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QUALITATIVE CHARACTERIZATION OF FAT FRACTION FROM CRUNCHY CEREAL PRODUCTS AVAILABLE ON THE POLISH MARKET

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Abstract

The paper presents the qualitative assessment of fat isolated from the selected crunchy cereal products available on the Polish market. The samples were characterized by determination of the fatty acids composition and distribution in triacylglycerol structure. Additionally, oxidative stability was identified. To estimate the quality of the fat, the acid value and the peroxide value were also determined. The results showed that the tested products were a good source of monounsaturated and polyunsaturated fatty acids, especially oleic and linoleic acid. Analyzed products showed statistically different resistance to oxidation. The longest time of oxidation induction was determined in the case of fat extracted from crunchy cereal bar covered with chocolate, while the shortest for the fat extracted from crunchy breakfast cereals with chia seed. The analysis of the peroxide and the acid values did not show any abnormalities regarding the quality of the fat tested.

Introduction

Cereal products belong to one of the most important groups of products that are considered when preparing a balanced diet. The continuous growth of consumer nutritional expectations contributes to the develop-

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ment of the market of cereal products. Among a large variety of bread and many confectionery products, such as cakes, cookies, rolls and croissants, breakfast cereals and crunchy products occupy a significant place. To crunchy products, we can include crunchy breakfast cereals and cereal bars based on oat flakes. Both, when made of the whole grain oat, are claimed to be rich in fiber, vitamins, and minerals such as phosphorus and manganese. LASKOWSKI et al. (2019) studied the food sources of energy and 28 nutrients from cereals and cereal products in the average Polish diet. The results indicated that cereals and cereal products are the source of 30.4% of total dietary energy, providing a significant percentage of manganese, carbohydrates, dietary fibre, iron, folate and copper. Polyunsaturated fatty acids (PUFA) were supplied at the level of 10–20%. For such nutrients like total fat, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) the share of cereals and cereal products contribution was below 10%. The assortment of crunchy cereal products is varied and dependent on the additives that were used in the production process, such as dried fruit, nuts, seeds, and chocolate. Oat grain, the basic raw material used for the production of crunchy products, contains the soluble fiber, protein, carbohydrates, fats, minerals and vitamins, some antioxidants, such as phytic acid, vitamin E and polyphenolic compounds (OTLES and CAGINDI 2006). In comparison to wheat and rye, oats are characterized by a high-fat content, which may range from 8 to 10% in dehusked oat grain, and about 5% in the raw one (GĄSIOROWSKI 1995). Pearl millet grain has a wide range of opportunity for utilization in production of ready-to-eat, nutritionally rich cereal bar products along with better sensory qualities. The product was found to be a source of 10.84% protein, 4.39% fat, 5.43% fiber, 3.17 mg/100g zinc, 5.13 mg/100 g iron, and 215.63 mg /100 g phosphorus (KUMARI et al. 2019). Bioactive compounds present in cereals help in preventing the risk of chronic diseases as a functional ingredient (SOFI et al. 2019). Vegetable fats occurring in cereal products have been recognized by physicians, dieticians, and nutritionists as one of the important sources of unsaturated n-3 and n-6 fatty acids (ACHREMOWICZ and SZARY-SWORST 2005). Therefore, they should be consumed by contemporary society to prevent cardiovascular diseases, which are the results of both, an inadequate diet and a lack of physical activity. It is known, that the condition of the blood circulation system depends primarily on the amount and the quality of fat consumed (CONNOR 2000, JELIŃSKA 2005). The quality of fats is influenced by many factors, such as the composition of fatty acids, its bioavailability, and resistance to oxidation. Considering the fact, that crunchy products are mostly consumed in large quantities, especially by the children, hence their fat profile can affect human health.

The aim of the study was to characterize and assess the quality of fat fraction extracted from crunchy cereal products available on the Polish market by determining such parameters as: fatty acids composition and distribution in triacylglycerol structure, oxidative and hydrolytic stability.

Materials and Methods

Determination of Fatty Acids (FA) Composition

The research material consisted of three kinds of crunchy cereal bars (covered with chocolate [1], with nuts and almonds [2], and with dried cranberries and raspberries [3]) and four crunchy breakfast kinds of cereal (banana-flavored with chocolate [4], and with chia seeds [5], with dried fruit [6], and classic [7]), all purchased in the local store.

