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The Quality of Salted Potato Chips Available on the Polish Market

Introduction

Modern technologies of food production influences changes in human diet. Due to the fact that people have less time to prepare meals more and more consumers are choosing foods that can be consumed "on the go" [Babicz-Zielińska, Jeżewska-Zychowicz & Laskowski 2010; Presha *et al.* 2008]. Potato chips are a commonly known and popular snack, which is selected by people of all ages [Salvador *et al.* 2009; *Pedreschi et al*. 2005]. Due to the high fat and salt content, as well as contents of acrylamide [Granda, Moreira & Tichy 2004; Tareke *et al.* 2002; Zhang *et al.* 2005], aldehydes, ketones and trans fatty acids [Moros *et al.* 2009], resulting from high temperature frying, they are considered to be unhealthy for human [Yi *et al.* 2015]. Acrylamide is associated with cancer risk, neurotoxic effects as well as reproductive toxicity, genotoxicity, and mutagenicity [Medeiros-Vinci et al. 2011; Exon 2006; Bolger, Leblanc & Setzer 2010; Erkekoglu & Baydar 2010].

Nevertheless, due to their desirable taste, oftentimes improved by the addition of monosodium glutamate, potato chips are frequently consumed during social events. It is also a snack eaten during the day,

especially by children [Allshouse, Frazao & Turpening 2002; Hassan & Al-Dosari 2008].

There are many companies that produce potato chips on the market [Salvador *et al.* 2009]. The products, however, differ significantly regarding the price and the claimed nutritional value. Nevertheless, nowadays consumers are more aware of the relationship food-nutrition-health. They are more informed about the quality of products they consume [Arias-Mendez *et al.* 2013; Shiroma & Rodriguez-Saona 2009]. That is why the aim of the study was to assess the quality of salted potato chips available on the Polish market.

Material and methods

The research was conducted on 8 varieties of salted potato chips available on the Polish market and produced by 7 different manufacturers. The samples were bought in supermarkets in Cracow. All the analyzed samples had original and tight packaging. The material comprised of four production batches and was collected in 2015. The samples were coded with letters A-H.

The research program was prepared on the basis of Polish Standard PN-A-74780:1996 "Potato products. Fried potato snacks" and was divided into two stages.

The first stage of the study involved determination of chemical composition of the potato chips and calculation of their energy value. It included examinations of:

- peroxide value (PV) according to iodometric method by measuring the iodine liberated from potassium iodide

(KI) after reacting with the peroxides present in samples [PN-A-74780:1996],

- acid value (AV) by neutralization of the free fatty acids with potassium hydroxide [PN-A-74780:1996],
- water according to the oven-drying method in 105°C to constant weight [PN-A-74702:1978],
- fat according to Soxhlet method [PN-A-74780:1996],
- salt according to Mohr's method [PN-A-74702:1978],
- protein according to Kjeldahl's method [PN-75/A-04018:1975/Az3:2002] and
- total ash by incineration in 400°C with prior carbonization [PN-A-74702:1978].

Carbohydrates' contents were calculated and with a use of Atwater's coefficients energetic values of the products in kcal units were estimated. The amounts of chips with defects and damaged by weight were also determined.

In the second phase of the research sensory analyses were performed by a team of 10 selected assessors. The panelists were chosen and trained according to the methodology described in EN ISO 8586:2014 standard. The panelists assessed shape and size, color, odor, taste as well as texture using 5-point scale in accordance with Polish Standard PN-A-74780:1996.

The data thus obtained went through statistical analysis. Empirical distributions of continuous variables were summarized using means and standard deviations. A one-way ANOVA followed by post hoc Tukey's HSD test was used to compare means. A p-value of 0.05 was required for statistical significance. Clustering was performed on standardized group averages using hierarchical method with Euclidean

distance and complete linkage. All data processing and statistical calculations were performed using R 3.2.3. software.

Results and discussion

The chips production process involves immersing cut potatoes in continuous fryers with oil heated to high temperatures. It usually takes between 1 and 3 minutes for chips to be fried. Such conditions should guarantee desired color, texture and moisture loss to less than 2% of the primary water content [Brennan 2006]. However, during deep-fat frying the moisture loss results in oil uptake that may even amount to 40% of total product weight [Pedreschi *et al.* 2012; Kita, Lisińska & Gołubowska 2007; Saguy & Dana 2003]. High fat content poses risk of potential adverse health effects for consumers, such as obesity, high blood pressure and coronary disease [Cheng 2012; Sayon-Orea *et al.* 2014; Stier 2013]. The quality of oil used for frying influences the quality of food [Rani & Chauhan 1995].

