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METABOLIC EFFECTS OF DIETARY APPLE SEED OIL IN RATS

S u m m a r y

The aim of this study was to determine the fatty acid profile of apple seed oil and its effects on the caecal functions, blood lipids, and markers of antioxidant status and inflammation in rats. A nutritional experiment was performed on Wistar rats allocated to 3 groups of 8 animals each. The animals were fed with a diet containing different sources of fat: pork lard (group LA), rapeseed oil (group RO) and apple seed oil (group AO). Apple seed oil was rich in linoleic acid and oleic acids (57 % and 32.3 % of total fatty acids, respectively). The short chain fatty acid concentration in the caecal digesta was comparable among all groups, whereas the ammonia concentration was lower in groups AO and RO than in group LA (0.32 and 0.3, respectively vs 0.42 mg/g). The plasma alanine (ALT) and aspartate transaminase (AST) activities also decreased in the AO and RO groups (ALT, 19.34 and 19.81, respectively vs 30,7 U/L and AST, 115.1 and 107, respectively vs 138.3 U/L) The plasma triacylglycerols (TG) concentration and the atherogenic index (ATI) of plasma were significantly decreased in the AO group compared to the LA group (TG, 1.79 vs 2.62 mmol/L and ATI, 0.095 vs 0.313). Apple seed oil is a valuable source of unsaturated fatty acids and its dietary addition has slightly better metabolic effects on rat organism than does rapeseed oil.

Key words: apple seeds, linoleic acid, caecal microbiota, fermentation, triacylglycerols, transaminases

Introduction

Epidemiological studies have shown many health benefits associated with a diet rich in fruits and vegetables. Due to their nutritional value and caecal phytochemical content, apples have been the subject of extensive health-related studies. Their consumption has been associated with beneficial effects in counteracting obesity, cancer, cardiovascular disease, diabetes and also in improving gastrointestinal functions [13]. For the most part, previous studies have focused on the health effects of the dietary

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fibre and polyphenols derived from fresh apples, apple peels, juice and pomace [6, 13]. However, recent *in vitro* studies have shown potential antioxidant, antimicrobial and antiproliferative activities of the oil extracted from apple seeds [28, 30]. Apple pomace as a by-product of juice production includes 2 - 3 % seeds [6]. Apple seeds have been shown to be rich in proteins, carbohydrate and minerals, making them useful as feed or fertiliser [31]. Moreover, owing to their relatively high lipid content (up to 29 %), apple seeds can also be utilised as a source of oil that is rich in linoleic acid and has comparable physicochemical properties to quality edible oils [4, 30, 32]. Apple seed oil is also a source of many bioactive compounds, such as sterols, tocopherols and hydrocarbons, especially squalene [4]. The fatty acid profile and the presence of bioactive compounds in apple seed oil indicates potential applications in the food industry. However, there is a lack of *in vivo* studies assessing the quality and health benefits of apple seed oil.

Due to its high energy density, fat has been recognised as the most important macronutrient affecting the development of many diet-related diseases, especially cardiovascular disease (CVD). It is well known that an overabundance of saturated fatty acids in the diet affects the blood lipid profile and therefore constitutes an important CVD risk factor [5]. On the other hand, dietary polyunsaturated fatty acids can ameliorate CVD development by improving the blood lipid profile, blood pressure, adipocyte hormones, and inflammatory response and endothelial function, along with many other beneficial effects that are both known and as yet undefined [1, 17, 20].

The aim of this study was to determine the fatty acid profile of apple seed oil and its effects on the caecal functions, blood lipids, and selected markers of inflammation and antioxidant status in rats. The animals were fed a diet in which the sole source of fat was apple seed oil, and this diet was compared to diets that contained lard and rapeseed oil as examples of common edible fats with well-established nutritional effects. The caecal microbial metabolism was scrutinised due to the potential antimicrobial activity of apple seed oil reported by Tian et al. [28].

Materials and methods

Dietary fats and their chemical analysis

Refined rapeseed oil (ZT Kruszwica SA, Kruszwica, Poland) and pork lard (S.K.A. Morliny, Ostróda, Poland) were purchased in a local supermarket. Their fatty acid profiles were as follows [%]: rapeseed oil – C16:0 – 4.6; C18:0 – 0.5; C18:1 n-9 – 63.5; C18:2 n-6 – 20.1; C18:3 n-3 – 9.0 and C20:0 – 2.2, lard – C14:0 – 1.6; C16:0 – 29.3; C18:0 – 0.5; C18:1 n-9 – 58.1; C18:2 n-6 – 8.9; C18:3 n-3 – 0.6 and C20:0 – 0.9. Unrefined cold-pressed apple seed oil was purchased from Greenaction (Kielce, Poland), and its detailed fatty acid profile is given in Table 1.

