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The influence of potato chemical composition on crisp texture

A. Kita

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

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Abstract

The aim of this work was determination of the relationship between the texture of potato crisps and starch, nitrogen compounds, non-starch polysaccharides and lignin content. Analyses of five different potato varieties—"Aster", "Karlena", "Ania", "Saturna", "Panda" harvested in 1996 and 1997, were conducted on potato tubers, before and after peeling, and the crisps produced. Crisps were characterised by proper colour, odour, flavour and texture. The most advantageous, as far as the texture was concerned, were the "Saturna" and "Panda" varieties, while the least successful were "Ania". The texture of crisps depended on the content of starch in potato tubers and nitrogen substances and non-starch polysaccharides. Among non-starch polysaccharides, protopectins had the most important influence on crisp texture. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Potato chips; Texture; Non-starch polysaccharides

1. Introduction

Highly important among snack products are potato crisps. The main quality factor, apart from colour, odour and flavour, is their characteristic crunchy texture. It is a well known fact that texture of this product depends on the quality of raw potato and technology parameters used in the course of production.

Crisp texture is connected with the dry matter content of raw potato tubers (Lisińska & Leszczyński 1989). Crisps obtained from potatoes rich in dry matter (above 25%) can exhibit hard textures, whereas crisps of too low a specific gravity (low in dry matter), containing much oil, are characterised by greasy and sticky textures. The dry matter of potato tubers is composed of various substances: starch (15%), sugars, nitrogen compounds, lipids, organic acids, phenolic compounds, mineral substances and non-starch polysaccharides.

In recent years, many scientists have paid attention to substances known as non-starch polysaccharides. These compounds constitute the main building material of cell walls in all types of plant tissues. From the chemical point of view, non-starch polysaccharides are heterogeneous mixtures, containing glycoproteins, waxes, phenolic esters and non organic compounds (Asp, 1996; Ramesh & Tharanthan, 1999). In the cell wall cellulose fibrils build a kind of skeleton cemented by a polymeric phenolic substance—lignin. Hemicellulose accompanies cellulose in the cell wall. Pectic substances, occurring mainly in middle lamellae, play an important role as hydrating agents and cementing materials in the cellulose network (Chang et al., 1993; Müller 1984). The content of non-starch polysaccharides in potato tubers is about 6% of dry matter. The most numerous fraction is cellulose — 2.7–3.8%, and then hemicelluloses—1.8%, pectin substances—0.7–1.5% and lignin—1.1–1.6% (Lisińska & Leszczyński, 1989).

Even though these substances have become a subject of investigation by many scientists, no satisfying explanation of their role has been attempted in the quality of potato crisps. Although crisps may be produced from potato tubers of similar starch content, they often show significant differences in texture quality. Therefore, the chemical substances of potato tuber that create structural characteristics in potato crisps need to be identified.

The aim of this work was determination of the relationship between the texture of potato crisps and starch, nitrogen compounds, non-starch polysaccharides and lignin content.

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2. Materials and methods

2.1. Samples

Materials for this investigation were potato tubers before and after peeling as well as the crisps produced from them. The samples were subsequently collected from the plant in the autumn 1996 and 1997. Five varieties of potato were under investigation: "Aster"—very early Polish variety (Institute of Potato, 1996), "Karlena"—mid-early Dutch-German variety (BSA, 1993), "Ania"—mid-late Polish variety (Institute of Potato, 1996), "Saturna"—mid-late Dutch-German variety (BSA, 1993), "Panda"—late German variety (BSA, 1993).

Potato samples were collected from the plant after they had been washed in a rinsing drum and selected on inspection belts. The raw material obtained amounted to 10 kg of tubers and constituted the samples of unpeeled tubers. Another portion of tubers, 10 kg of each different variety, was collected after the raw material had been peeled in carborundum peelers and additionally cleaned on the inspection belts. In that way the samples of peeled and unpeeled tubers were obtained and transported to the laboratory of the Department of Food Storage and Technology to undergo further analysis.

The samples of crisps were collected after the slices had left the continuous frier and before the addition of spices. They were produced from the same portions of potatoes as the tubers chosen, before and after peeling. Technological crisp production was as follows: peeled potato tubers were sliced (1.2–0.1 mm thick) and washed in cold water. Then they were blanched at 75 °C for 2 min. Crisps were fried in a continuous frier, using palm oil. The initial temperature of oil was 180–185 °C, and the final oil temperature ranged from 155 to 160 °C. The duration of frying time was 2 min. After discharging of the oil and cooling, crisps were packed in aluminium foil packages and taken to the laboratory for analysis.