The results of physicochemical analyses are presented in Table 1.

Table 1. The results of physicochemical analyses

Parameter	**Product**								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**p***
Water, [%]	1,92 (0,17)	1,63 (0,37)	1,65 (0,08)	1,65 (0,16)	1,79 (0,06)	2,06 (0,17)	1,82 (0,07)	2,50 (0,49)	<0,001
Total ash, [%]	3,78 (0,16)	4,13 (0,65)	3,46 (0,3)	4,41 (0,3)	5,27 (2,56)	2,98 (0,05)	3,76 (0,22)	3,17 (1,09)	0,07

Insoluble ash, [%]	0,20 (0,22)	0,53 (0,43)	0,63 (0,71)	0,34 (0,28)	0,53 (0,18)	0,33 (0,4)	0,32 (0,18)	0,08 (0,08)	0,552
Sodium chloride, [%]	2,31 (0,55)	1,69 (0,14)	2,52 (0,21)	2,33 (0,47)	1,49 (0,22)	2,17 (0,16)	1,69 (0,23)	2,44 (0,7)	0,002
Protein, [%]	5,92 (1,26)	6,40 (0,53)	5,71 (0,62)	5,64 (0,54)	7,05 (1,25)	5,52 (0,1)	6,23 (0,91)	6,25 (0,66)	0,237
Fat, [%]	38,22 (2,45)	34,38 (6,12)	34,35 (1,84)	31,27 (2,52)	31,8 (0,75)	10,02 (0,46)	35,26 (1,91)	36,85 (4,35)	<0,001
Carbohydrates, [%]	49,80 (2,29)	54,85 (4,43)	53,41 (3,77)	57,89 (2,65)	54,24 (2,24)	78,06 (2,65)	52,94 (2,59)	52,09 (3,56)	<0,001
Energetic value, [kcal/100g]	568,32 (13,05)	552,06 (36,05)	544,83 (16,83)	532,14 (13,14)	531,33 (7,01)	430,46 (2,35)	553,99 (9,03)	564,25 (28,98)	<0,001
Acid value, [mg KOH/1g]	0,57 (0,36)	0,91 (0,36)	0,63 (0,12)	0,50 (0,25)	0,58 (0,09)	0,99 (0,42)	0,57 (0,4)	0,35 (0,31)	0,245
Peroxide value, [mequiv/kg]	0,70 (0,46)	1,49 (1,23)	1,19 (0,64)	0,55 (0,41)	1,28 (0,81)	2,24 (1,86)	1,40 (1,13)	1,04 (0,56)	0,396
Broken parts, [%]	46,58 (9,21)	43,18 (5,43)	54,83 (8,42)	40,11 (7,63)	42,38 (14,97)	33,55 (10,57)	41,18 (11,04)	47,03 (11,33)	0,259
Defects, [%]	18,26 (6,28)	26,99 (10,77)	16,66 (6,11)	19,42 (11,41)	14,5 (8,76)	1,97 (2,5)	26,29 (5,72)	17,68 (5,62)	0,005

Source: own research

Peroxide value and acid value

During deep frying in the presence of moisture and air, a number of chemical reactions occur. They include oxidation and hydrolysis. The thermal decomposition of fats leads to an increase in

the acid and peroxide values [Zhang *et al.* 2015; Lalas & Dourtoglou 2003].

The levels of lipid oxidation along with sorbed water content influence potato chips' quality [Quast, Karel & Rand 1972; Quast & Karel 1972]. Lipid oxidation rate depends on oxygen and water partial pressures as well as the extent of the oxidation reactions [Del Nobile 2001]. To protect chips from breakage and spoilage, they are packed in polymeric films with inert gas. In this way, the oxygen and water partial pressures are kept in a package at a low level. This slows down lipid oxidation rate and thus extends product's shelf-life [Del Nobile, 2001].

Determination of **peroxide value (PV)** in foods containing fats is of utmost importance from a quality assurance perspective. This parameter reflects the amount of oxidation products, mainly hydroperoxides and secondary oxidation products (ketones and aldehydes) in fat. These compounds are responsible for flavor deterioration [Guillén & Cabo 1999, 2000; Mehta, Darji & Aparnathi 2015]. Oxidative processes may occur during storage and processing through auto- or photo-oxidation [Choe & Min 2006; Inarejos-García et al. 2010]. The higher the PV, the lower food oxidative stability affecting product's quality [Pizarro *et al.* 2013]. The oxidation of fat in food may even result in product's toxicity [Yang *et al.* 2014].

