the relationship between French fry textures shaped by their mechanical properties (shear stress and shear work) and the content of particular non--starch polysaccharides (NSP) and lignin components. It was found that the tubers of the investigated potato varieties contained different amounts of non-starch polysaccharides and lignin, as well as their total amounts. The quantity of NSP fractions and lignin and their totals in French fries was higher than in the raw material. French fry textures depended on the contents of NSP and lignin. Acceptable textures were found in French fries produced from potato tubers of the Bryza and Mila variety, which had only average values of their mechanical properties. The most significant effect on shaping French fry texture was that of NSP and lignin fraction total − nearly 37% in the model, 28% for lignin, 25% for hemicelluloses and 10.2% for pectin. The values of shear stress and shear work were strictly dependent on the data for French fry texture and remained in a directly proportional relation.

INTRODUCTION

For potato chemical components, special attention should be paid to cell wall building elements, *i.e.* non-starch polysaccharides (NSP) and lignin, commonly called "raw fiber" or dietary fiber. The content of dietary fiber in plant tissues varies and depends on the source of origin: vegetables, fruit and cereal products. NSP and lignin contents in potato tubers account for about half of the dry non-starch tuber mass [Lisińska & Leszczyński, 1989].

Non-starch polysaccharides, involving cellulose, hemicelluloses and pectins as the most important components, are carbohydrates from a chemical point of view. Lignin on the other hand is a isophenylopropane polymer [Kowalczyk & Żebrowska, 1997]. Among potato non-starch polysaccharides, the cellulose fraction occurs in the highest amount and depending on the particular potato variety, its value ranges from 0.45% to 0.7% in raw tuber masses [Lewosz *et al.,* 1976].

The remaining fractions of dietary fiber are hemicelluloses − accounting for 0.32-0.46% of potato mass and pectin substances to be found in plant cell walls and intercellular spaces ranging from 0.32-0.38% in fresh masses of potato tubers [Kita, 2002].

A less numerous fraction of dietary fiber is lignin. It accumulates on cell walls in the final stage of cell growth and strengthens cell wall construction through tight binding with cellulose fibers, which prevents its damage [Hasik *et al*., 1997]. Kita [2002] reports that lignin content in potato tubers varies from 0.15% to 0.22%, while according to Tajner-Czopek [2000] its percentage ranges from 0.16% to 0.25%.

The dietary properties of non-starch polysaccharides (NSP) and lignin [Hasik *et al*., 1997], have already been recognized, while there have been studies into the effect of the concentration of these substances on the sensory features of potato fried products [Kita, 2002; Tajner-Czopek, 2003]. One of the main sensory features of the products is their texture (consistence). Definitions regarding texture and consistence are still quite broad, yet not strictly determined notions, although numerous authors have made efforts to precisely define them [Bourne & Szcześniak, 1993; Kołożyn-Krajewska, 1995; Baryłko-Pikielna & Janicki, 1997]. So far in literature there has not been a strict distinction between the terms "texture" and "consistence", therefore they have remained terms in parallel use.

The texture of fried products made of potatoes, *i.e*. French fries and chips, can be determined on the basis of sensory estimation, as well as with the use of objective (instrumental) methods using Stevens QTS or Instron [Kołożyn-Krajewska, 1995]. Measurement of french fries by an objective method enables the determination of selected properties: maximum shearing force [F_{max}], shear stress [τ_{max}] and shear work [ω] needed to obtain maximum shear stress. These factors constitute the basic parameters which can be obtained by the shearing of material with the use of a knife of determined blade geometry [Sitkei, 1986; Lin *et al.*, 1998; Figiel & Frontczak, 2001] or a plate under conditions of technological shearing. The shift of a shearing tool from the moment of touching shorn material results in an increase in shearing force values. The maximum values of shearing force, shear stress and shear work are mechanical properties which are important in assessing raw material dam-

* Author's address for correspondence: Agnieszka Tajner-Czopek, Agricultural University of Wrocław, Faculty of Food Storage and Technology, Norwida Str. 25/27, 50-375 Wrocaw, Poland, e-mail: Tajner@wnoz.ar.wroc.pl; fax: (48 71) 320 52 21

aged when harvested or transported [Gieroba & Dreszer, 1993] and the texture of the ready product for evaluation.