2.2. Analysis

In the laboratory of the Department of Food Storage and Technology the portion of tuber samples before and after peeling was selected in order to determine the content of dry matter (AOAC) and starch (the method by Evers-Grosfeld) as well as to prepare lyophilysate.

In lyophilysate made from the potatoes before and after peeling the following contents were determined (in three replications): total nitrogen (according to Kjeldahl method), (protein content was estimated with the use of 6.25 multiplier), protein nitrogen—by Berstain method, aminoacid nitrogen—by Sörensen method, total sugars, reducing sugars and sucrose—by a chromatographic method (Borys & Kubacki, 1973), non-starch polysaccharides and lignin—by the Jaswal (1970) and Dever, Bandurski, and Kivilaan methods (1968) modified by Tajner-Czopek, Kita, and Lisińska, (1997) at the Department of Food Storage and Technology at the Agricultural Academy in Wrocław, total pectins, protopectins and soluble pectins—by the Jaswal (1969) and McComb and McCready (1952) methods, modified by Kita, Tajner-Czopek and Lisińska (1997) at the Department of Food Storage and Technology at the Agricultural Academy in Wrocław.

In the crisps made from different potato varieties the following data were determined: the content of dry matter—balance method (AOAC), fat content—by Soxhlet method, crisp texture—with the use of Stevens QTS-25 apparatus, compatible with CP/AT computer with Stevens' software (the force needed for cutting crisps was measured with the use of a rectangular cutting attachment. To all the measurements a crosshead speed of 250 mm/min was applied. The measurement of the texture was performed in 30 laboratory repetitions for each sample), organoleptic qualities—colour, flavour, odour and texture were assessed according to the five-grade scale (5 points—the best, 1 point—the worst).

2.3. Statistical evaluation

To determine whether the contents of particular chemical components in the examined tubers before and after peeling (of a chosen potato variety) differ statistically the method of two-way variance analysis was applied. Comparison of crisp quality (the crisps produced from the tubers mentioned above) involved one-way variance analysis. In the case of stating statistically significant differences, homogeneous groups were determined by Tukey's multiple comparisons test (level of significance $\alpha = 0.05$). To assess rank variables (organoleptic crisp evaluation on the 1–5 scale), the non-parametric Kruskal–Wallis test was used. Homogeneous groups were shaped on the basis of the determined ranks. Relationships between crisp texture and particular chemical components of potatoes were estimated with the use of a multiple regression analysis method for a linear model. Statistical analysis was performed using Stetgraphics 5.0 (Dabrowski, Gnot, Michalski, & Strzednicka, 1994).

3. Results and discussion

Potato varieties: "Aster", "Karlena", "Ania", "Saturna" and "Panda" were used in this investigation. Early varieties were "Aster" and "Karlena", mid-late were represented by "Ania" and "Saturn", while "Panda" was representative of the late variety. All those varieties, as well as "Rita", "Tomensa" and "Lady Claire" are most commonly used raw materials for the production of crisps in Poland (in the region of Lower Silesia).

Table 1
Chemical composition of five varieties of potato tubers before and after peeling[a]

Potato variety	Dry matter (%)		Starch (%)		Total nitrogen (%)		Protein nitrogen (%)		Reducing sugars
	Not peeled a	Peeled b	Not peeled a	Peeled b	Not peeled a	Peeled b	Not peeled a	Peeled a	Not peeled
Aster	19.92 a	19.46 a	15.19 a	14.86 a	0.32 a	0.33 a	0.150 b	0.150 b	0.114 d
Karlena	22.91 d	21.89 c	17.65 b	17.06 b	0.38 c	0.43 c	0.136 a	0.138 a	0.028 b
Ania	20.16 b	19.55 b	14.98 a	14.79 a	0.35 b	0.34 a	0.149 b	0.138 a	0.127e
Saturna	23.28e	23.47e	18.40 c	18.37 d	0.37 c	0.41 b	0.180 c	0.162 c	0.040 c
Panda	22.71 c	22.29 d	17.57 b	17.36 c	0.38 c	0.42 b	0.159 b	0.152 b	0.012 a

[a] Different letters within a column indicate significant differences ($\alpha \leqslant 0.05$).