According to the Polish Standard PN-A-74780, PV in potato chips must not exceed 6 mequiv/kg. All analyzed potato chips samples met this requirement. Although some differences between the analyzed samples were found, they were statistically insignificant. The lowest mean of PV was noted in case of product D (0,55 mequiv/kg) and the highest for product F (2,24 mequiv/kg). Relatively high standard

deviations indicated large fluctuations between samples of different production batches.

Wójcik-Stopczyńska and Grzeszczuk [2003] noted mean values ranging from 2,02 mequiv/kg to 4,04 mequiv/kg. Nevertheless, in case of 2 products, in single production batches, they determined 8,08 mequiv/kg and 9,18 mequiv/kg, which exceeded the limit set by the PN-A-74780 standard. In the research by Zychnowska, Krygier and Iwańczuk [2015] two products had peroxide value slightly above the limit set by the Polish Standard (6,09 mequiv/kg and 6,17 mequiv/kg) and in one case limit was exceeded significantly - 10,11 mequiv/kg. PV determined for other products they tested ranged from 1,09 mequiv/kg to 5,31 mequiv/kg.

Acid value (AV) indicates the amount of free fatty acids in the food products. The lower the value the better quality of fat contained in the food. The product of high AV may cause gastrointestinal discomfort or even diarrhea as well as liver damage [Zhang *et al.* 2015].

According to Polish Standard PN-A-74780, AV in potato chips must not exceed 1 mg KOH/g. All product samples analyzed were in accordance with this requirement. The lowest value was determined for product H (0,35 mg KOH/g) and the highest for product F (0,99 mg KOH/g). The differences were, however, insignificant. High standard deviations, indicated quality differentiation between production batches.

In the research by Wójcik-Stopczyńska and Grzeszczuk [2003] mean acid value ranged from 0,56 mg KOH/g to 0,7 mg KOH/g. Nevertheless, in single batches, in case of 2 products, they determined AV exceeding the limit of 1 mg KOH/g. The acid value noted in potato

chips analyzed by Zychnowska, Krygier and Iwańczuk [2015] fluctuated from 0,25 mg KOH/g to 0,69 mg KOH/g. In case of one product the acid value was above the limit set by the PN-A-74780 standard (1,53 mg KOH/g).

Moisture and fat

Moisture and fat content are two common parameters used to control potato chips' quality [Shiroma & Rodriguez-Saona 2009].

Fat content is one of the most important parameters checked during the quality control process of potato chips. It affects the product's texture [Mazurek, Szostak & Kita 2016]. The content of fat along with little thickness of potato chips give them a desirable flavor-texture combination [Pedreschi *et al.* 2012]. Most of the oil does not penetrate into the microstructure of potato chips during frying but during cooling [Pedreschi *et al.* 2008; Durán *et al.* 2007]. Commercial potato chips vary in fat content. Low fat product contain up to 10% of fat, while regular chips even 30-40%. The factors that influence fat uptake include: quality of raw material, the type of oil fraction, and technological process - mainly parameters such as temperature and time of frying [Mazurek, Szostak & Kita 2016; Kita, Lisińska & Golubowska 2007].

According to Polish Standard PN-A-74780, fat content in potato chips must not exceed 45%. In this research the lowest fat content of 10,02% was determined in the chips that were produced using potato flour and baked (sample F). Other product contained from 31,27% (sample D) up to 38,22% (sample A) of fat. The statistically significant difference concerned only these two marginal products (A and D).

The mean fat content in potato chips tested by Wójcik-Stopczyńska and Grzeszczuk [2003] ranged from 33,14% to 33,94%, whereas in products analyzed by Ratusz and Wirkowska [2008] from 22,9% to 40,1% and by Zychnowska, Krygier and Iwańczuk [2015] from 27% to 36%.

Moisture content above 3% disqualifies potato chips as their texture becomes unacceptable for consumers [Matz 1984]. Moreover, high water content, through acceleration of fat degradation, negatively affects product's shelf life [Wójcik-Stopczyńska & Grzeszczuk 2003].

