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Content of nutrient and bioactive non-nutrient components in different oat products

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RESEARCH ARTICLE

Abstract

The major grains in human diet are wheat, rice and corn, but in the last few years oats (*Avena sativa* L.) have received increased attention by the food industry because of their unique chemical composition and structure. They are known as a healthy food containing high biological value protein, polyunsaturated fatty acids and a significant amount of soluble dietary fibre. Due to the increasing number of civilisation diseases, the regular consumption of whole grains and whole grain products is recommended. Oat has the advantage that it is consumed as a whole grain cereal. The present study analyses the content of nutrients (protein, minerals, lipids, starch) and bioactive (β-glucan, dietary fibre, total phenolics) components of oat products available on the market. Analysed material included concentrated oat fibre, oat flour, two kinds of rolled oats and bran. The highest amount of nutrients and bioactive components was observed in concentrated oat fibre, particular in terms of protein (22.9%), lipids (10.2%), dietary fibre (27.7%) and its important β-glucan fraction (14.9%), as well as in oat bran with high fibre content. Concentrated oat fibre even in small amounts can be used for enrichment of human daily diet, while the high fibre oat bran is more popular and available on the market.

Keywords: β-glucan, dietary fibre, lipids, oats, protein

1. Introduction

During the last few years oat (*Avena sativa* L.) has received increased attention by the food industry because of its benefits associated with unique chemical composition and structure of its grains. Due to the increasing number of civilisation diseases, the regular consumption of whole grains and whole grain products is recommended. Although wheat and rice are consumed in considerably higher quantities worldwide, oat has the advantage that it is consumed as a whole grain cereal (Peterson, 2001).

Kernel structure, shape, size, mass and microstructure are individual for cereal species, and are associated with quality parameters, health benefits and utilisation of grains (Evers and Millart, 2002). There are significant differences between tissue composition of oat and wheat. The outer layers of both grains consist of the testa, nucellus and aleurone. In wheat there is also the pericarp that comprises an intermediate layer, while in oat this layer is absent (Black *et al.*, 2006). The chemical composition of outer layers and products obtained from these parts are also different for oat and wheat. Endosperm oat flour contains higher amounts of valuable compounds, such as dietary fibre (DF), proteins, unsaturated fatty acids, vitamins, minerals and phytochemicals in comparison to endosperm wheat flour. The main DF components of oat are β-glucan and arabinoxylan (AX), whereas the fibre of endosperm wheat flour primarily consists of AX and fructan, (1.3-2.9 and 1.7%, respectively) (Haskå *et al.*, 2008; Ordaz-Ortiz and Saulnier, 2005; Shewry *et al.*, 2010). β-glucan and AX are concentrated more in the bran fraction than in the endosperm, but the solubility of AX is higher in endosperm (Westerlund *et al.*, 1993). Another difference between oat and other cereals is starch physicochemical properties. They are connected with factors like different proportions of amylose and amylopectin in starch granules, the length of amylose chain, the frequency and spacing of branch points within the amylopectin molecule and their length (Hoover *et al.*, 2003; Zhou *et al.*, 1998). It has untypical properties such as small size of granules that form clusters with well-developed surface and high lipid content (Berski *et al.*, 2011). Oat and its products are perceived as a potential source of low cost protein with good nutritional value.

The highest concentration is in the subaleurone layer with globulins as the main fraction (70-80%), next are prolamins (4-14%) and albumins (12%), whereas wheat flour contains only 3-5% of the last fraction, that is very important and should be consumed by people who doesn't eat animal albumins (milk protein, hen egg ovalbumin), e.g. vegans. Among all cereals oat is the richest source of lipids. The most of oat lipids are located in the endosperm. Their account in endosperm oat flour is 9.1%, while in endosperm wheat flour only 1.7-2.3% (Health Canada, 2010). What is very important is their stability at room temperature. Results obtained by Keying *et al.* (2009) showed that the lipid content in an intact oat kernel stored for 1 year at room temperature is stable, due to the protection from endogenous antioxidants, such as tocopherols, L-ascorbic acid, thiols, phenolic amino acids and other phenolic compounds. Other compounds, which make oat unique among cereals are avenanthramides (Avns) that are evenly distributed in the grain. Avns are soluble polyphenolic antioxidants and are the substituted cinnamic acid amides of anthranilic acids. There are at least 25 distinct entities of which over 20 different types of Avns are present in oat, and the three major ones are A, B, and C (Bratt *et al.*, 2003).