Table 1. Fatty acid profile of apple seed oil [%]
Tabela 1. Profil kwasów tłuszczowych oleju z nasion jabłka [%]

Fatty acid / Kwasy tłuszczowe	$\bar{x}$	SD / s
C16:0	5.49	0.38
C16:1	1.43	0.07
C18:0	1.11	0.08
C18:1 n-9	32.26	0.12
C18:2 n-6	57.03	0.44
C18:3 n-3	0.71	0.07
C20:0	1.54	0.01
Others / Pozostałe	0.43	0.07

Fatty acid profiles were analysed after conversion of the fatty acids into methyl esters. An oil sample, together with pentadecanoic acid as an internal standard (0.1 μg/μL of oil), was dissolved in a solution of methanol:chloroform:sulphuric acid (100 : 100 : 1 v/v/v) and heated at 100 °C for 2 h. Afterwards, an analysis was performed using a gas chromatograph (Clarus 600, Perkin Elmer, Massachusetts, USA) with a flame ionisation detector and a Supelcowax 10 column (30 m × 0.32 mm × 0.25 μm). The column, injector and flame ionisation detector temperatures were 190 °C, 250 °C and 250 °C, respectively, and the flow rate of helium, used as a carrier gas, was 1.6 mL/min. Fatty acid methyl esters were identified using TotalChrom software.

Animal study

The animal protocol used in the present study was approved by the Local Institutional Animal Care and Use Committee (Olsztyn, Poland). The nutritional experiment was performed on six-week-old, male Wistar rats allocated to 3 groups of 8 animals each and housed individually in cages. The initial body weight was comparable among groups and equalled 128 ± 6 g on average. For 8 weeks, each group was fed a modified version of the semi-purified rodent diet recommended by Reeves [23]. The experimental diets differed according to the fat type (70 g/kg in each diet) and included lard (group LA), rapeseed oil (group RO) or apple seed oil (group AO, Table 2). Both group LA and RO were treated as controls. The diets were freshly prepared at weekly intervals, stored in hermetic containers at -20 °C and administered *ad libitum*. The animals were maintained under standard conditions at a temperature of 21-22 °C and a relative air humidity of 50-70 % with intensive room ventilation (15×/h) and a 12 h lighting regimen. The individual body weights and food intakes were recorded on a daily basis.

Table 2. Compositions of the diets fed to rats
Tabela 2. Skład diet eksperymentalnych

Component / Składnik [g/kg]	Group / Grupa		
	LA	RO	AO
Casein / Kazeina	200	200	200
DL-methionine / DL-metionina	3	3	3
Lard / Smalec	70	-	-
Rapeseed oil / Olej rzepakowy	-	70	-
Apple seed oil / Olej z nasion jabłka	-	-	70
Cellulose / Celuloza	50	50	50
Sucrose / Sacharoza	100	100	100
Maize starch / Skrobia kukurydziana	530	530	530
Mineral mix / Mieszanka mineralna[1]	35	35	35
Vitamin mix / Mieszanka witaminowa[1]	10	10	10
Choline chloride / Chlorek choliny	2	2	2

Explanatory notes: / Objaśnienia:
LA – lard / smalec; RO – rapeseed oil / olej rzepakowy; AO – apple seed oil / olej z nasion jabłka.
[1] Recommended for AIN-93G diet/ Zalecane dla diety AIN-93G [23].

Sample collection and analysis

Upon termination of the experiment, the rats were weighed and anesthetised with sodium pentobarbital (50 mg/kg body weight). Their body composition was then analysed by time-domain nuclear magnetic resonance (Minispec LF 90II, Bruker, Karlsruhe, Germany). After laparotomy, blood samples were collected from the caudal vein and stored in tubes containing ethylenediaminetetraacetic acid, and the cecum and liver were removed and weighed.