Table 2
Non-starch polysaccharides and lignin contents in five varieties of potato tubers before and after peeling[a]

Potato variety	Protopectin (%)		Soluble pectin (%)		Hemicelluloses (%)		Cellulose (%)		Lignin (%)		Total (%)	
	Not peeled b	Peeled a	Not peeled b	Peeled a	Not peeled b	Peeled a	Not peeled b	Peeled a	Not peeled b	Peeled a	Not peeled b	Peeled a
Aster	0.26 b	0.22 a	0.09 b	0.06 a	0.32 a	0.22 a	0.48 b	0.13 a	0.15 a	0.11 a	1.30 a	0.47 a
Karlena	0.26 b	0.25 b	0.10 c	0.08 c	0.43 b	0.37 b	0.49 b	0.15 a	0.22 b	0.16 b	1.50 c	1.01 c
Ania	0.24 a	0.21 a	0.09 b	0.08 c	0.42 b	0.36 b	0.40 a	0.13 a	0.15 a	0.12 a	1.30 a	0.90 b
Saturna	0.26 b	0.24 b	0.11 d	0.09 d	0.45 c	0.39 b	0.46 b	0.14 a	0.20 b	0.15 b	1.48 b	1.01 c
Panda	0.30 c	0.27 c	0.08 a	0.07 b	0.46 c	0.41 c	0.55 c	0.16 a	0.21 b	0.16 b	1.60 d	1.07 c

[a] Different letters within a column indicate significant differences ($\alpha \leqslant 0.05$).

The content of dry matter ranged from 19.92–23.28%, while the content of starch was 15.2–18.4% (Table 1). Percentage of dry matter in potatoes for crisp production should be 20–25% and that of starch should be more than 15% (Polish Norm PN-A-74780). Similarly, the content of total sugars should be less than 0.23% and reducing sugars less than 0.12%, which also meet the Polish norms. The quantity of nitrogen compounds in potato tubers is not the subject of norm limits. Those compounds, and especially protein nitrogen, could influence the quality of crisps. In this investigation protein nitrogen ranged from 0.136 to 0.180%.

Potato tubers of analysed varieties were harvested from the field when physiologically fully ripe. They were of oval shape, standard size and had a small numbers of "eyes". The tubers were healthy and suitable for storage. Therefore, the material collected for analysis was of a high quality, and, presumably, the crisps made from it, following all technological regimes, were necessarily of a good quality.

One of the first stages of crisp production is the peeling of potatoes in carborundum peelers. In that process, the chemical content of potato tubers undergoes some change. The changes of the content of dry matter and starch, although they do not exceed 1%, remain statistically significant (Table 1), despite the fact that contents of some components, especially those present in the outer parts of tubers become markedly affected by peeling. Non-starch polysaccharides and lignin can be mentioned here. In unpeeled tubers, the content of the latter components ranged from 1.3% ("Aster" and "Ania" variety) to 1.6% ("Panda" variety) (Table 2). Similar results were also obtained by other authors for potato tubers (Johnston & Oliver, 1982; Thed & Philips, 1995; Varo, Veijalainen, & Koivistoinen, 1984). As proved by the investigation, the following components could be found in non-starch polysaccharides of unpeeled potato tubers: cellulose (average 33%), hemicellulose (29%), pectin compounds (about 25%) and lignin (13%; Fig. 1). Similar data for the contents of analysed fractions of non-starch polysaccharides (NSP) in potato tubers were recorded by Zgórska and Frydecka-Mazuczyk (1985). The changes after peeling affect both contents and proportions between particular substances of the NSP. The amounts of non-starch polysaccharides and lignin in peeled tubers were nearly half those of the unpeeled ones (Table 2). The most dramatic changes occurred with the content of cellulose (33% of the NSP fraction and lignin in not peeled tubers to 14% in the peeled ones). The content of hemicelluloses increased (37%), while the amounts of pectin compounds (24%) and lignin (15%; Fig. 1) were unchanged. The components which underwent the biggest changes regarding their content constituted the outer parts of the tubers; they were present also in the