The composition of fatty acids in crunchy cereal products was determined by gas chromatography, after prior extraction of the fat phase from the product under study. Lipid fraction was extracted from cereal products according to the procedure described by SHAHIDI et al. (1997). After mechanical grinding, 30 g of the sample was homogenized with 100 mL of hexane in a glass bottle with a screw-cap at room temperature. After 1 hour of homogenization, the content was filtered and dried with $MgSO_4$ by 30 minutes. The organic solvent was removed by the rotary evaporator at 40°C. The residue of hexane was removed by applying nitrogen flow. The fat sample was stored at -18°C until it was analyzed.

In order to determine the composition of fatty acids in the lipid fraction of crunchy cereal products, a gas chromatography (GC) method was used. Methyl esters of fatty acids were obtained by the addition of a 1M solution of KOH in methanol according to *Oleje i tłuszcze roślinne*… PN-EN ISO 5509: 2001. A Shimadzu GC 17A chromatograph equipped with a flame ionization detector and a BPX-70 capillary column of 0.22 mm (internal diameter) 30 m length and 0.25 mm film thickness was used. The oven temperature was programmed as follows: 60°C for 1 min, then it was increased by 10°C/min to 170°C; from 170°C to 230°C, it was increased by 3°C/min; then kept at 230°C for another 15 min. The temperature of the split injector was 225°C, with a split ratio of 1:100, and the detector temperature was 250°C. Nitrogen flowing with the rate of 1 ml/min was used as the carrier gas. The identification of fatty acids was carried out using the lipid standard purchased from Sigma Aldrich, Supelco Analytical, Bellefonte, PA, USA.

Determination of Fatty Acids Distribution

In order to determine the distribution of fatty acids in the lipid fraction of crunchy cereal products, the Brockerhoff method (partial hydrolysis of triacylglycerol) was carried out in the presence of an enzyme – pancreatic lipase (BROCKERHOFF 1965, HAZUKA et al. 2003). 100 mg of fat was weighed on the analytical balance into a 20 ml centrifuge tube, then 1 ml of a 1 M TRIS-HCl (pH = 8), 0.1 ml of 2.2% calcium chloride solution and 0.25 ml of 0.05% bile salt were added. The sample was mixed intensively for 30 seconds. 20 mg of pancreatic lipase was added and a mixture was mixed intensively for the next 30 seconds. The sample was then incubated in a water bath at 40°C for 3 minutes. After incubation, 1 ml of a 6 M HCl and 4 ml of diethyl ether were added to the sample and also mixed intensively for 60 seconds. The sample was then placed in the centrifuge for 5 minutes. Separated organic layer was concentrated under a nitrogen atmosphere to a volume of approx. 1 ml and the mixture was applied to a plate coated with silica gel in the dimensions 20 cm x 20 cm. The plate was placed in the chamber with the appropriate solvents system. Isolated sn-2 monoacylglycerols (MAG) were removed from the plates along with the gel and subjected to extraction. The determination of the fatty acids present in sn-2 position was done by the use of gas chromatography (HAZUKA et al. 2003).

The share of fatty acids for the sn-1 and sn-3 positions was calculated based on the knowledge of the starting composition of triacylglycerols and isolated sn-2 monoacylglycerols as followed:

$$\text{sn-1,3} = \frac{3 \cdot (\text{FA in TAG}) - (\text{FA in sn-2 MAG})}{2}$$

where:
sn-1,3 – the content of a given fatty acid in the sn-1 and sn-3 positions [%]
FA in TAG – the content of a given fatty acid in starting triacylglycerols [%]
FA in sn-2 MAG – the content of a given fatty acid in sn-2 monoacylglycerols [%].

The percentage of selected fatty acids in the sn-2 position of monoacylglycerols in relation to the total fatty acid content in all triacylglycerol positions was calculated as followed:

$$\text{sn-2} = \frac{\text{FA in sn-2 MAG}}{3 \cdot (\text{FA in TAG})}$$

Determination of Oxidative Stability

In order to determine the oxidative stability of the fat extracted from crunchy cereal products, the oxidation time was obtained by the use of pressure differential scanning calorimetry (PDSC).

For each measurement, 3–4 mg of the fat sample was weighed in an aluminum pan. The prepared sample together with the control sample (empty aluminum vessel) was placed in the measuring chamber of the Thermal Analysis DSC Q20. The measurements were carried out in isothermal conditions at 140°C and under 1400 kPa of oxygen pressure. From resulting PDSC exotherms the time to reach the peak maximum (τ_{max}) was determined and used for the assessment of the oxidative stabilities of the samples.

Determination of Peroxide and Acid Value

Both, the peroxide value (PV) and the acid value (AV) were performed according to the Polish Standards (*Oleje i tłuszcze roślinne…* PN-EN ISO: 3960: 2012, *Oleje i tłuszcze roślinne…* PN – EN ISO 660: 2010).