Efforts put in last years into improving nutritional habits of society have not been very effective and meals still contain too much sugar, salt, saturated fatty acids and not enough of DF. Nowadays, the science of personalised nutrition is increasingly evolving and is going to be one of the key nutrition and health trends for 2018 and next years. Oats and its products could be important parts of this new strategy, due to the unique structure, chemical composition and still increasing popularity. Therefore, the aim of this study was to evaluate the content of nutritional and bioactive components in selected popular oat products available on the market in Poland and possibly other European countries. All products were compared to each other and also to oat grains to indicate the most valuable among them.

2. Materials and methods

Materials

The materials were six various oat products available on the Polish market: concentrated oat fibre (COF), oat bran with high fibre content (HFBO), regular oat bran (ROB), quick rolled oats (QRO), regular rolled oats (RRO) and oat flour (OFL). Because the raw material for the production of food is dehulled oat grain, two reference varieties, Bingo and Krezus, were included for comparison purposes (Danko Plant Breeders Ltd, Kościan, Poland). Additionally, one extra flour sample was tested, residual oat flour (ROFL), which is a by-product in the production of concentrated oat fibre. Both products were kindly donated by Microstructure Ltd., Co. (Warsaw, Poland). All samples were produced in 2016.

Samples preparation

Before the chemical analysis both types of oat bran, rolled oats and grains were ground in a Perten Laboratory Mill 3100 (Hägersten, Sweden) with 0.5 mm diameter sieves. All oat samples were stored in the fridge, in sealed plastic cups until analysed.

Analytical methods

Minerals content was determined gravimetrically, by sample incineration in a muffle furnace at 500 °C for 5 h, according to the AOAC method 923.03 (AOAC, 1995). Protein content was determined using the Dumas method on a Rapid N Cube apparatus (Elementar, Langenselbold, Germany) according to the AOAC 990.03 method (AOAC, 1995), using N×6.25 as a conversion factor. Total lipids content was determined gravimetrically by extraction using an acid solvent consisting of chloroform, methanol and concentrated hydrochloric acid (60:40:1, v/v/v) as described by Marchello *et al.* (1971). Available starch was measured using the Megazyme procedure (Bray, Ireland), consistent with the AACC approved method 76-13 (AACC, 2003). DF content was determined using the enzymatic-chemical method in accordance with the AACC 32-25 and AOAC 994.13 procedures as a sum of non-starch polysaccharides (NSP) and lignin with associated polyphenols (AACC, 2003; AOAC, 1995).

NSP content with its fractionation to soluble (S-NSP) and insoluble (I-NSP) fractions was determined using gas chromatography as previously described by Englyst and Cummings (1984). According to this procedure NSP of each fraction is a sum of individual monomers: arabinose, xylose, mannose, galactose and glucose. After enzymatic hydrolysis of starch, the samples were centrifuged and split into soluble (ethanol precipitates from supernatant) and insoluble (remaining pellet) fractions. Each of these fractions was hydrolysed to monosaccharides using 12 M sulphuric acid (100 °C) and converted to volatile alditol acetates. The alditol acetates were separated on the Clarus 500 gas chromatograph (Perkin Elmer, Shelton, CT, USA) equipped with autosampler, splitter injection port, flame ionization detector and a capillary quartz column Rtx-225 (0.53 mm × 30 m). Carrier gas was He. Separation was performed at 225 °C, and injection and detection at 275 °C.

Lignin and other insoluble residues were determined gravimetrically as described by Theander and Westerlund (1986). The percentage content of lignin and associated polyphenols was calculated on the basis of weight loss by incinerating the dried insoluble material. β-glucan content was analysed using the Megazyme procedure (Bray, Ireland) in accordance with the AACC 32-23 and AOAC 995.16 methods.

Total phenolic content (TPC) was determined using the Folin-Ciocalteu colorimetric method (Naczk *et al.*, 1998). In the first step phenolics from the samples were extracted with 80% methanol, and after centrifugation, with 70% acetone. Next, extracts were reacted with Folin-Ciocalteu reagent and neutralised with sodium carbonate. After 100 min, the absorbance of the resulting solution was measured at 750 nm. Gallic acid was used as the standard and TPC was expressed as mg GAE/100 g of sample. All chemical analyses were performed in duplicate and the results are reported on dry weigh basis [% of dw], measured according to the AACC method 44-15A (AACC, 2003). Mean values of results were accepted if their difference was below 10%.