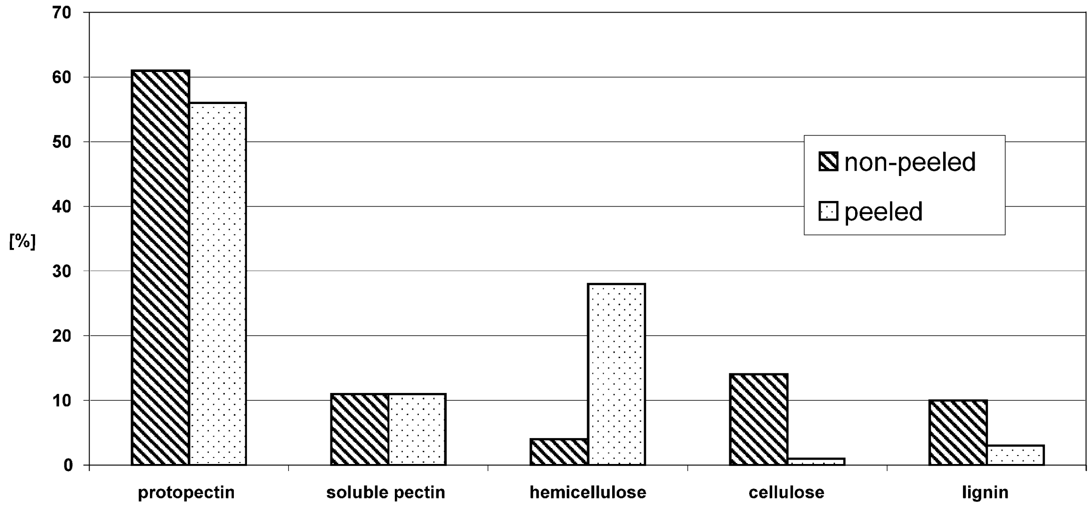

Fig. 1. Participation of fractions in total NSP and lignin content in potato tubers before and after peeling (average values of analysed potato varieties).

Table 3
Oil content and sensory quality of potato crisps produced from five potato varieties[a]

Potato variety	Oil content (%)	Colour (Points 1–5)	Odour	Flavour	Texture	
Aster	39.44 e	4.50 b	4.50 b	5.00 b	4.25 b	23.00 b
Karlena	38.35 c	4.75 c	4.50 b	5.00 b	4.46 c	25.07 c
ania	39.38 d	3.25 a	4.00 a	4.50 a	3.48 a	15.87 a
Saturna	37.89 b	4.75 c	4.75 c	5.00 b	4.60 d	25.99 d
Panda	35.77 a	5.00 d	4.75 c	5.00 b	4.70 d	26.34 e

[a] Different letters within a column indicate significant differences ($\alpha \leqslant 0.05$).

inner part of potato tubers and therein were less affected by the changes.

Peeled potatoes were sliced, blanched and then fried. In the experiment, the crisps were produced by the same process. Therefore the qualities of the products resulted from the chemical compositions of particular tuber varieties. The crisps made of ‘‘Aster’’, ‘‘Karlena’’, ‘‘Saturna’’ and ‘‘Panda’’ varieties were characterised by an appropriate golden-yellow colour, typical flavour and odour, a slightly darker colour characterising the crisps produced from ‘‘Ania’’ potato variety. The latter variety contains more reducing sugars, which is the crucial factor regarding the colour of a ready product. The effects of sugar quantities on crisp colour were the subject of numerous research papers (Donouqe & Marangoni, 1996; Jakuczun Zgórska, & Zimnoch-Guzowska, 1995; Rodrigues-Saona & Wrolstad, 1997; Roe & Faulkes, 1991).

Fat contents, in the examined crisps differed (Table 3). The highest fat content was in crisps made of the ‘‘Aster’’ potato variety—39.44%, while those produced from the ‘‘Panda’’ variety had 35.77% of fat. As proved by many authors, fat content is related to starch and dry matter content of the raw material (Gamble, Rice, & Selman, 1987, Lisińska, Jaworska, & Malkiewicz, 1989). Potatoes of higher dry mass content produce crisps with lower fat content than those with lower dry matter values. That relationship was confirmed by the results obtained. The highest fat content was in the crisps made from the ‘‘Aster’’ variety, characterised by the lowest dry matter, while the highest fat values were recorded for the potatoes of the ‘‘Panda’’ variety with a high dry matter content.