The pH of the caecal digesta was measured using a microelectrode and a pH/ION meter (model 301; Hanna Instruments, Vila do Conde, Portugal). Fresh caecal digesta was used for the determination of the ammonia content, which was extracted and trapped in a solution of boric acid, then quantified by direct titration with sulphuric acid [14]. The concentration of short-chain fatty acids (SCFA) was measured using gas chromatography. A known amount of fresh caecal digesta was mixed with 0.2 mL of formic acid and stored at −80 °C. Afterwards, the sample was diluted with deionised water, centrifuged at 10.000 g for 5 min, and filtered through a 0.45 μm membrane. The supernatant was then decanted for injection into a gas chromatograph (Shimadzu GC-14A, Shimadzu Co., Kyoto, Japan, equipped with a glass column, 2.5 m × 2.6 mm, containing 10% SP-1200/1% H_3PO_4 on 80/100 Chromosorb W AW; column tempera-

ture 110 °C; flame ionisation detector temperature 180 °C; injector temperature 195 °C).

The liver fat and lean mass were analysed shortly after dissection by time-domain nuclear magnetic resonance (Minispec LF 90II, Bruker, Karlsruhe, Germany). After storage of the liver at -20 °C, the glutathione and glutathione disulphide contents were determined using the enzymatic recycling method described by Rahman et al. [22].

The blood was centrifuged for 15 min at 380 g, and the obtained plasma was then stored at -20 °C until analysis. The plasma concentration of triglycerides, the total cholesterol content and its HDL fraction (HDL-cholesterol), and the plasma activity of aspartate transaminase (AST) and alanine transaminase (ALT) were estimated using reagents from Alpha Diagnostics Ltd. (Warsaw, Poland). Based on the plasma lipid profile, the atherogenic index was calculated as previously described using the following formula: log(triglycerides (mmol/L)/HDL- cholesterol (mmol/L)) [14]. Non-HDL-cholesterol was calculated using the following formula: total cholesterol – HDL-cholesterol. The plasma C-reactive protein (CRP) concentration was determined using a validated rat enzyme immunoassay kit (hs-CRP; Cusabio, Wuhan, China). In addition, the rat tumour necrosis factor alpha (TNFα) was determined using a validated rat enzyme immunoassay kit (TNF alpha; Thermo Scientific, Rockford, IL USA). The plasma antioxidant capacity of water-soluble substances (ACW) and the antioxidant capacity of lipid-soluble substances (ACL) (kit; Analytik Jena AG, Jena, Germany) were determined by a photochemiluminescence detection method using a Photochem (Analytik Jena AG). In the photochemiluminescence assay, the generation of free radicals was partially eliminated through reactions with antioxidants present in the plasma samples, and the remaining radicals were quantified by luminescence generation. Ascorbate and Trolox calibration curves were used to evaluate ACW and ACL, respectively, and the results were expressed as mmol ascorbate or Trolox equivalents in mL of plasma.

Statistical analysis

The statistical analysis was performed using a one-way analysis of variance and the Duncan's multiple range post hoc test, providing that the data were normally distributed and the variances were homogenous. Alternatively, the Kruskal-Wallis test and a post hoc analysis using the least significant difference between the mean ranks were applied. All data are expressed as the mean and the standard error of the mean, and the differences among the groups are denoted as significant at $p \leq 0,05$.

Results and discussion

The dietary apple seed oil was especially rich in linoleic and oleic acids (57 % and 32.3 %, respectively, Table 1). The fatty acid profile of the apple seed oil differed

from the profiles described in the literature [8, 28, 29, 30]. Similar results were obtained in studies by Tian et al. [28] and Yu et al. [30], in which the contents of oleic and linoleic acids in apple seed oil were higher by 5.2 - 7.5 % points and lower by 5.6 - 8 % points, respectively. Another study reported that seed oils from dessert and cider apples had oleic and linoleic acid contents that were 17 and 25 % higher, respectively [8]. The observed differences could be the consequence of the species used for oil production, the procedure of extraction and the growth conditions of the apples as it is observed in oily plants [2]. It is noteworthy that the fatty acid profile of rapeseed oil used in this study in group RO was considered typical (USDA National Nutrient Database for Standard Reference, Release 25).

After 8 weeks of feeding, there were no significant differences in the diet intake, body weight gain, body fat content and adiposity among the experimental groups. Additionally, in all experimental groups, the liver weight and fat content were also similar (Table 3). Notably, all diets in this study had the same caloric value; therefore, it can be concluded that dietary apple seed oil was metabolised to the same extent as were the other dietary fats.