Statistical analysis

To study variability in the content of chemical components within different oat products, a one-way fixed model of analysis of variance (ANOVA) and Tukey's contrast analysis were performed. Principal component analysis (PCA) was carried out to obtain an overview of the differences between the analysed oat products and their particular components. PCA analysis was performed using Statistica 12 software (StatSoft Inc., Tulsa, OK, USA).

Table 1. Average content of nutrient components in oat products and oat grains [% of dw].

Product[1]	Protein	Minerals	Lipids	Starch
COF	22.9a	4.4a	10.2a	26.5e
HFBO	17.3b	2.4b	6.3d	55.8d
ROB	15.4c	2.0e	7.3cd	58.4bc
QRO	13.9e	2.0e	6.7d	61.5ab
RRO	14.6d	1.9f	7.2d	58.9bc
OFL	14.9d	2.1d	7.1d	57.5bc
ROFL	13.9e	1.6g	7.4cd	63.8a
BINGO[2]	14.4d	2.0e	8.3bc	56.7d
KREZUS[2]	14.5d	2.2c	8.6b	56.8d
F-statistic	1,033.3	3,978.2	34.1	202.3
P-value	<0.0001	<0.0001	0.0001	<0.0001

[1] COF = concentrated oat fibre; HFOB = oat bran with high fibre content; OFL = oat flour; QRO = quick rolled oats; ROB = regular oat bran; ROFL = residual oat flour; RRO = regular rolled oats.
[2] BINGO and KREZUS are oat grain varieties.

3. Results and discussion

Nutrients

The content of nutrient components in tested samples is presented in Table 1. Results are described in particular groups of products: COF, flour, bran, flakes and oat grain.

Among all analysed products, the highest amount of protein, minerals and lipids, at a level of 22.9, 4.4 and 10.2% respectively, was determined in COF, but it contained the lowest amount of starch (26.5%). These results are consistent with the quality specification provided by the manufacturer. The protein and minerals contents are similar to those reported by Lambo *et al.* (2005), who obtained 22-23 and 3-4%, respectively, however the lipids content determined in our study was much lower (21 vs 10.2%). The reason for these differences is the COF production technology used, which is adapted only for four oat cultivars and based on physical methods, without the use of any chemicals. According to the manufacturer, COF has a reduced content of lipids and carbohydrates, therefore in our study COF contains two times less lipids in comparison to Lambo *et al.* (2005) results. It causes that the residual flour (ROFL), which is a by-product of the production process for this concentrate, contains the highest amount of starch (63.8%) and one of the highest lipids content (7.4%) among all the analysed products. In comparison with common flour (OFL) available on the market, the residual flour is characterised by the lowest level of protein (13.9 vs 14.9%) and minerals (1.6 vs 2.1%) and significantly higher level of starch (63.8 vs 57.5%). Both kinds of flour are valuable source of nutrients but utilising the ROFL is cheaper being a by-product. The results obtained for both flours are consistent with previously reported studies (Choi *et al.*, 2012; Hüttner *et al.*, 2010), where obtained values were in the range between 56.4-67.7% for starch, 5.2-10% for lipids, 11.1-17.1% for protein and 1.6-2.2% for minerals. Two kinds of oat flakes were the next group of characterised products. QRO in comparison with RRO were characterised by a significantly lower amount of protein (13.9 vs 14.6%) and a higher amount of starch (61.5 vs 58.9%). The content of minerals and lipids was slightly different between this two types of flakes. QRO contained 2.0% of minerals and 6.7% of lipids, whereas these features were 1.9 and 7.2%, respectively, for RRO. Considering the most important oat nutrient components, such as protein and lipids, the RRO are it's a better source than QRO. Obtained data are in accordance with the results reported by Hu *et al.* (2014), who described the following: protein in the range 10.3-14.8%, ash in the range 1.5-4.2% and lipids in the range 2.9-8.3%. In case of oat bran, HFOB, besides COF, was the second product with the highest amount of protein (17.3%) and minerals (2.4%) whereas starch content was at the level of 55.8%. Additionally, this product had the lowest, but not significantly, quantity of lipids (6.3%). These results indicate that it is a more valuable product than ROB. Moreover, ROB was characterised by significantly lower content of protein (15.4%) and minerals (2.0%), whereas the lipids (7.3%) and starch (58.4%) content was higher. Similar results for protein, minerals and lipids were reported by Beccerica *et al.* (2011), who analysed the chemical composition of a commercial oat bran. Luhaloo *et al.* (1998) also determined the amount of nutrient compounds in oat bran collected from different countries and obtained values in the range between 9.6-21.0% for protein, 2.0-4.1% for minerals, 8.2-12% for lipids and 40.4-60.5% for starch. Wide variations in the content of protein (5.5-27.8%), minerals (2.3-9.1%), lipids (1.0-12.0%) and starch have also been found previously in different types of oat bran (Marlett, 1993). The results obtained for reference oats varieties are relatively common and have been described by Biel *et al.* (2009) and Sterna *et al.* (2016). In our research the amount of protein, minerals and starch in oat grains was comparable to all products, except COF and in the case of protein also HFOB. The oat grains were characterised by the highest lipids content following the COF. Among all analysed products the highest variability of nutrients content was observed for minerals (CV=40%; coefficient of variation), much lower for starch (CV=23%) and protein (CV=20%) and the lowest for lipids (CV=17%). The high variability in the nutrients content between oat samples is mainly connected with the technological process of oat grains, because all kinds of products require different treatments during production, like milling, fractioning or hydro-thermal treatment. Moreover, the chemical composition of raw materials can be very diverse and depending on, among all, environmental conditions, growing location and degree of fertilisation.