Statistical Analysis

All tests were performed in triplicate. The statistical analysis of the results was conducted using Statistica 10 PL (StatSoft Poland Sp. z o.o, Kraków, Poland). ANOVA analysis was also performed. The significance of differences between means were determined using Tukey's test at a significance level of $p < 0.05$.

Results and Discussion

The content of individual groups of fatty acids and composition of FA in all position of TAGs is shown in Figure 1 and Table 1. In the fat isolated from the crunchy cereal bar covered with chocolate, the highest part was saturated fatty acids (SFA), 60.07%, whereas monounsaturated fatty acids (MUFA) and polyunsaturated acids (PUFA) contributed 33.99% and 5.95%, respectively. Among saturated fatty acids, the highest proportion of stearic acid (C18:0) was found (31.67%). Unsaturated fatty acids – oleic acid (C18:1 n-9c) and linoleic acid (C18:2 n-6c) were detected in the amount of 33.53% and 5.25%, respectively – Table 1. The highest content of SFA was found in fat isolated from a crunchy cereal bar with cranberries and raspberries (67.20%) whereas MUFA and PUFA contributed 23.54%

and 9.26%, respectively (Fig. 1). Among the saturated fatty acids, the highest share of palmitic acid (C16:0) was found (25.30%). Oleic acid (C18:1 n-9c) was detected in the amount of 23.19%, while polyunsaturated fatty acid – linoleic acid (C18:2 n-6c) – at a level of 8.82% – Table 1.

Table 1

Composition of the most important fatty acids in internal and external positions of triacylglycerols (TAG) in fat extracted from three crunchy cereal bars: covered with chocolate [1], with nuts and almonds [2], with dried cranberries and raspberries [3], and the share [%] of individual fatty acids in internal position (sn-2)

Fatty acid (FA)	Composition of FA in all positions of TAGs [%]			Distribution of FA in positions, sn-2 and sn-1,3 [%]						Share of FA in sn-2 position [%]		
				sn-2			sn-1,3					
	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]
C12:0	–	–	23.58	–	–	29.73	–	–	20.51	–	–	42.03
C14:0	–	–	–	–	–	15.25	–	–	8.08	–	–	48.55
C16:0	26.40	18.43	25.30	8.38	7.80	15.41	35.41	23.76	30.25	10.58	14.12	20.30
C18:0	31.67	15.58	4.76	5.56	3.22	3.47	44.73	21.76	5.41	5.85	6.84	24.30
C18:1 (n-9c)	33.53	53.62	23.19	70.92	70.35	25.59	14.84	45.26	21.90	70.50	43.75	36.78
C18:2 (n-6c)	5.25	7.55	8.82	10.76	14.70	8.40	2.50	3.96	9.03	68.32	64.90	31.75

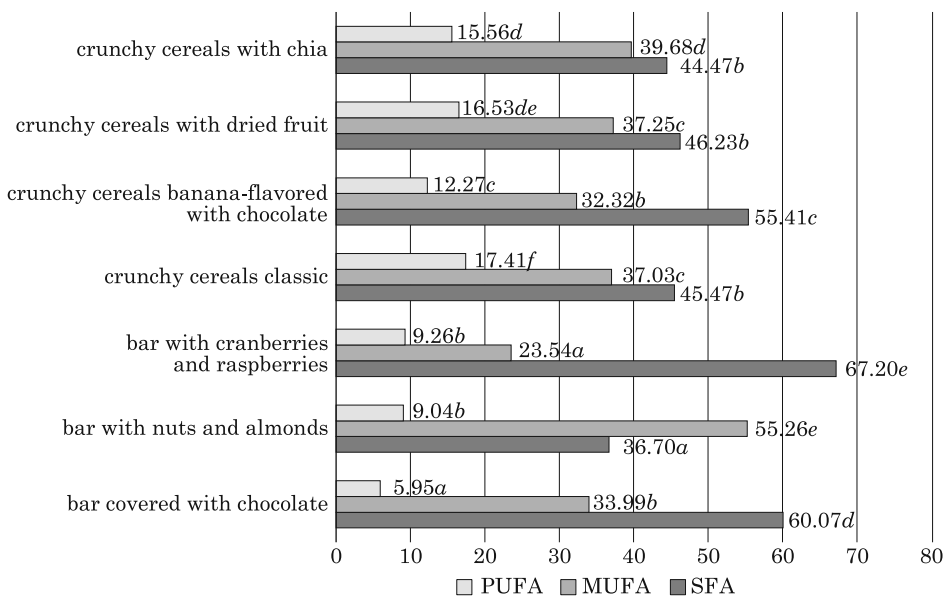

Fig. 1. The content of saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids in crunchy cereal products available on the Polish market. The values with the same letter for the same category of fatty acids do not differ statistically on the level $p < 0.05$