Table 3. Animal growth, body and liver fat and lean contents of rats fed diets differing according to the type of fat

Tabela 3. Spożycie diety, masa zwierząt oraz zawartość tłuszczu i tkanki beztłuszczowej w ciele i wątrobie szczurów żywionych dietami eksperymentalnymi

Parameters Parametry	LA		RO		AO	
	$\bar{x}$	SEM	$\bar{x}$	SEM	$\bar{x}$	SEM
Body weight gain Przyrost masa ciała [g]	231.7	9.65	216.0	9.53	217.9	7.02
Diet intake Spożycie diety [g]	965.8	17.8	934.5	24.3	927.4	18.6
Body fat content Zawartość tłuszczu w ciele [g/kg]	370	7.40	367	6.80	381	8.70
Body lean content / Zawartość tkanki beztłuszczowej w ciele [g/kg]	329	11.7	344	11.1	334	13.7
Liver mass Masa wątroby [g/100 masy ciała]	3.32	0.10	3.60	0.11	3.30	0.08
Liver fat content Zawartość tłuszczu w wątrobie [g/kg]	300	17.5	261	19.3	262	9.30
Liver lean content / Zawartość tkanki beztłuszczowej w wątrobie [g/kg]	544	12.1	589	22.0	574	15.2

Explanatory notes as in. Tab. 2. / Objasnienia jak w tab. 2.

The markers of the cecum function and the caecal SCFA contents are shown in Table 4. The digesta contents were similar among all groups, whereas the tissue weight was the highest in group RO, was slightly lower in group AO and was significantly lower in group LA ($p < 0.05$). Furthermore, a previous study performed in our laboratory showed that the type of dietary fat can affect caecal microbial metabolism [14]. In addition, an *in vitro* study with apple seed oil showed its potent inhibitory effect on the growth of bacteria [28]. In our experiment, no signs of antibacterial activity in the cecum were observed, as evidenced by the lack of significant changes in the bacterial production of SCFA and the pH value of the caecal digesta among all experimental groups. However, when compared to group LA, the dietary apple seed oil significantly decreased the ammonia concentration in the caecal digesta ($p < 0.05$). However, a similar effect was obtained for dietary rapeseed oil, which indicates that it is rather not associated with the antibacterial activity of apple seed oil reported in the literature.

Table 4. Markers of cecal function in rats fed diets differing according to the type of fat
Tabela 4. Wskaźniki funkcjonowania jelita ślepego u szczurów żywionych dietami eksperymentalnymi

Parameters	LA		RO		AO	
	$\bar{x}$	SEM	$\bar{x}$	SEM	$\bar{x}$	SEM
Tissue / Tkanka [g/100 body mass]	0.139^{b}	0.007	0.164^{a}	0.006	0.153^{ab}	0.006
Digesta mass / Masa treści [g/g cecal tissue]	3.45	0.25	3.55	0.36	3.91	0.37
pH of cecal digesta / pH treści jelita ślepego	7.41	0.13	7.19	0.10	7.26	0.10
NH_3 [mg/g]	0.46^{a}	0.06	0.30^{b}	0.03	0.32^{b}	0.02
SCFA [μmol/g digesta]:						
acetic / octowy	122.5	7.56	119.9	6.51	128.9	15.0
propionic / propionowy	20.4	1.24	20.4	0.79	19.4	2.13
isobutyric / izomasłowy	1.97	0.51	2.21	0.13	2.64	0.54
butyric / masłowy	23.7	2.40	26.9	2.89	24.3	1.44
isovaleric / izowalerianowy	2.38	0.37	2.73	0.58	3.26	0.87
valeric / walerianowy	3.10	0.17	3.29	0.36	3.55	0.43
Total SCFA / Suma SCFA	174.1	10.5	175.6	9.10	182.0	17.1

Explanatory notes: / Objaśnienia:
The mean values within a row with different superscript letters (a, b) were significantly different at $p < 0.05$ / Wartości średniez odmiennymi literami przypisanymi w indeksie górnym (a, b) różniły się statystycznie istotnie na poziomie $p < 0,05$.