Two notions contribute to French fry texture: external texture – crispness, and internal texture – internal mealiness. The external layer should not be tough, skinny or ruby, while the inter part should feature mealiness without any impression of being watery or gluey and it should not separate from the other layer [Lisińska, 1994]. Products featuring such a texture can be obtained in the course of the appropriately carried out technological process of French fry production, but primarily its texture depends on the physical properties and chemical composition of the raw material used [Burton, 1989; Lisińska & Leszczyński, 1989; Jaswal, 1991]. The textures of fried potato products are shaped by the tubers' dry matter and starch content, as well as the building components of cell walls, *i.e.* non-starch polysaccharides (NSP) and lignin.

The aim of this study was to determine the relationship between French fry texture shaped by mechanical properties (shear stress and shear work) and the content of particular non-starch polysaccharides (NSP) and lignin components.

MATERIAL AND METHODS

For the investigation, tubers of six potato cultivars: Aster (very early), Mila (middle-early), Ania, Arkadia, Bryza and Saturna (middle-late) were used. As the subject for investigation, potatoes were collected from the experimental fields owned by the Department of Crop Production of Agricultural University in Wrocław. The tubers of all potato varieties were harvested at random from fields in full physiological maturity and the samples of about 20 kg weight were prepared. Immediately after harvesting they underwent laboratory analysis.

Each potato sample was processed into French fries using two-stage frying methods. After the material had been frozen at a temperature of -18^{0}C, each of the samples of the tubers and French fries underwent drying with the use of a 4K Modulyo Lyophilizing cabinet produced by the Ewards company. In a ground lyophilizate made of potatoes and degreased (fat-free) French fries, the particular fractions of non-starch polysaccharides (pectins, hemicelluloses and cellulose) and lignin itself by the method of fractioning were determined [Jaswal, 1991; Tajner-Czopek, 2000]. Pectin substances were subsequently separated through extraction with the ammonium oxalate of the homogenizate, devoid of soluble compounds in alcohol and starch (reaction with α--amylase). After this, hemicellulose fractions were separated by soda lye extraction, while for the separation of lignin fraction concentrated sulphuric acid was used. Cellulose constituted the final fraction (in the process).

After 5-min frying, the texture was determined using a Steven's type QTS-25 apparatus provided with a cutting attachment QTS-25-SB "Share blade". The cutting attachment was moving at the speed of 250 mm/min^{-1}. Fifteen French fries were taken for repeated laboratory measurements. All samples were cut in half. The maximum force [N] required for French fries to be cut from a force-time curve was determined. The highest peak force was determined for French fry texture and firmness. Simultaneously, the shear stress and work were determined. Shear stress (τ_{max}) is the force action, expressed in units of force per unit area. The work [ω] was determined by measuring the area under the curve [Bourne, 1982].

The results obtained were subject to a statistical analysis with the use of the Statgraphics v.6.0. program. Homogenous groups were determined by a Tuckey test (at a significance level of $\alpha = 0.05$). The correlation coefficient between French fries texture and the contents of their particular fractions of non-starch polysaccharides (NSP) and lignin were calculated, as well as their sums. To investigate the dependence of the effect of particular NSP fractions and lignin on French fries texture, an analysis was used of multiplied regressions for a linear model and the share of particular components in a given model was presented.

RESULTS AND DISCUSSION

The investigated potato varieties featured different contents of particular NSP fractions and lignin, as well as their total values (Figure 1). The content of non-starch polysaccharides and lignin sum in the investigation ranged from 6.21% to 7.94% of tuber dry matter and reached similar values to the results obtained by other authors: Englyst & Hudson [1996] who reported values of 6.7% and Anderson *et al.* [1994] of 8.58%, depending on the potato variety used. The Aster variety (very early) had the lowest NSP and lignin total content at 6.21% d.m., which also contained the lowest number of hemicellulose fractions (1.56% d.m.) and lignin (0.76% d.m.) (Figure 1). Ania variety (middle late) potato tubers contained more hemicelluloses (by 30%), lignin (by 35%) and total NSP and lignin fractions (by about 22%) than potato tubers of the Aster variety.