In contrary, the fat isolated from a crunchy cereal bar with nuts and almonds contained in the majority the monounsaturated fatty acid (55.26%) probably due to the addition of nuts which naturally contain a lot of MUFA (Fig. 1). Subsequent groups of fatty acids were saturated (35.70%), and polyunsaturated (9.04%). In the group of SFA, the highest share of palmitic acid (C16:0) was observed (18.43%). Oleic acid (C18:1 n-9c) was found at a level of 53.62%, while linoleic acid (C18: 2 n-6c) – 7.55% (Table 1).

Crunchy breakfast cereals were another group of products tested. Among analyzed samples, the largest share of MUFA (39.68%) was characterized in the fat from crunchy flakes with chia seeds, but PUFA (17.41%) – crunchy cereal classic. Oleic acid (C18:1 n-9c) was present in the tested sample of fat from crunchy flakes with chia seeds in amount of 40.10%, whereas linoleic acid (C18:2 n-6c) had a wading share of 14.36% – Table 2.

Table 2

Composition of the most important fatty acids in internal and external positions of triacylglycerols (TAG) in fat extracted from two crunchy breakfast cereals: banana-flavored with chocolate [4], with chia seeds [5] and share [%] of individual acids in internal position (sn-2)

Fatty acid (FA)	Composition of FA in all positions of TAGs [%]		Distribution of FA in positions, sn-2 and sn-1,3 [%]				Share of FA in sn-2 position [%]	
			sn-2		sn-1,3			
	[4]	[5]	[4]	[5]	[4]	[5]	[4]	[5]
C12:0	8.75	–	17.67	–	4.29	–	67.31	–
C14:0	4.18	–	3.21	–	4.67	–	25.60	–
C16:0	27.75	37.12	11.83	18.42	35.71	46.47	14.21	16.54
C18:0	–	4.46	–	3.62	–	4.88	–	27.06
C18:1 (n-9c)	31.72	40.10	46.17	54.61	24.50	32.85	48.52	45.39
C18:2 (n-6c)	11.55	14.36	16.86	20.12	8.90	11.48	48.66	46.70

Similar dependencies were also found in the case of crunchy cereal with dried fruit. The fat was the richest in saturated fatty acids (46.23%) with two other groups, MUFA and PUFA, resulting in 37.25% and 16.53%, respectively (Figure 1). Among the saturated fatty acids, the highest share of palmitic acid (C16:0) was found (35.19%). Oleic acid (C18:1 n-9c) was detected on a level of 36.63%, while linoleic acid (C18:2 n-6c) was present in the tested sample in the amount of 15.65% – Table 3. The fat isolated from crunchy breakfast cereal banana-flavored with chocolate was characterized by the highest share of saturated fatty acids (55.41%), among which palmitic acid dominated (C16:0) (27.75%) – Table 2.

Next groups were monounsaturated fatty acids (32.32%), and polyunsaturated acids (12.27%) – Figure 1, with the share of oleic acid (C18:1 n-9c) (31.72%) and linoleic acid (C18:2 n-6c) (11.55%), respectively (Table 2). In the fat sample extracted from crunchy cereals classic, the highest proportion of saturated fatty acids was found (45.47%). The subsequent groups observed were MUFA (37.03%) and PUFA (17.4%) with the content of oleic acid (C18:1 n-9c) (36.77%) and linoleic acid (C18:2 n-6c) (16.71%), respectively (Table 3).

Table 3

Composition of the most important fatty acids in internal and external positions of triacylglycerols (TAG) in fat extracted from two crunchy breakfast cereals: with dried fruit [6], classic [7] and the share [%] of individual acids in internal position (sn-2)

Fatty acid (FA)	Composition of FA in all positions of TAGs [%]		Distribution of FA in positions, sn-2 and sn-1,3 [%]				Share of FA in sn-2 position [%]	
			sn-2		sn-1,3			
	[6]	[7]	[6]	[7]	[6]	[7]	[6]	[7]
C12:0	2.99	3.35	5.81	6.36	1.58	1.85	64.77	63.28
C16:0	35.18	33.77	13.60	14.86	45.97	43.23	12.87	14.67
C18:1 n-9c	36.63	36.77	48.98	51.82	30.46	29.25	44.57	46.98
C18:2 n-6c	15.65	16.71	20.18	22.65	13.39	13.76	42.98	45.11