The plasma lipid profiles of the rats differed according to the type of fat in the diet, as shown in Table 5. Numerous studies have confirmed that substituting saturated fat with a variety of polyunsaturated or monounsaturated fatty acids (PUFA and MUFA, respectively) can lower blood triglyceride concentrations [3, 27, 26]. Further-

more, it is known that PUFA are more effective at decreasing triglyceride concentrations than are MUFA [9]. The effect of PUFA on the triglyceride concentration appeared to be mediated by the inhibition of hepatic lipase activity and liver VLDL synthesis as well as by the enhancement of lipoprotein lipase activity in the liver, which results in reduced postprandial triglyceride levels [33]. In our study, the plasma triglyceride concentration and the atherogenic index were significantly decreased in group AO compared to those in group LA ($p < 0.05$), whereas the plasma levels of total cholesterol and its HDL and non-HDL fractions were similar among all the groups. These beneficial effects of dietary apple seed oil may be in part associated with other bioactive compounds that have been found in apple seed oil, such as squalene and sterols [4], as the triglyceride lowering activity of these compounds has been reported in the literature [15, 16].

In the present study, the plasma ALT activity was decreased in the RO and AO groups compared to that in the LA group ($p < 0.05$, Table 5). The plasma AST activity was the highest in group LA, was slightly lower in group AO and was significantly lower in group RO ($p < 0.05$). The elevated levels of ALT and AST activity in group LA were most likely a consequence of essential fatty acid deficiency, which has been also noted in patients during parenteral nutrition [26]. The 8-week feeding with dietary rapeseed and apple seed oils prevented unfavourable elevations in plasma ALT and AST activity and thus reduced the risk of hepatocellular injury. However, the AST activity was significantly decreased only in the rapeseed oil-containing dietary group, which may be the result of the relatively high α-linolenic acid content compared to both the apple seed oil- and lard-containing dietary groups.

Low-grade inflammation is considered as a key element of many chronic diseases, like obesity, diabetes type 2, atherosclerotic vascular disease and fatty liver disease, which can be affected by dietary factors [29]. Moreover, recent studies have indicated that a dietary overabundance of linoleic acid can be harmful for the body and promote inflammation [7]. This effect was not observed in the presented experiment, in which the plasma markers of inflammation were not affected by the linoleic acid-rich apple seed oil (TNF-α and CRP, Table 5). In addition, in the study by Magdalon et al. [18], the TNF-α levels in rat macrophages were similar between animals treated orally with water and those treated with linoleic acid. However, in the study by Poudel-Tandukar et al. [21], the serum CRP level in men was significantly higher when their diet was rich in linoleic acid.

Over the past three decades, it has become clear that abnormalities in oxidative stress can lead to many diseases, especially CVD [12]. In this respect, it is noteworthy that PUFA can act as anti- rather than pro-oxidants in vascular endothelial cells, hence diminishing inflammation, giving them beneficial effects against CVD [19, 24].

Table 5. Plasma lipid profile, antioxidant status, markers of liver function and inflammation in rats fed diets differing according to the type of fat

Tabela 5. Profil lipidowy osocza, status antyoksydacyjny oraz markery funkcjonowania wątroby i stanu zapalnego szczurów żywionych dietami eksperymentalnymi

Parameters Parametry	LA		RO		AO	
	$\bar{x}$	SEM	$\bar{x}$	SEM	$\bar{x}$	SEM
Plasma lipid profile / Profil lipidowy osocza [mmol/L]						
total cholesterol / cholesterol całkowity	2.0	0.08	1.86	0.16	2.04	0.09
HDL-cholesterol / cholesterol HDL	1.26	0.09	1.31	0.15	1.41	0.07
non-HDL-cholesterol / cholesterol nie-HDL[1]	0.74	0.05	0.55	0.06	0.63	0.07
triacylglycerols / triacyloglicerole	2.62^{a}	0.23	2.19^{ab}	0.19	1.79^{b}	0.16
Atherogenic index / Wskaźnik aterogenności[2]	0.313^{a}	0.050	0.227^{ab}	0.065	0.095^{b}	0.048
Antioxidant status / Status antyoksydacyjny						
ACW ([mol/ml plasma]	2.8	0.30	8.05	5.47	2.79	0.24
ACL [mmol/ml plasma]	19.2	1.03	23.1	2.32	19.3	0.68
GSH / GSSG [µmol/g liver]	6.20	0.41	7.74	1.38	5.15	0.69
Liver function tests / Wskaźniki funkcjonowania wątroby						
ALT [U/L plasma]	30.7^{a}	1.81	19.81^{b}	1.41	19.34^{b}	1.41
AST [U/L plasma]	138.3^{a}	7.36	107^{b}	1.53	115.1^{ab}	4.19
Inflammation markers Wskaźniki stanu zapalnego						
CRP [ng/ml plasma]	0.158	0.044	0.194	0.034	0.097	0.050
TNFα [pg/ml plasma]	95.6	22.7	139.7	27.7	88.5	24.9