Bioactive components

The content of bioactive components in oat products is presented in Table 2. As expected, COF had the highest amount of DF and NSP at a level of 27.7 and 25.1%, respectively. The predominant part of oat DF is a soluble fraction, responsible for the functional and health promoting properties of this cereal. This fraction consists mainly of the soluble part of NSP, among which the β-glucans are the most important components. In case of COF the content of S-NSP was at the level of 15.9%, whereas the β-glucans content was almost 15%. Other important DF constituents in COF were lignins with an average value of 2.7%. This product was also the main source of TPC (1.8 mg GAE/g). Obtained results were corresponding with data previously reported for concentrated oat fibre (Nordisk Innovations Centre, 2015), where DF content was in the range between 20 and 35% and β-glucans between 15 and 22%. However, they were inconsistent with results from Lambo *et al.* (2005), where the average DF content in fibre concentrate was at a level of 44.6%. The reason for these differences can be attributed to the different production process for each oat concentrate, as well as different DF content in the oat grain used as a raw material to produce these concentrates. Sterna *et al.* (2016) reported that total DF content of oat varied from 13.7 to 30.2%. The second product with the highest content of bioactive compounds was HFOB, which contained 11.8% of DF, 10.6% of NSP, 5.3% of β-glucans, and 1.2% of lignin. The amount of these components was significantly lower (except lignin and TPC) in regular oat bran (ROB), 9.5, 8.4, 4.3 and 1.1%, respectively. The content of each NSP fraction was also lower in comparison with HFOB. Luhaloo *et al.* (1998) analysed the chemical composition of commercial oat brans. He obtained DF content in the range between 10.7 and 19.4% and β-glucan content in the range between 4.7 and 8.3%. The same authors reported a slightly higher content of lignin, with mean value of 1.5%. The results obtained for TPC content of both kinds of oat bran were comparable (1.3 vs 1.2 mg GAE/g) but lower in comparison with values obtained by other authors. Piątkowska *et al.* (2010) analysed TPC in oat bran and obtained values in the range between 1.6 and 2.0 mg/g. The Folin-Ciocalteau method is commonly used to determine the TPC but some differences in the analytical process, like reducing agents or time of extraction can be observed between different laboratories. This may be the reason for the different results of TPC. There were no significant differences in the content and composition of DF between the QRO and RRO oat flakes. The DF content in both products was observed at a level of 9.3 and 9.0%, with NSP at a level of 8.3 and 7.9%. Likewise in case of other oat products, the main part of NSP was its soluble fraction and the obtained values ranged between 4.9% for RRO and 5.2% for QRO. The content of lignin and TPC in oat flakes was also comparable and the average values were 1.1% and 1.3 mg GAE/g, respectively. Bigger, but not significant, differences between oat flakes were observed in case of β-glucan content, at a level of 4.6% for QRO and 4.1% for RRO. Obtained results were consistent with previously reported studies, where the β-glucan content was in the range between 2.9 and 8.3%, with mean value of 4.9% (Hu *et al.,* 2014). Other studies reported a similar amount of β-glucan in oat flakes (4-5%), but a slightly higher content of DF, in the range between 10 and 12% (Nordisk Innovations Center, 2015). However, earlier studies described lower amount of β-glucan (3.6%), higher content of TPC (1.5-1.8 mg GAE/g) and similar DF concentration in oat cereals (Ryan *et al.,* 2011). All these differences, especially in the DF content, may be connected with the different processes for flakes production and simultaneously different participation of outer layers of oat grain, which constitute the main source of DF. Moreover, the oat varieties used, the technological process and the country of oat origin with their specific environmental conditions can also impact the content of its individual components. The two kinds of oat flour analysed were also a good source of bioactive components. Common oat flour (OFL) in comparison with ROFL was characterised by a significantly higher content of all bioactive compounds, except lignin and TPC. DF content in OFL was at a level of 9.1%, whereas in residual flour it was only 6.1%. Additionally, in comparison with ROFL, the content of NSP and its fractions was nearly double that of OFL, with values for individual parameters at a level of: NSP (8.1 vs 5.1%), I-NSP (3.0 vs 1.9%), S-NSP (5.1 vs 3.2%) and β-glucan (4.4 vs 2.3%). As mentioned previously the cause of these differences is the fact that ROFL is a by-product, which is created during the production of concentrated oat fibre (COF). The values obtained for β-glucan content in OFL are consistent with those reported by Hüttner *et al.* (2010) (3.8-4.5%), whereas the results obtained for ROFL are typical for DF and β-glucan content in oat endosperm flour (Nordisk Innovations Center, 2015). TPC measured in both types of flour was at the same level (0.8 mg GAE/g). Likewise in case of previously described oat bran these results are inconsistent with the results presented by Piątkowska *et al.* (2010), where the content of phenolics in oat flour was in the range between 1.3 and 1.9 mg/g. In comparison to oat grain ROFL was characterised by lower content of all bioactive compounds. Others products, except COF, had similar amounts of these components. In comparison to COF oat grain contained almost 4 fold less of β-glucan and 3 fold less of DF. The highest variability of bioactive components for analysed products was observed for β-glucan content (CV=24.1%), slightly lower for NSP, TPC and DF with CV values at a level of 21.8, 21.5 and 19.9%, respectively and the lowest for lignin content (CV=7.7%). Because of extremely different values of bioactive components, the COF was excluded from the above analysis.