The share of PUFA is higher in the fat extracted from breakfast cereal than in the fat extracted from crunchy cereal bars. Among the last group the largest share of these fatty acids is found in the fat extracted from the crunchy cereal bar with cranberries and raspberries as well as nuts and almonds, the smallest in the fat extracted from the crunchy cereal bar covered with chocolate. Comparable SFA content was found in the fat extracted from crunchy breakfast cereals with dried fruit, classic and with chia seeds. Figure 1 presents that there are statistically significant differences in the content of MUFA and PUFA between the tested samples.

According to LANGE (2009) in the oat oil dominated unsaturated fatty acids with preference to linoleic (26–53%), oleic (19–48%) and α-linolenic (0.5–5%). According to WIRKOWSKA and BRYŚ (2009), who investigated the composition of fatty acids in cereal biscuits, similarly, unsaturated fatty acids contributed more with preference to oleic acid (37.8– 54.6%), linoleic acid (11.4–38.2%), and α-linolenic acid (0.2–4.3%). Our results for crunchy breakfast cereals with chia seeds are the only cereal product corresponding with mentioned research. PASZCZYK et al. (2007) investigated composition of fatty acids and trans isomers of fatty acids in fats of selected confectionery products. In the examined confectioneries the participation

of saturated fatty acids in fat in first group of products (biscuits, cakes, gingerbreads, sponge cakes and croissant) ranged from 24.4% to 81.2%, whereas that of monounsaturated fatty acids – from 14.1% to 63.2%, and polyunsaturated fatty acids – from 4.8% to 11.8%. In fat of second group of products (wafers), saturated fatty acids constituted from 35.4% to 63.4%, monounsaturated fatty acids – from 29.1% to 63.2%, and polyunsaturated fatty acids – from 3.2% to 10.0%. In our study, in all cases, except for the crunchy cereal bar with nuts and almonds, the largest amount of saturated fatty acids was detected (44.4–67.20%). Monounsaturated and polyunsaturated fatty acids were present in the range of 23.54–55.26% and 5.95–17.41%, respectively. CALIONARA et al. (2015) analyzed chemical composition and fatty acids profile of chocolates produced with different cocoa (*Theobroma cacao* L.) cultivars. They concluded, that C16:0, C18:0, C18:1n9 and C18:2n6 were, quantitatively, the most important fatty acids in all of the studied samples. The prevalence of saturated fatty acids on unsaturated fatty acids is considered to be negative from a nutritional point of view. TORRES-MORENO et al. (2015) investigated nutritional composition and fatty acids profile in cocoa beans and chocolates with different geographical origin and processing conditions. For cocoa, differences in fatty acid profile were found in C12:0, C14:0, C16:0, C16:1, C17:0, C17:1 and C18:0 whilst for chocolates only differences were found in C16:0, C18:0, C18:1 and C18:2. For all samples, C16:0, C18:0, C18:1 and C18:2 were quantitatively the most important fatty acids. Ecuadorian chocolate showed a healthier fatty acid profile having higher amounts of unsaturated FA and lower amounts of saturated fatty acids than Ghanaian chocolate. The SFA content in the human diet largely affects the serum cholesterol level. KRIS-ETHERTON (1999) showed that saturated fatty acids, such as palmitic, myristic or lauric, are responsible for hypercholesterolemic action, thereby increasing cholesterol and low-density lipoprotein (LDL) levels. SFA causes vascular clots and increases the tendency of platelets to aggregate. A diet rich in SFA increases the risk of myocardial infarction or cardiovascular disease (JIMENEZ-COLMENERO et al. 2001). In the case of fat extracted from the crunchy bar with nuts and almonds, MUFA had the largest share. In all tested products, we can observe the smallest share of polyunsaturated fatty acids. Based on the results, it can be concluded that there are statistically significant differences between SFA content in analyzed samples.