Explanatory notes: / Objaśnienia:

The mean values within a row with different superscript letters (a, b) were significantly different at $p < 0.05$ / Wartości średnie z odmiennymi literami przypisanymi w indeksie górnym (a, b) różniły się statystycznie istotnie na poziomie $p < 0,05$.

ACW – antioxidant capacity of water-soluble substances / pojemność przeciwutleniająca substancji rozpuszczalnych w wodzie; ACL – antioxidant capacity of lipid-soluble substances / pojemność przeciwutleniająca substancji rozpuszczalnych w lipidach; ALT – alanine transaminase / transaminaza alaninowa; AST – asparagine transaminase / transaminaza asparaginowa; GSH/GSSG – glutatione/glutathione disulphide / glutation/dwusiarczek glutationu; CRP – C-reactive protein / białko C-reaktywne; TNFα – tumour necrosis factor Ralpha / czynnik martwicy nowotworu alfa; [1]Total cholesterol-HDL cholesterol / [1]cholesterol całkowity – cholesterol HDL; [2]log[triacylglycerols [mmol/L] / HDL-cholesterol [mmol/L] / [2]log[triacyloglicerole [mmol/L] / cholesterol HDL [mmol/L]].

However, high doses of PUFA, especially n-3 PUFA, may even trigger oxidative stress, which might be easily explained by their high degree of unsaturation that makes them potential substrates in lipoperoxide formation [10]. On the other hand, in a study

by Guo et al. [11], a purified linoleic acid from *Pinus armandi franch* seed oil effectively improved the antioxidant status of hyperlipidemic rats. In the present study, the type of dietary fat had no effect on the antioxidant statuses of rats (plasma ACW and ACL levels and GSH/GSSG ratio in the liver, Table 5).

Conclusion

1. Apple seed oil is a valuable source of linoleic acid and oleic acid, and its dietary addition has slightly better beneficial metabolic effects on rat organism than does rapeseed oil.
2. When compared with dietary lard, dietary apple seed oil favourably reduces caecal ammonia formation, plasma triglyceride concentrations and the atherogenic index, decreases the risk of hepatocellular injury and has no effects on the antioxidant status of the organism.

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Literatura

[1] Achremowicz K., Szary-Sworst K. Wielonienasycone kwasy tłuszczowe czynnikiem poprawy stanu zdrowia człowieka. Żywność. Nauka. Technologia. Jakość, 2005, **3 (44)**, 23-35.

[2] Ahmad A. Abdin M.Z.: Interactive effect of sulphur and nitrogen on the oil and protein contents and on the fatty acid profiles of oil in the seeds of rapeseed (*Brassica campestris* L.) and mustard (*Brassica juncea* L. Czern. and Coss.). J. Agron. Crop. Sci., 2000, **185 (1)**, 49-54.

[3] Allman-Farinelli M.A., Gomes K., Favaloro E.J., Petocz P.: A diet rich in high-oleic-acid sunflower oil favorably alters low-density lipoprotein cholesterol, triglycerides, and factor VII coagulant activity. J. Am. Diet Assoc., 2005, **105 (7)**, 1071-1079.

[4] Arain S., Sherazi S.T.H., Bhanger M.I., Memon N., Mahesar S.A., Rajput M.T.: Prospects of fatty acid profile and bioactive composition from lipid seeds for the discrimination of apple varieties with the application of chemometrics. Grasas Aceites, 2012, **63 (2)**, 175-183.

[5] Astrup A., Dyerberg J., Elwood P., Hermansen K., Hu F.B., Jakobsen M.U., Kok F.J., Krauss R.M., Lecerf J.M., LeGrand P., Nestel P., Risérus U., Sanders T., Sinclair A., Stender S., Tholstrup T., Willett W.C.: The role of reducing intakes of saturated fat in the prevention of cardiovascular disease: where does the evidence stand in 2010? Am. J. Clin. Nutr., 2011, **93 (4)**, 684-688.