According to Polish Standard PN-A-74780 water content in potato chips must not exceed 4%. In this research statistically significantly highest water content was detected in product H (2,5%). Other samples contained from 1,63% (product B) to 2,06% (product F) of water.

In the research by Wójcik-Stopczyńska and Grzeszczuk [2003] water content in potato chips ranged from 0,76% to 3,29%.

Sodium chloride

Sodium ions are necessary to maintain the pressure and volume of the blood. They are also used by the nervous system enabling transmission of impulses and are needed for metabolism of carbohydrates and proteins. On the other hand, too much sodium consumed with food may cause hypertension or high blood pressure [Beernaert, Van der Mijnsbrugge & Martelaere 1984]. Currently, the advised maximum intake of salt accounts for 6 g a day [Referencyjne wartości… nd].

According to Polish Standard PN-A-74780 salt content in potato chips must not exceed 3,5%. The highest sodium content was determined in product H (2,44%) and in product C (2,52%), the lowest in product E (1,49%). Differences between the two samples of the highest sodium chloride concentration and the product of the lowest sodium chloride content were statistically significant. The determined content of sodium chloride in all analyzed samples indicated that eating potato chips adds a significant amount of this compound to the daily diet.

Salt content in potato chips analyzed by Wójcik-Stopczyńska and Grzeszczuk [2003] ranged from 0,69% to 2,66%. These were, however, flavored potato chips.

Proteins

Proteins are crucial components in human nutrition as they perform numerous, essential roles within the organism. It has been proved that proteins from potatoes are equally as nutritious as egg or soy proteins [Waglay & Karboune 2016].

The samples analyzed contained from 5,52% (sample F) to 7,05% (sample E). However, the differences were insignificant.

Carbohydrates

Carbohydrates are the main source of energy for organisms. In this research the statistically significantly highest content of carbohydrates was noted in product F, containing also the smallest amount of fat - 78,06%. Concentrations of carbohydrates in other

products ranged from 49,8% (sample A) to 57,89% (sample D). The differences between samples A and D were statistically significant.

Minerals

Minerals are essential elements of the human diet. They play an important role in the maintenance of physiochemical conditions crucial for sustaining life of an organism [Ikanone & Oyekan 2014]. Total ash content enables estimation of their concentration in a food product.

Total ash content varied from 2,98% (sample F) to 5,27% (sample E). The differences were statistically insignificant.

The insoluble ash is an indicator of products contamination, mainly with quartz components. In case of potato chips, it may point to inaccurate process of raw material washing.

The amount of insoluble ash determined ranged from 0,08% (sample H) to 0,63% (sample C). As in case of total ash, the differences were statistically insignificant.

Chips with defects and damaged

According to the Polish Standard PN-A-74780, the number of broken potato chips must not exceed 8% and chips with defects cannot exceed 0,8%. In this research all damaged potato chips were counted, even with small missing pieces. This resulted in the number of broken chips ranging from 33,55% (sample F) to 54,83% (sample C). The lowest number of chips with defects was determined in sample F (1,97%). Nevertheless, this product was produced with the use of

potato flour. The number of chips with defects in other products ranged from 14,5% (sample E) to 26,99% (sample B).

Similarly in the research by Wójcik-Stopczyńska and Grzeszczuk [2003] majority (85%) of analyzed products did not meet requirements of the PN-A-74780 standard.

Sensory characteristics

Thanks to frying, a unique appearance, flavors and texture of potato chips are created resulting in high palatability. Appreciated color and mechanical characteristics of a fried product are developed [Yu *et al.* 2016; Arabhosseini *et al.* 2009].

Consumers are the final judges of any product. Sensory characteristic of the food product plays a crucial role when making purchase decisions [Gatchalian 1999]. It is difficult to replace a human sensory evaluation by instrumental methods [Mehta, Darji & Aparnathi 2015]. Therefore, the producer needs to evaluate sensory quality that affects the level of product's acceptability. In case of potato chips the following parameters are evaluated: shape and size, color, odor, taste, texture.

The results of sensory analysis are presented in Table 2.