The quality of fats depends not only on the composition of fatty acids but also on the distribution of fatty acids in the triacylglycerol molecule (TAG). The distribution of fatty acids in the triacylglycerol molecule is important in the digestion tract, absorption of fats in the human body, as

well as in the process of modifying the structure of triacylglycerols. Pancreatic lipase participates in the digestion of fats in the human digestive tract. It has a specific ability due to which fatty acids are detached from the external position (sn-1 or sn-3) of triacylglycerols, which results in the formation of free fatty acids in the small intestine and sn-2 substituted monoacylglycerols (BRYŚ et al. 2011). If saturated fatty acids occupy the sn-2 position, polyunsaturated fatty acids move freely in digestion track. PUFA and their salts show a high coefficient of absorption (WIRKOWSKA et al. 2012). If, on the other hand, SFA occupy external positions (sn-1, sn-3) this is unfavorable from the nutritional point of view. Saturated fatty acids, moving freely in the human body, they tend to form hard-soluble calcium salts, which may lead to calcium deficiencies in the body (HUNTER 2001). The results of the performed analysis of fatty acid distribution in crunchy cereal products available on the Polish market are presented in Tables 1–3. The proportion of selected fatty acids in the sn-2 position of triacylglycerols in the fat extracted from three crunchy cereal bars: covered with chocolate [1], with nuts and almonds [2], and with cranberries and raspberries [3] is shown in Table 1. In two products, [1] and [2], the sn-2 position was occupied mainly by oleic acid (70.92% and 70.35%, respectively), and its share in this position was 70.50% and 43.50%, respectively. The content of linoleic acid in the sn-2 position for all crunchy cereal bars was within comparable, yet statistically different, range (8.40 –14.70%). Among the SFA group, the highest content in the sn-2 position contributed to palmitic acid in two crunchy cereal bars [1] and [2], but in case of crunchy cereal bar with cranberries and raspberries [3], the lauric acid was in the majority in that location (29.73%) and the next myristic and palmitic acid. The presence of the stearic acid was detected for all three bars, but it was rather minor importance (3.22–5.56%). Table 2 shows the share of selected fatty acids in the sn-2 position of triacylglycerols in fat extracted from two crunchy breakfast cereals: banana-flavored with chocolate [4] and with chia seeds [5]. In the largest number in the sn-2 position there was oleic acid (46.17% and 54.61%, respectively) and its share was equal 48.52% and 45.39%, respectively. The content of linoleic acid in the sn-2 position was 16.86 (banana-flavored with chocolate), with 48.66% share, and 20.12 (crunchy cereals with chia) – with 46.70% share. Among the SFAs, the highest amount in the sn-2 position was reported for lauric acid (17.67%), with 67.31% share. The highest amount in sn-2 position was found for oleic acid (54.61%), and its share in this location was as much as 45.39%. The content of linoleic acid in the sn-2 position was 20.12%, with 46.70% share. Among saturated fatty acids, palmitic acid (18.42%) was the most popular in the sn-2 position, and its share in this position was 16.54%.

The content of stearic acid in the sn-2 position was 3.62%, with 27.06% share. Table 3 shows the share of selected fatty acids in the sn-2 position of triacylglycerols in the fat extracted from next two crunchy breakfast cereals: with dried fruits [6] and classic [7]. In the largest amount in the sn-2 position there was oleic acid in both types of bar (48.98% [6] and 51.82% [7]), and its share in this position was 44.57% and 46.98%, respectively. The content of linoleic acid in the sn-2 position was also comparable, 20.18% and 22.65%, respectively, with similar share in each fat. Among the SFAs, the highest content in the sn-2 position was determined for palmitic acid in each sample (13.60% and 14.86%, respectively). The content of lauric acid in TAGs was similarly low for both crunchy cereal bars [6] and [7], 2.99% and 3.35%, respectively however, when present, it occupied mainly the sn-2 position, with 64.77% and 63.28% share respectively.

After analyzing the obtained results, fat isolated from crunchy breakfast cereals with dried fruit as well as crunchy cereals classic have a very similar fatty acid composition and distribution in sn-2 and sn-1,3 positions as well as share of a given fatty acid in sn-2 positions. In all analyzed fats, except the fat isolated from crunchy cereal bar with cranberries and raspberries, the oleic acid was noticed to have the highest percentage in the sn-2 position. Noticed distribution of saturated fatty acid in the sn-1,3 position in the triacylglycerol molecule can have a negative effect on the digestion and absorption of fats in the human body. In contrary, in the fat extracted from the crunchy cereal bar with cranberries and raspberries, there was the highest content of saturated acids in the sn-2 position. The dominant fatty acids in this position were lauric acid (29.73%), and its share in this position was as much as 42.03% and myristic acid – 15.25%, with 48.55% share. Among the unsaturated fatty acids high oleic acid content was found in the sn-2 position of triacylglycerols, and its share in this position was 36.78%.