Principal component analysis

PCA was used to illustrate the differences between individual oat products. The results of PCA analysis are presented in Figure 1. Both principal components, PC1 and PC2, accounted for over 95% of the total variability between analysed oat products. The first principal component (PC1) allowed us to separate two groups of products. The first group was COF, which was significantly distinguished in terms of all analysed features from all other products, which constitute the second group (Table 1 and 2). A detailed analysis by the PC2 component (9.09% of variability) enabled the division of the second group of products into three subgroups. The first consists of OFL and HFOB, the second group involved four products: QRO, RRO, ROB and ROFL, whereas the third group consist of both oat grains. The differences between these three groups were mainly connected with the lipids, lignin and total phenolics content.

4. Conclusions

Analysed products independently of their origin and production process, constitute very rich sources of grain components with high biological value, like protein, lipids and DF, including β-glucans, that have functional and nutritional properties. The highest content of nutrients and bioactive compounds was determined in concentrated oat fibre that even in small amounts, can be used for enrichment of human daily diet. This product has higher amount of all, except starch, nutrient and bioactive components than the raw materials used to produce it. The second product that can play an important role due to its popularity and availability on the market is oat bran with high fibre content. This research showed that various oat products and even by-products, all differing in content of nutrients and bioactive compounds, can be very useful raw materials for designing and creating novel functional foods. All analysed products are characterised by health promoting properties and are rich source of DF according to Regulation (EC) No 1924/2006 of the European Parliament and of the Council. Considering the poor nutrition habits and growing number of diet-related diseases in the society, all these products should be promoted for daily consumption as often as possible.

Table 2. Average content of bioactive components in oat products and oat grains [% of dw].[1]

Product[2]	β-glucan	I-NSP	S-NSP	NSP	Lignin	DF	TPC[3]
COF	14.9a	9.1a	15.9a	25.1a	2.7a	27.7a	1.8a
HFBO	5.3b	4.5b	6.2b	10.6b	1.2b	11.8b	1.3c
ROB	4.3cd	3.3cd	5.1b	8.4d	1.1b	9.5c	1.2c
QRO	4.6c	3.1cd	5.2b	8.3d	1.0b	9.3c	1.2c
RRO	4.1de	3.0d	4.9b	7.9d	1.1b	9.0c	1.3c
OFL	4.4cd	3.0bc	5.1b	8.1cd	1.0b	9.1c	0.8d
ROFL	2.3f	1.9e	3.2c	5.1e	1.0b	6.1d	0.8d
BINGO[4]	4.1de	3.2d	4.1b	7.3d	1.4b	8.7c	1.7ab
KREZUS[4]	3.7e	3.9c	5.0b	8.9bc	2.7a	11.6b	1.6b
F-statistic	1,702.7	285.7	145.3	292.8	38.7	243.8	139.5
P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001

