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FAT CONTENT AND FATTY ACID COMPOSITION IN OILSEED RAPE GROWN IN THE LUBELSKI REGION UNDER DIFFERENT LEVELS OF SOIL SULPHUR FERTILITY

ZAWARTOŚĆ TŁUSZCZU I SKŁAD KWASÓW TŁUSZCZOWYCH W NASIONACH RZEPAKU UPRAWIANEGO W WARUNKACH ZRÓŻNICOWANEJ ZASOBNOŚCI GLEB LUBELSZCZYZNY W SIARKĘ

Abstract: A new problem arising in plant production is the increasing deficit of sulphur in Polish soils. This can lead to low-levels in yield for many crops, along with deterioration in the quality of harvested plant samples. Therefore, the purpose of this study was to evaluate the relationship between soil fertility and sulphur in the Lubelski region, in addition to certain quality characteristics of spring rapeseeds. The research samples consisted of soil and plant samples taken from the Lubelski region. The soil samples were selected taken into consideration their agronomic category and sulphate sulphur content. The spring rape was chosen as a test crop and was harvested at full maturity. The test plants were selected because of their high nutritional requirements for sulphur. The results of this study indicate that the quantity of sulphur in the soils of the Lubelski region was characterised by a large variability, ranging in quantity from the low to very high. This affected the fat content in seeds and the fatty acid composition. The lowest fat content was characterised as rapeseed harvested in the localities of high or very high sulphur content in the soil. In addition, the percentage of oleic acid clearly increased with increasing soil fertility in the S-SO_4. This content in terms of its valuable health benefits, essential fatty acids, clearly decreases with increasing sulphur content in the soil in a form directly available to plants. There was no clear relationship between the soils sulphur fertility in the Lubelski region and the share of undesirable erucic acid from the perspective of nutritional point of view.

Keywords: spring oilseed rape, fat content, fatty acid composition, soil fertility in the S-SO_4

Sulphur, in addition to nitrogen, phosphorus, and potassium, is considered as an essential nutrient for the proper growth and development of living organisms. It is part of the composition of many important compounds, the lack of which causes disturbance in plant development as well as holding a possible disease threat for humans and animals [1, 2].

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Despite this importance, until the early 1980s, European countries did not pay too much attention to this. Determining fertilizer needs for crops were also not taken into account. This was connected with the fact that in most parts of our continent the sulphur balance was positive. The positive balance of this component is primarily SO_2 emitted in significant quantities into the atmosphere [3–5].

The excessive sulphur compounds adversely affected the health of ecosystems and the growth and development of crops. The scale of devastation was so great that several actions to reduce the amount of SO_2 emitted into the atmosphere were taken [6].

A reduction of sulphur deposits from the atmosphere and a decrease in the quantity of this ingredient put together with mineral fertilizers have led to a shortage of sulphur in plant production [2, 4, 5].

Studies conducted in our country have shown that about 57 % of Polish soil contains a natural sulphur level, which indicates a low fertility of this valuable nutrient [4, 7]. An absence of this component can be expected especially in lighter, usually acidified mineral soils, located far away from industrial centres [8, 9].

In the case of oil seed crops, the lack of sulphur usually leads to a reduction in the percentage of fat in the seeds along with changes in fatty acids [5, 10, 11]. This is due to the relatively high nutritional requirements of rape in relation to its sulphur content. It was assumed that with an average volume yield, the plants uptake 30 to 60 kg $S \cdot ha^{-1}$ [3, 4, 12].

Consequently, the purpose of this study, based on field preliminary results and studies of literature, was an attempt to assess some characteristics of the seed quality for spring rape grown under different sulphur soil conditions of the Lubelski region.

Materials and methods

The study was performed based on soil and plant samples taken from the villages of the Lubelski province: Nosow, Halasy and Jablonna Majatek. The selection of soils for the studies took into account their agronomic category separated on the basis of silt and clay fraction content (diameter fraction < 0.02 mm). Each individual category was characterised by its agronomic soil content of silt and clay fraction: very light to 10 %, light 11–20 %, average 21–35 %, heavy over 35 % (Table 1).