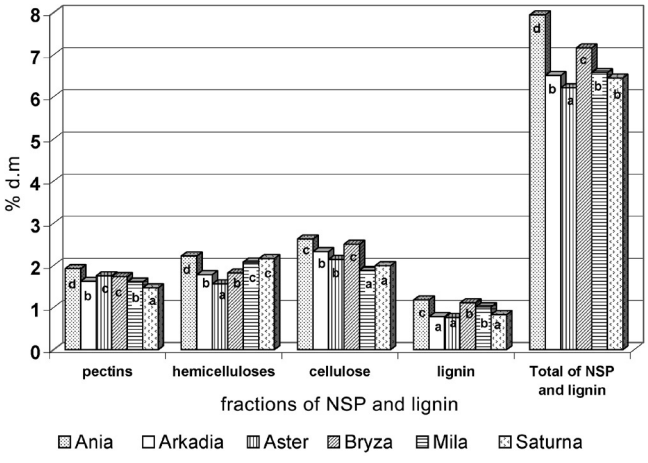

FIGURE 1. The content of non-starch polysaccharides (NSP) and lignin in dry matter of six varieties of potato tubers.

The content of non-starch polysaccharides and lignin in French fries made of potato tubers of the varieties under investigation are shown in Figure 2. It was stated that the content of NSP and total lignin in French fries ranged from 6.21% d.m. (Aster variety) to 8.17% d.m. (Ania variety). On the basis of the results presented in Figures 1 and 2, it could be stated that the French fries generally contained higher amounts of total NSP and lignin than raw material. Thed & Philips [1995] noticed that frying potatoes in oil resulted in an increase in

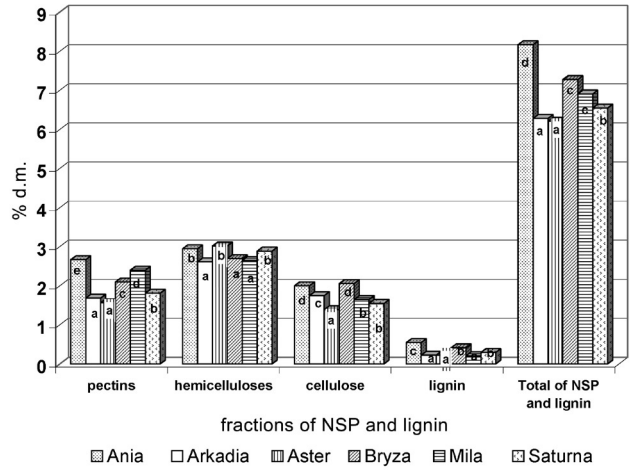

FIGURE 2. The content of non-starch polysaccharides (NSP) and lignin in dry matter of prepared French fries from six varieties of potato tubers.

water insoluble cellulose components. Thermal processes, *i.e.* blanching, cooking or frying which potatoes undergo in the process of production can cause an increase in NSP and lignin content [Thed & Philips, 1995; Asp, 1996].

The results of texture determination [N] in French fries made of the tubers of six potato varieties are shown on Figure 3. The results obtained regarding the texture of ready product ranged from 15.39 N (French fries - of Aster variety, featuring too soft texture) to 22.84 N (French fries of the Ania variety, too tough texture). French fries obtained from potato tubers of the Ania variety contained the highest amount of non-starch polysaccharides (NSP) and lignin of all the investigated samples, while French fries produced from Aster potato tubers featured the lowest content of those compounds and had the lowest amount of these substances in raw material (Figure 1 and Figure 2).