The feature differentiating the crisps produced from raw materials of ‘‘proper’’ chemical composition is crisp texture. Texture is listed in Table 3. The highest score was given to texture of crisps made from the ‘‘Panda’’ and ‘‘Saturna’’ potato varieties. Worse textures were produced from the ‘‘Aster’’ and ‘‘Karlena’’ tubers and the worst from the ‘‘Ania’’ potato variety. As mentioned, all used potatoes met the norms: they were characterised by sufficient dry matter and starch contents—the components responsible for shaping crisp texture. However, the results obtained proved that crisp texture could also depend on other factors.

Statistical analysis (Table 4) showed that crisp texture was influenced, apart from starch and protein nitrogen, also by non-starch polysaccharides. In spite of relatively low contents of these components in potato: 7%—in

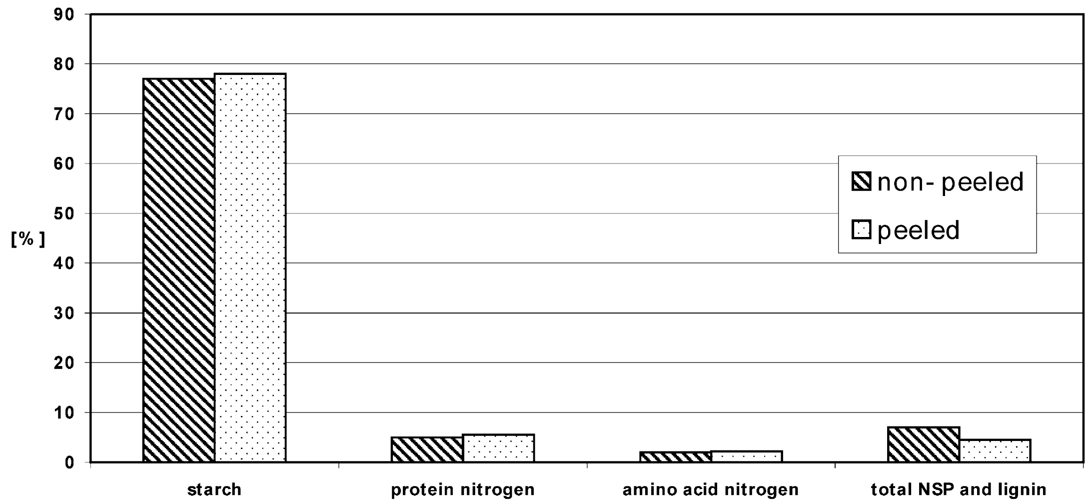

Fig. 2. Chemical components of potato tubers before and after peeling (average values of analysed potato varieties).

Table 4
The relationship between the texture of crisps and the starch, nitrogen compounds, non-starch polysaccharides and lignin content in unpeeled and peeled potato tubers according to multiple regression model[a]

Feature	(%) Participation in model		Significance level
	Not peeled a	Peeled b	
Starch	79	66	$\alpha = 0.001$
Protein nitrogen	11	12.5	$\alpha = 0.001$
Amino acid nitrogen	1	–	–
Total nsp and lignin	9	21.5	$\alpha = 0.001$

$R_a^2 = 0.9132$
$R_b^2 = 0.9617$

[a] STEV = f (starch, protein nitrogen, amino acid nitrogen, non-starch polysaccharides and lignin).

Table 5
The relationship between the texture of crisps and the non-starch polysaccharides and lignin content in unpeeled and peeled potato tubers according to multiple regression model[a]

Feature	(%) Participation in model		Significance level
	Not peeled a	Peeled b	
Protopectin	61	56	$\alpha = 0.001$
Soluble pectin	11	11	$\alpha = 0.001$
Hemicelluloses	4	28	$\alpha = 0.01$
Cellulose	14	1	$\alpha = 0.01$
Lignin	10	4	$\alpha = 0.001$

$R_a^2 = 0.9655$
$R_b^2 = 0.9786$

[a] Stev = f (protopectin, soluble pectin, hemicelluloses, cellulose, lignin).

non-peeled tubers and 4.9% in peeled ones (Fig. 2), their participation in crisp texture was high enough. Their participation was 9–21% in the model (Table 4), compared to starch—66–79% and protein nitrogen—11–12%.

Jaswal (1970, 1989, 1991) investigated crisp texture in relation to specific gravity and polysaccharide content in potatoes which served as the material for crisp production. He reported that polysaccharides, separated from potato tubers of different specific gravities, differed in their molecular mass. Potatoes of higher specific gravity contained non-starch polysaccharides of higher molecular mass than potatoes of lower specific gravity. While french fries undergo partial degradation of polysaccharides, that process is more rapid during heat treatment of low-specific gravity potatoes. The author explains this phenomenon by the fact that, in the potatoes of high specific gravity, polysaccharides are more stable and the thin structure is more compact, which prevents their degradation. Therefore, the french fries produced from potatoes of high specific gravity, which were not the subject of polysaccharide degradation, showed better texture.