The food quality is influenced by various processes, both biochemical and physicochemical. Oxidation contributes to undesirable changes occurring in food, which leads to a significant drop in products' quality, and even to its damage (HĘŚ and KORCZAK 2007). Pressure differential scanning calorimetry can be used to determine thermodynamic parameters and the oxidative stability of lipids. The determination of the induction time is aimed to estimate the oxidative stability of the fat being tested. In this study, the principle is assumed that the longer the induction time, the greater the oxidative stability of the test sample (THURGOOD et al. 2007). To test the resistance of fat from crunchy cereal products for oxidation, the PDSC test was performed isothermally, at 140°C. Average times of induction of crunchy cereal products are shown in Figure 2. Analyzing the ave-

rage time needed to initiate oxidation process of the fat isolated from crunchy cereal products, statistically significant differences were observed.

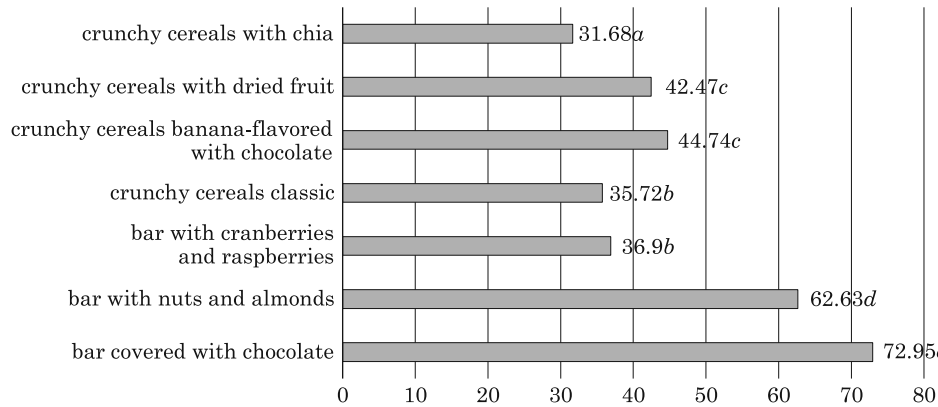

Fig. 2. Induction time [min] for fat extracted from crunchy cereal products available on Polish market. The values with the same letter do not differ statistically on the level $p < 0.05$

The longest time of induction was determined for fat extracted from crunchy cereal bar covered with chocolate (72.95 min), while the shortest time of oxidation induction was detected for the fat extracted from crunchy breakfast cereals with chia seeds (31.68 min) – Figure 2. A bit longer time was found for the fat extracted from crunchy cereal bar with cranberries and raspberries (36.90 min) and fat extracted from classic crunchy breakfast cereals (35.72 min). Time of oxidation induction of fat extracted from crunchy breakfast cereals banana-flavored with chocolate (44.74 min) and fat extracted from crunchy cereals with dried fruit (42.47 min) did not differ statistically. Unexpectedly, despite the high content of monounsaturated fatty acids in TAGs, the induction time of fat extracted from crunchy cereal bar with nuts and almonds was quite high – 62.63 min.

Peroxide value (PV) determines the degree of fat oxidation, taking into account the content of primary oxidation products. Analyzing the data on the peroxide value, it can be concluded that there were statistical differences between the obtained values for different crunchy cereal products (Fig. 3). The smallest value of the peroxide value was obtained for the fat extracted from the crunchy cereal bar with cranberries and raspberries (1.63 mEq O_2/kg fat). The highest peroxide value was determined for the fat extracted from crunchy breakfast cereals with chia seeds (6.70 mEqO_2/kg fat). The obtained values are consistent with the composition of fatty acids. A high proportion of unsaturated fatty acids in the structure of triacylglycerols induced higher values peroxide value. It is worth emphasizing that fat extracted from crunchy breakfast cereals with chia seeds was also

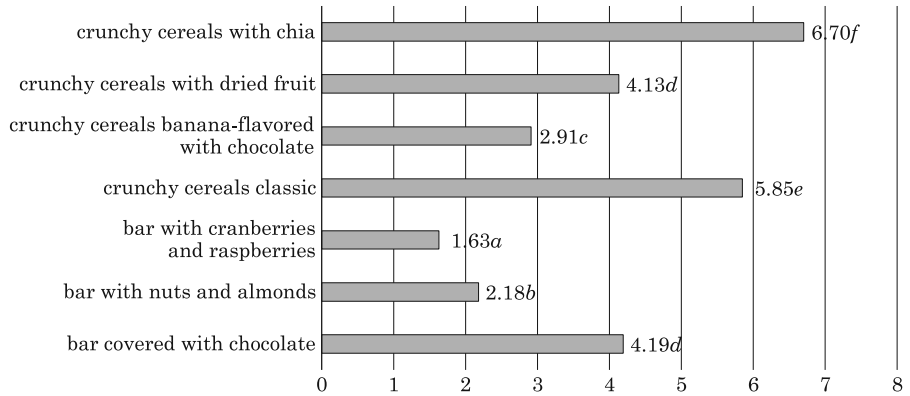

Fig. 3. Peroxide value for crunchy cereal products available on Polish market. The values with the same letter do not differ statistically on the level $p < 0.05$

distinguished by the shortest time of induction.