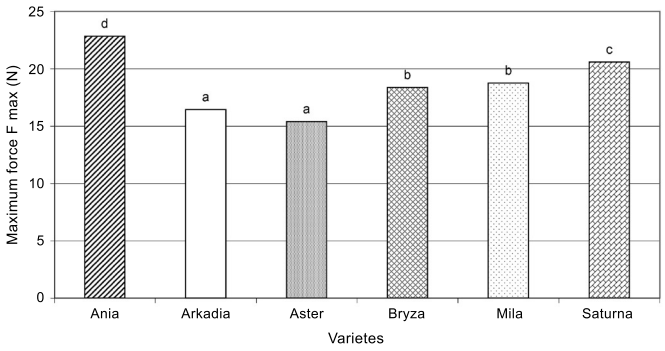

FIGURE 3. The comparison of the texture [N] of French fries prepared from potato tubers of six varieties by the usage of Stevens QTS-25 apparatus.

French fries made of Bryza and Mila potato tubers had an appropriate texture, while NSP and lignin sum content in the ready product reached an average level of about 7% d.m. It was assumed in this study that non-starch polysaccharides and lignin content in potato tubers effected the shaping of the texture of ready products. In the course of French fry production, potatoes undergo thermal processing, *i.e*. blanching, initial drying and frying. These processes have an effect on the creation of the so-called "skeleton" in potato tissue, which contains different proportions of carbohydrate compounds, which in turn, can be responsible for shaping the ready product texture [Gołubowska & Lisińska, 2003].

The shear stress values for French fries produced from potato tubers of six varieties are shown n Figure 4. It was determined that French fries texture data ranged from 153.9 kPa (Aster v. fries) to 228.4 kPa (Ania v. fries). The shear stress values for French fries produced from Mila and Bryza, had appropriate texture at about 180 kPa. The shear stress maximum values were a multiplication of maximum force values (texture), since the shorn surfaces were identical in French fries produced from all potato varieties.

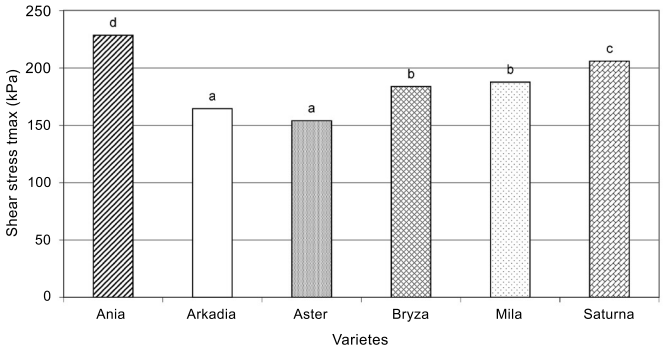

FIGURE 4. The comparison of shear stress of French fires prepared from potato tubers of six varieties.

The results regarding the values of work needed to obtain maximum shear stress are shown in Figure 5. The lowest work values were connected with shearing French fries of soft consistence, produced from potato tubers of the Aster variety (1.78 mJ), while the highest values were obtained for shearing the Ania potato variety fries with excessively tough texture. The work values of the latter samples were 36% higher than the French fries with excessively soft textures. The work needed to obtain maximum force values corresponds with the field situated under the shear curve. That field is limited by the contact point between the shearing attachment with a sample and the point which shearing force reaches its maximum value (Figure 3), which effects the values of determination work. These values, in turn, depend on the maximum shearing force and on shifting the shearing attachment between the points mentioned above.

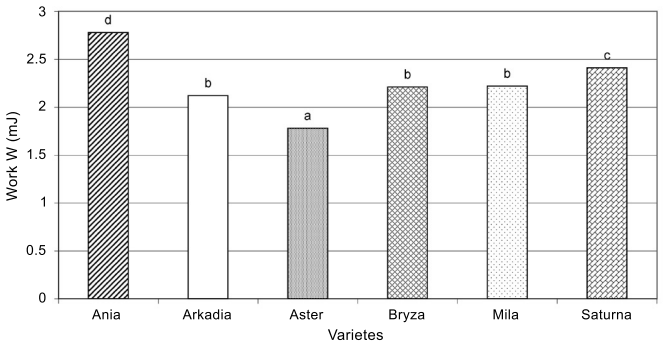

FIGURE 5. The comparison of the work which is needed to obtain the maximum shear stress.