[6] Carson K.J., Collins J.L., Penfield M.P.: Unrefined, dried apple pomace as a potential food ingredient. J. Food Sci., 1994, **59 (6)**, 1213-1215.

[7] Choque B., Catheline D., Rioux V., Legrand P.: Linoleic acid: Between doubts and certainties. Biochimie, 2014, **96**, 14-21.

[8] Fromm M., Bayha S., Carle R., Kammerer D.R.: Comparison of fatty acid profiles and contents of seed oils recovered from dessert and cider apples and further Rosaceous plants. Eur. Food Res. Technol., 2012, **234 (6)**, 1033-1041.

[9] Gardner C.D., Kraemer H.C.: Monounsaturated versus polyunsaturated dietary fat and serum lipids. A meta-analysis. Arterioscler. Thromb. Vasc. Biol., 1995, **15 (11)**, 1917-1927.

[10] Giordano E., Visioli F.: Long-chain omega 3 fatty acids: molecular bases of potential antioxidant actions. Prostaglandins Leukot. Essent. Fatty Acids, 2014, **90 (1)**, 1-4.
[11] Guo J.X., Wang C.L., Wu Z.J.: Study on antioxidant activities of *Pinus armandi* franch seed oil. Adv. Mater. Res., 2013, **634**, 1294-1301.
[12] Hansson G.K.: Inflammation, atherosclerosis, coronary artery disease. N. Engl. J., 2005, **352 (16)**, 1685-1695.
[13] Hyson D.A.: A comprehensive review of apples and apple components and their relationship to human health. Adv. Nutr., 2011, **2**, 408-420.
[14] Jurgoński A., Juśkiewicz J., Zduńczyk Z.: A high-fat diet differentially affects the gut metabolism and blood lipids of rats depending on the type of dietary fat and carbohydrate. Nutrients, 2014, **6 (2)**, 616-626.
[15] Kelly G.S.: Squalene and its potential clinical uses. Altern. Med. Rev., 1999, **4 (1)**, 29-36.
[16] Kohno Y., Egawa Y., Itoh S., Nagaoka S., Takahashi M., Mukai K.: Kinetic study of quenching reaction of singlet oxygen and scavenging reaction of free radical by squalene in n-butanol. Biochim. Biophys. Acta, 1995, **1256 (1)**, 52-56.
[17] Lunn J., Theobald H.E.: The health effects of dietary unsaturated fatty acids. Nutr. Bull., 2006, **31 (3)**, 178-224.
[18] Magdalon J., Vinolo M.A., Rodrigues H.G., Paschoal V.A., Torres R.P., Mancini-Filho J., Calder P.C., Hatanaka E., Curi R.: Oral administration of oleic or linoleic acids modulates the production of inflammatory mediators by rat macrophages. Lipids, 2012, **47 (8)**, 803-812.
[19] Mińkowski K., Grześkiewicz S., Jerzewska M.: Ocena wartości odżywczej olejów roślinnych o dużej zawartości kwasów linolenowych na podstawie składu kwasów tłuszczowych, tokoferoli i steroli. Żywność. Nauka. Technologia. Jakość, 2011, **2 (75)**, 124-135.
[20] Obiedzińska A., Waszkiewicz-Robak B.: Oleje tłoczone na zimno jako żywność funkcjonalna. Żywność. Nauka. Technologia. Jakość, 2012, **1 (80)**, 27-44.
[21] Poudel-Tandukar K., Nanri A., Matsushita Y., Sasaki S., Ohta M., Sato M., Mizoue T.: Dietary intakes of alpha-linolenic and linoleic acids are inversely associated with serum C-reactive protein levels among Japanese men. Nutr. Res., 2009, **29 (6)**, 363-370.
[22] Rahman I., Kode A., Biswas S.K.: Assay for quantitative determination of glutathione and glutathione disulfide levels using enzymatic recycling method. Nat. Protoc., 2006, **1 (6)**, 3159-3165.
[23] Reeves P.G.: Components of the AIN-93 diets as improvements in the AIN-76A diet. J. Nutr., 1997, **127 (5)**, 838S-841S.
[24] Richard D., Kefi K., Barbe U., Bausero P., Visioli F.: Polyunsaturated fatty acids as antioxidants. Pharmacol. Res., 2008, **57 (6)**, 451-455.
[25] Richardson T.J., Sgoutas D.: Essential fatty acid deficiency in four adult patients during total parenteral nutrition. Am. J. Clin. Nutr., 1975, **28 (3)**, 258-263.
[26] Ros E., Mataix J.: Fatty acid composition of nuts--implications for cardiovascular health. Br. J. Nutr., 2006, 96 (2), 29-35.
[27] Sanderson P., Finnegan Y.E., Williams C.M., Calder P.C., Burdge G.C., Wootton S.A., Griffin B.A., Joe Millward D., Pegge N.C., Bemelmans W.J.: UK Food Standards Agency alpha-linolenic acid workshop report. Br. J. Nutr., 2002, **88 (5)**, 573-579.
[28] Tian H., Zhan P., Li K.: Analysis of components and study on antioxidant and antimicrobial activities of oil in apple seeds. Int. J. Food Sci. Nutr., 2010, **61 (4)**, 395-403.
[29] Uusitupa M., Schwab U.: Diet, inflammation and prediabetes - impact of quality of diet. Can. J. Diabetes, 2013, **37 (5)**, 327-331**.**
[30] Walia M., Rawat K., Bhushan S., Padwad Y.S., Singh B.: Fatty acid composition, physicochemical properties, antioxidant and cytotoxic activity of apple seed oil obtained from apple pomace. J. Sci. Food Agric., 2014, **94 (5)**, 929-934.