[1] DF= dietary fibre; I-NSP = insoluble non-starch polysaccharides; S-NSP = soluble non-starch polysaccharides; TPC = total phenolic content.
[2] COF = concentrated oat fibre; HFOB = oat bran with high fibre content; OFL = oat flour; QRO = quick rolled oats; ROB = regular oat bran; ROFL = residual oat flour; RRO = regular rolled oats.
[3] TPC is expressed in [mg of gallic acid/g].
[4] BINGO and KREZUS are oat grain varieties.

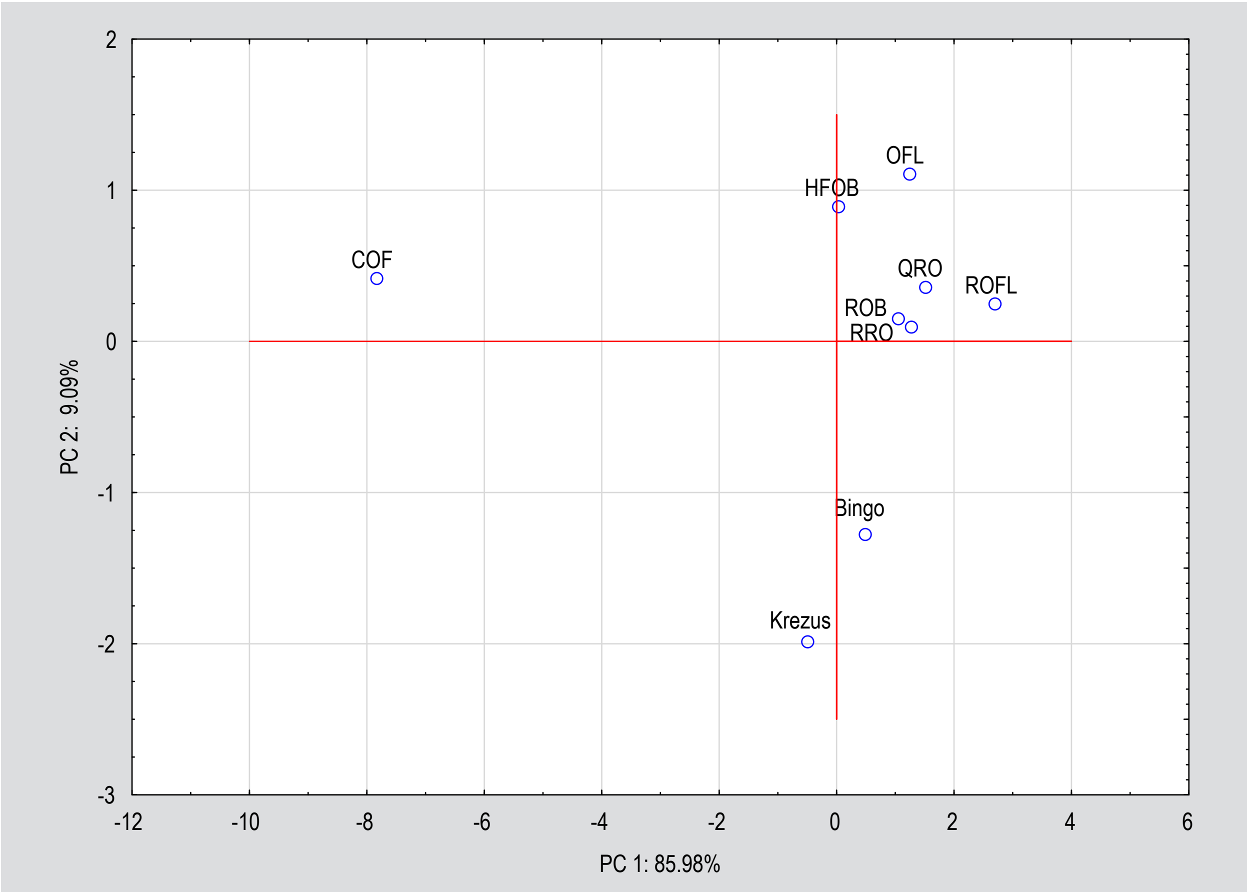

Figure 1. Score plot for the first two principal components from analysis of oat products and oat grains.

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