Codex Alimentarius informs that the peroxide value for cold-pressed oils should be lower than 10 mEq O_2/kg. All results were significantly lower than the allowed standard. WIRKOWSKA and BRYŚ (2009) in their research on the quality of the lipid fractions in cereal biscuits analyzed, inter alia, the peroxide value. The peroxide value for fat extracted from cereal biscuits was from 1 to 4 mEq O_2/kg fat. The results of the peroxide value obtained in our study are mostly comparable to the results obtained by WIRKOWSKA and BRYŚ (2009).

The acid value (AV) is a measure of the content of free fatty acids, therefore it determines the degree of fat hydrolysis. It is defined as the number of mg of potassium hydroxide needed to neutralize fatty acids present in 1 gram of fat (BERG et al. 2005). Analyzing the results on the acid value, it can be concluded that there were statistically significant differences between the individual acid values for crunchy cereal products. Results obtained

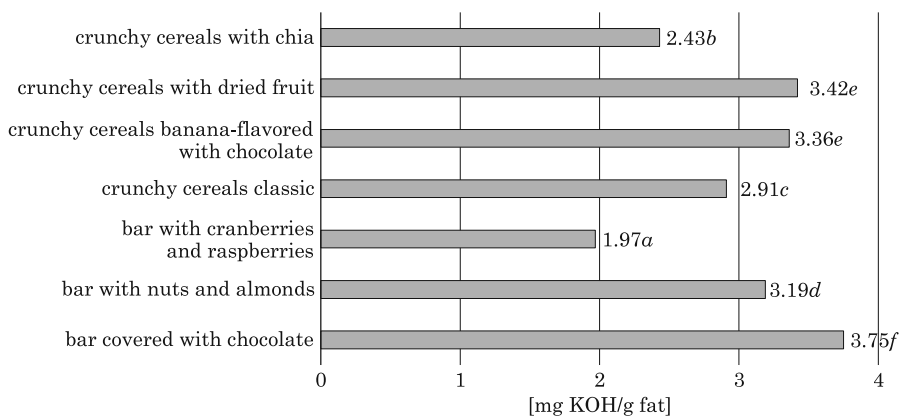

Fig. 4. Acid value for crunchy cereal products available on Polish market. The values with the same letter do not differ statistically on the level $p < 0.05$

for fats extracted from crunchy cereal products are presented in Figure 4. The lowest acid value was determined in the case of the fat extracted from the crunchy cereal bar with cranberries and raspberries (1.97 mg KOH/g fat), while the highest value for the fat extracted from the crunchy cereal bar banana covered with chocolate (3.75 mg KOH/g fat).

According to the Polish standard (*Oleje i tłuszcze roślinne…* PN-EN ISO 660:2010) the value of AV for cold-pressed oil should not exceed 4.00 mg KOH/g fat. None of crunchy cereal products exceeded the limit regarding acid value given in the Polish Standard, hence all tested crunchy products were formed from good quality grains and their processing, as well as storage conditions, were adequate.

Conclusions

The result of the present study showed that fat isolated from crunchy cereal bars and crunchy breakfast cereal are a source of favorable monounsaturated and polyunsaturated fatty acids, especially oleic and linoleic acid. The share of PUFA was higher in the fat extracted from breakfast cereal than in the fat extracted from crunchy cereal bars. Among the tested group of products the largest share of these fatty acids was found in the fat extracted from the crunchy cereal classic. Fat isolated from bar with nuts and almonds was the reachest source of monounsaturated fatty acid. In all analyzed fats, except the fat isolated from crunchy cereal bar with cranberries and raspberries, the oleic acid was noticed to have the highest percentage in the sn-2 position. Fat extracted from crunchy cereal bar covered with chocolate was characterized by greatest oxidative stability, whereas fat isolated from crunchy breakfast cereals with chia seeds was most susceptible to oxidation. Fat fractions isolated from crunchy cereal products were of acceptable hydrolytic and oxidative stability.

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