The effects of particular non-starch polysaccharides fractions and lignin on crisp texture were analysed by multiple regression (Table 5). The most important role played in shaping crisp texture was that of pectin substances and among these the protopectin fraction. Their effect was statistically estimated as 56%. The next most important fraction which affected crisp texture was hemicelluloses (28%). The remaining two fractions—cellulose and lignin did not influence crisp texture. Their total participation in the model was only 5%.

There appear to be no literature data considering the effect of non-starch polysaccharides and lignin on shaping crisp texture. Reports are confined to the texture of boiled tubers. According to Hughes, Faulkes, and Grant (1975) an important role in the texture of such tubers is played by pectin. The change of boiled potato texture is connected with the effects of calcium–pectin gels in the cell middle lamella.

Mechanisms of starch, non-starch polysaccharides and lignin effects on crisp texture have not yet been explained. Probably, as in the case of boiled potato, a kind of "skeleton", consisting of carbohydrate complexes, is formed at high temperature, which affects tenderness of the boiled product. Varying amounts of those compounds in the tubers of different varieties can result in different crisp texture.

Crisps of the best texture were produced from the "Panda" potato variety and they were characterised by the highest contents of starch, non-starch polysaccharides and lignin. The following compounds could be found in non-starch polysaccharides of that potato variety: pectins—0.38%, hemicelluloses—0.46%, cellulose—0.5%. Lignin constituted 0.21% (Table 2). The worst crisp texture was in potato tubers of the "Ania" variety. Those tubers contained 0.33% of pectin, 0.42% of hemicelluloses, 0.4% of cellulose and 0.15% of lignin. These results suggested that pectin compounds, in addition to starch content of the potato tubers could be factors affecting on crisp texture.

As far as the assessment of potato varieties chosen for crisp production is concerned, knowledge about chemical content of raw material, before and after peeling, is still important. Although, in most cases, crisps are produced from peeled tubers, technology without that stage can also be accepted. Knowing the degree to which potato peeling changes quantitative relationships between particular tuber components, it is possible to predict the quality of raw material obtained from particular potato portions. Constant improvement of potato cultivation technology can probably lead to a raw material of stricly "programmed" chemical content, with not only appropriate amounts of dry matter, starch or sugars, but also appropriate amounts of non-starch polysaccharides, and especially pectin compounds. Such a situation could ensure the desired crisp quality and their excellent texture.

Instrumental measurement of crisp texture was carried out to introduce an objective texture assessment. The force needed to break crisps was determined with the use of a Stevens QTS-25 apparatus. The results obtained were compared to organoleptic estimation. The hardest crisps were made from the "Panda" potato variety (26,34N), while the "Ania" potato variety was responsible for the lowest hardness (15,87N). The best crisps texture was from the "Panda" potato variety and "Ania" potato variety proved to be the worst (Table 3). The crisps of higher hardness (instrumental measurement) were scored higher by the sensory judges than the crisps of lower hardness.

Hoûska, Ciganik, Valentova, Kalinova, and Kynos (1996) investigated correlations between sensory and instrumental texture estimation of several kinds of tender products. They reported that some sensory qualities (e.g. texture) correlated well with mechanical hardness, i.e. the force required to break or crush a product with the use of the Instron 1140 apparatus. They found a correlation between hardness estimated by fingers (sensory estimation) and maximum force required to break a product (instrumental assessment).

Many authors (Iles & Elson, 1972; Seymour & Hamann, 1988; Vickers & Christensen, 1980) have reported that correlations between sensory hardness of snack products, and crisps among them, and instrumental texture estimation.

4. Conclusions

Results showed that crisps produced from four out of five potato varieties were of appropriate colour, flavour, odour and texture. The best texture was in the crisps made from "Saturn" and "Panda" potato varieties, while "Ania" was the worst in that respect. Crisp texture depended mainly on starch contents of the potato tubers and, after this on the sum of non-starch polysaccharides, lignin and protein nitrogen. Pectin-protopectin compounds played a crucial role in the case of non-starch polysaccharides and lignin regarding crisp texture.

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