[31] Yu X., Voort F.R., Li Z., Yue T.: Proximate composition of the apple seed and characterization of its oil. Int. J. Food Eng., 2007, **3 (5)**, 1556-3758.
[32] Yukui R., Wenya W., Rashid F., Qing L.: Fatty acids composition of apple and pear seed oils. Int. J. Food Prop., 2009, **12 (4)**, 774-779.
[33] Zuliani G., Galvani M., Leitersdorf E., Volpato S., Cavalieri M., Fellin R.: The role of polyunsaturated fatty acids (PUFA) in the treatment of dyslipidemias. Curr. Pharm., 2009, **15 (36)**, 4087-4093.

WPŁYW DODATKU OLEJU Z NASION JABŁKA DO DIETY NA METABOLIZM SZCZURÓW

S t r e s z c z e n i e

Celem pracy było określenie zawartości kwasów tłuszczowych w oleju z nasion jabłka oraz ocena jego wpływu na funkcjonowanie jelita ślepego, profil lipidowy krwi, markery stresu oksydacyjnego oraz stanu zapalnego szczurów. Eksperyment żywieniowy przeprowadzono na szczurach Wistar przydzielonych do 3 grup po 8 osobników w każdej. Zwierzęta żywiono przez 8 tygodni dietami zawierającymi następujące rodzaje tłuszczu: smalec wieprzowy (grupa LA), olej rzepakowy (grupa RO) oraz olej z nasion jabłka (grupa AO), który charakteryzował się znaczną zawartością kwasu oleinowego oraz linolowego (odpowiednio 32,3 % oraz 57 % całkowitej zawartości kwasów tłuszczowych). Po 8 tygodniach doświadczalnego żywienia stężenie krótkołańcuchowych kwasów tłuszczowych w treści jelita ślepego szczurów było porównywalne we wszystkich grupach doświadczalnych, natomiast stężenie amoniaku było niższe w grupach AO oraz RO w porównaniu z grupą LA (0,32 i 0,3, w porównaniu z 0.42 mg/g). W grupach RO i AO odnotowano również spadek aktywności aminotransferazy asparaginowej oraz alaninowej oznaczonej w osoczu badanych zwierząt. Stężenie triacylgliceroli w (TG) w osoczu krwi oraz aterogenność osocza (ATI) w grupie AO były istotnie niższe w porównaniu z grupą LA (TG, 1.79 w porównaniu z 2.62 mmol/L oraz ATI, 0.095 w porównaniu z 0.313). Dodatek do diety oleju z nasion jabłka, będącego cennym źródłem nienasyconych kwasów tłuszczowych, wpływa w sposób nieznacznie bardziej korzystny na organizm szczura niż powszechnie stosowany w żywieniu olej rzepakowy.

Słowa kluczowe: nasiona jabłka, kwas linolowy, jelito ślepe, fermentacja, triacyloglicerole, transaminazy