Table 2. The results of sensory analysis

Parameter	**Product**								**p ***
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	
Shape and size	2,75 (0,5)	2,00 (0,82)	2,38 (0,48)	3,00 (1)	4,67 (0,58)	4,67 (0,58)	3,2 (0,84)	2,00 (0)	<0,001

Color	3,62 (0,48)	2,80 (0,84)	3,62 (1,25)	3,50 (1)	4,00 (0)	4,88 (0,25)	2,90 (0,55)	2,50 (0,58)	0,002
Odor	4,00 (0)	3,20 (0,84)	4,12 (0,85)	4,62 (0,48)	4,38 (0,48)	4,75 (0,5)	3,90 (0,74)	3,38 (0,75)	0,016
Taste	4,00 (0)	3,20 (0,84)	4,00 (0,82)	5,00 (0)	5,00 (0)	5,00 (0)	3,80 (0,57)	3,50 (0,58)	<0,001
Texture	4,00 (0,41)	3,80 (0,45)	4,25 (0,5)	4,62 (0,48)	4,75 (0,5)	4,75 (0,5)	3,70 (0,67)	3,75 (0,5)	0,011
SQI	3,67 (0,15)	3,07 (0,48)	3,68 (0,41)	4,22 (0,31)	4,54 (0,23)	4,81 (0,18)	3,50 (0,48)	3,02 (0,26)	<0,001

Source: own research

Shape and size

Products E and F received the highest notes regarding shape and size (4,67 points). The statistically significantly lower scores and the lowest in the analyzed group of products were granted to products B (2 points), H (2 points), C (2,38 points) and A (2,75 points).

In the research by Wójcik-Stopczyńska and Grzeszczuk [2003] and by Mozolewski, Wieczorek and Pomianowski [2011] all analyzed products were scored below 3 points.

Color

Color and appearance of the food product are the first quality parameters that are assessed by consumers before the food is consumed [Pedreschi *et al.* 2006; Demattè *et al.* 2009]. Thus, they influence consumer perception of a product. Consumers often associate color

with flavor, safety, nutrition and satisfaction [Pedreschi *et al.* 2012]. Therefore, sensory evaluation of color is often used in product quality control [Murray *et al.* 2001]. According to Pedreschi *et al.* [2006], the color of potato chips is the first and most critical product feature assessed by consumer and influencing product acceptance.

The Maillard reaction between reducing sugars and amino acids has a great influence on potato chips color. Therefore, the amount of these compounds in chips along with time and temperature of frying have an impact on obtaining a favorable color [Márquez & Ańón 1986]. The color on the surface of potato chips is also highly dependent on the amount and location of the oil in product's microstructure [Pedreschi *et al.* 2012].

The results of the research by Pedreschi *et al.* [2012] prove that chips of pale color are less appreciated by consumers as they do not have rich odor. 80% of panelists rejected such products. As many as 60% of them claimed that potato chips they had to be toasted and of golden brown color, but, not burnt.

In this research color of product F received the highest ratings (mean - 4,88 points). The worst products regarding color included sample H (2,5 points), B (2,8 points) and G (2,9 points). The differences in mean scores between product F and products B,G and H were statistically significant.

In the research by Mozolewski, Wieczorek and Pomianowski [2011] analyzed potato chips received ratings from 2,6 to 3,1 points.

Odor

Odor of fried potato chips is formed in Strecker's reactions, where methional is formed from methionine [Duckham, Dodson & Bakker 2002].

Sample F was the most appreciated for its odor (4,75 points) among analyzed products. Product B (mean - 3,2 points) received significantly lower scores and the lowest among all analyzed samples.

In the research by Wójcik-Stopczyńska and Grzeszczuk [2003] the mean odor scores ranged from 4,19 to 4,54 points. They, however, tested chips of various flavors. In the study by Mozolewski, Wieczorek and Pomianowski [2011] potato chips were scored from 3,1 to 3,8 points.

Taste

Consumers naturally perceive taste of a food product to be amongst the most crucial determinants affecting their choice [Thunström & Nordström 2015]. Taste of salted potato chips depends mainly on precursors of aromatic compounds in potatoes as well as type and quality of oil used as well as the amount of added salt [Lisińska 1994; Jansky 2010].

The highest ratings for taste were granted to products D, E and F (5 points). Significantly lower ratings were assigned to products B (3,2 points), H (3,5 points) and G (3,8 points).

In the research by Mozolewski, Wieczorek and Pomianowski [2011] potato chips received scores from 3,1 to 3,8 points.

Texture

Apart from color, odor and flavor, texture is an important feature of potato chips, influencing consumer acceptance [Kita 2001]. According to Scanlon *et al.* [1994], color and texture are actually the most important sensory parameters of potato chips.