Taking into account the results presented in Figure 3, 4 and 5 it could be stated that French fries produced from the Ania variety had an excessively tough texture, because they needed greater strength to be shorn and also more work outlay to obtain maximum shear stress. In the case of the Aster variety of French fries, which had an excessively soft texture, the mechanical properties data were significantly lower. French fries produced from potato tubers of the Bryza and Mila varieties had appropriate textures for their mechanical properties.

On the basis of the results regarding the correlation and significance level between French fry texture and the content of particular NSP fractions and lignin, as well as their totals (Table 1), it was found that NSP and lignin sum and fractions, *i.e.* lignin, hemicelluloses and pectins had a considerably effect on the texture of the all examined samples. The positive values of correlation coefficient indicated that the most significant effect on shaping the ready product texture was that of NSP and lignin total, followed by fractions of lignin, hemicelluloses and pectins. The total content of NSP and lignin in French fries is related to higher hardness values.

TABLE 1. The correlations coefficient between the texture of French fries and the content of non-starch polysaccharides (NSP) and lignin in dry matter of French fries.

The measuring apparatus	Components	Correlations coefficient (r)
Stevens QTS 25	Pectins	0.512*
	Hemicelluloses	0.744*
	Cellulose	0.219 -
	Lignin	0.779*
	Total of (NSP) and lignin	0.810*

* significant differences at the level $\alpha = 0.05$; (-) not significant

The data regarding the effect of particular NSP and lignin fractions, as well as their totals, on shaping French fries texture, expressed in percent of their share in a model are showed in Table 2. On the basis of an analysis of multiplied regression, it was stated that the most significant effect on shaping French fry texture was that of total content NSP and lignin (37% of share in a model), 28% lignin, 25% hemicelluloses and 10.2% pectins. Cellulose fraction, in spite of its relatively high content in French fries, did not have a considerable effect on the texture of fries.

On the basis of investigation it was stated that the contents of non-starch polysaccharides (NSP) and lignin in French fries could effect the shaping of their texture. According to research by Tajner-Copek [2000], Kita [2002], Gołubowska & Lisińska [2003], the content of total NSP amount and lignin plays an important role in texture formation in fried potato products, while the thermal processes which potato are subjected to in the course of their thermal processing cause an increase in these substances in the ready product [Jaswal, 1991; Thed & Philips, 1995; Asp, 1996].

TABLE 2. The influence of non-starch polysaccharides (NSP) and lignin in dry matter of French fries on the texture of French fries, created by multiplied regression for linear model.

Components	% share in model
Pectins	10.2*
Hemicelluloses	25*
Celullose	0.1-
Lignin	28.1*
Total of (NSP) and lignin	36.6*

$R^2 = 0.6348$, * significant differences at the level $\alpha = 0.05$, (-) not significant

CONCLUSIONS

1. The varieties of potato tubers contained different amounts of non-starch polysaccharides (NSP) and lignin, as well as the total sums, while middle late potato varieties featured a higher quantity of these substances in comparison to the very early potato variety. Alterations in NSP and lignin fractions in raw material and in French fries depended on the potato variety. The total content of non-starch polysaccharides (NSP) and lignin was higher than in the raw material.
2. French fry texture depended on NSP and lignin sum and on the fractions of lignin, and hemicelluloses, pectins remaining significant and highly correlated with one another. The most significant effect on shaping French fries texture was that of NSP and lignin fraction total and it amounted to nearly 37% in a model, 28% for lignin, 25% for hemicelluloses and 10.2% for pectin.
3. French fry texture was connected with NSP and lignin content in raw material. Bryza and Mila potato tubers had an appropriate texture and the total content of NSP and lignin reached about 7% d.m.
4. The values of shear stress and determination work depended on the maximum shearing force needed to shear French fries (texture). Alterations of related data were directly proportional.

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