The texture of potato chips is often associated with crispiness, hardness and crunchiness [Salvadro *et al.* 2009]. Crispiness is a very important quality of potato chips [Yu *et al.* 2016]. Raw material as well as manufacturing process conditions affect the crispiness of potato chips [Segnini, Dejmek & Öste 1999]. According to research by Salvador et al. (2009), high fat content negatively influences chips' crispiness.

According to the assessors potato chips E and F had the best texture (4,75 points). Significantly lower ratings for this parameter were given to product G (mean – 3,7 points).

In the research by Wójcik-Stopczyńska and Grzeszczuk [2003] all analyzed potato chips received ratings higher than 4 points, whereas in the study by Mozolewski, Wieczorek and Pomianowski [2011] potato chips were scored from 2,5 to 4,0 points.

SQI

Products E and F were of significantly highest sensory quality in the analyzed research material. Their sensory quality indices (SQI) were accordingly: 4,54 points and 4,81 points. Samples B and H were assessed as being of the worst sensory quality (3,07 points and 3,02 points respectively). It should be noted that according to Polish Standard PN-A-74780, products A, B, C, G and H should be disqualified for the shape and size as well as color ratings.

In the research by Wójcik-Stopczyńska and Grzeszczuk [2003] overall ratings for flavored potato chips ranged between 3,73 and 4,21 points and in the study by Mozolewski, Wieczorek and Pomianowski [2011] between 2,84 and 3,44 points.

Hierarchical clustering

The results of hierarchical clustering prove that the analyzed research material can be divided into two groups of similar products (see Figure 1.). The first cluster was formed of products A, B, G, H and the second of products C, D, E, F. The first group included products of the lowest price. Three of them A, G and H were private labeled products The products in the second cluster were sold under well-known brands and represented higher quality. Only one product (C) was sold under store brand. In this case, however, the seller was a premium delicatessen.

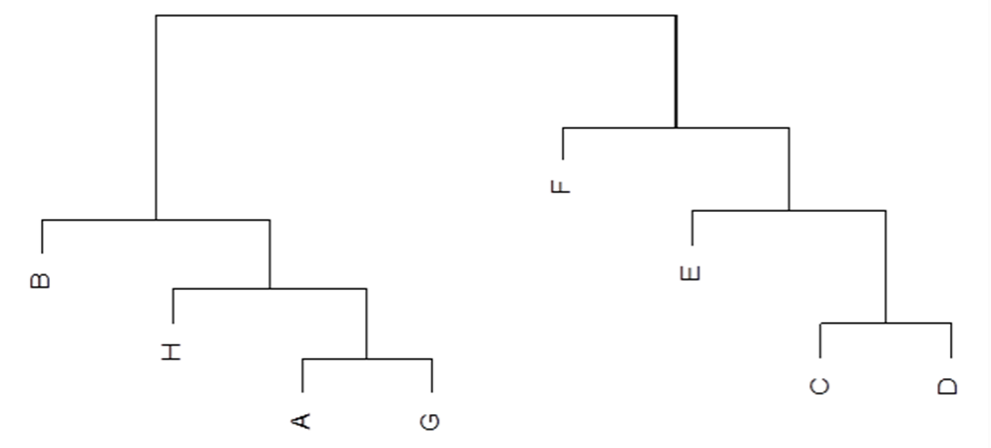

Figure 1. Visualization of hierarchical clustering results with the use of dendrogram
Source: own research

Conclusions

Today's consumers choose food that has desirable sensory properties. Nevertheless, more and more people begin to realize that nutrition affects their health. Potato chips are not among products that are advised to be included in everyday diet. Yet, unique sensory characteristics influence their high consumption rates.

Among commercially available potato chips differences regarding quality, nutritional value and sensory properties may be found. The best nutritional value can be attributed to products that actually cannot be classified as potato chips. They are made of potato flour and baked. This results in lower fat content. Nonetheless, they are still highly appreciated by consumers, what is proved by the results of analyses conducted for product F.

Certainly products of well-known manufacturers are of the highest sensory quality among the analyzed samples. Nevertheless, potato chips sold under delicatessen brand showed great similarity to these products. This was also confirmed by the results of hierarchical clustering.

Nutritional values of the analyzed potato chips, besides sample F, were similar. There were, however, statistically significant differences between single products regarding particular parameters. It is also worth noticing that the differences of salt content among products may reach even 40%. Therefore, in case of salted potato chips, the concentration of sodium chloride might be an important criterion for selection by consumers.

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