Table 1

Granulometric composition of the soil samples

No. attempt	Locality	Content of each fraction [%]			Granulometric groups
		1.0–0.1 mm	0.1–0.02 mm	< 0.02 mm	
1	Nosow	53	26	21	sandy silty clay
2	Nosow	60	25	15	light loamy sand
3	Halasy	45	29	26	slightly silty clay
4	Jablonna-Majatek	15	49	36	clay dust

Another criterion taken into account when choosing soil samples for the study was the sulphate sulphur content in the soil (Table 2).

Table 2

$S-SO_4$ content in the soil samples

No. attempt	Locality	$S-SO_4$ [$mg \cdot kg^{-1}$]
1	Nosow	21.0
2	Nosow	8.5
3	Halasy	52.5
4	Jablonna-Majatek	24.5

The soil samples were taken from a soil layer to a depth of 0–20 cm. From each locality, the five soil samples were collected and air-dried. The dried soil samples were triturated in a porcelain mortar and sieved through a 1 mm mesh. The analysis was then averaged over the sample resulting from mixing the primary samples and then the results were determined by:

– granulometric composition with areometric Casagrande's method modified by Pruszynski,

– sulphur sulphate – nephelometric according to the formula of Bardsley and Lancaster [13].

The plant samples (spring rape) were taken from the above-mentioned soil agronomic categories. The test plants were selected because of high nutritional requirements for sulphur by *Brassicaceae* plants. The plant samples were collected in accordance with established criteria for collecting and preparing of plant samples for agricultural chemical analysis.

The dried plant samples were crushed by mills to obtain a sample in the dust form, with as much of a uniform particle diameter as possible. The prepared averaged samples of rapeseeds were marked as:

– fat-extraction method in the Soxtec HT-6,

– fatty acids by gas chromatography (Unicam gas chromatograph).

This work includes the results obtained from preliminary field tests and literature studies on the influential effect of sulphur fertilization on rapeseed according to its quantity and quality of yield.

Results and discussion

Sulphate sulphur usually constitutes not more than several percent to the total soil sulphur. However, this form is the most important for agriculture and ecology because it determines the state of plants supply with this valuable nutrient [14].

An analysis of soil samples taken from the Lubelski region showed that the $S-SO_4$ content in the examined soil samples ranged from low to very high fertility (Table 3).

The assessment of soil pollution by sulphur at a depth of 0–20 cm usually is made by taking into account its natural content, depending on the type of soil, and it features including four levels of this chemical element content:

– I^o – low content,

– II° – average content,
– III° – high content,
– IV° – very high content (very high pollution).

Levels: I, II and III determine the natural content of sulphur forms in different soils, while level IV – content increased due to anthropogenic [15].

Table 3

Evaluation of soil sulphur fertility in $S\text{-}SO_4$ levels in Lubelski region

No. attempt	Locality	Fertility level
1	Nosow	II°
2	Nosow	I°
3	Halasy	IV°
4	Jablonna-Majatek	I°

The natural, low fertility of sulphur-sulphate soils were characterised with samples taken from Nosow (locality 2) and Jablonna-Majatek. While the number of $S\text{-}SO_4$ in the soil sample originating from the Nosow village was 2.9-times lower compared with the sample taken near Jablonna-Majatek at a level of 8.5 mg $S\text{-}SO_4 \cdot kg^{-1}$ soil (Table 2). Such amount of sulphur sulphate was found within agricultural soils of the Lubelski region, but it was almost 2-times lower than the average characteristic for this region amounting to 16.5 mg $S\text{-}SO_4 \cdot kg^{-1}$ soil [14]. This problem was also highlighted by other authors, who suggest that 64 % of Lubelski region soils contain less $S\text{-}SO_4$ than for the average for the whole region [7, 14].

The increased content of sulphate sulphur was identified in soil samples collected in Nosow (locality 1). However, the amount of $S\text{-}SO_4$ only slightly exceeded the average content from soil of the Lubelskie region and agricultural farmlands throughout the country (the average for Poland is – 17.9 mg $S\text{-}SO_4 \cdot kg^{-1}$ soil) [16].

Sulphur, besides nitrogen, phosphorus, and potassium, are considered as essential nutrients for the proper growth and development of living organisms. This stems from its role and participation in the metabolic processes of living organisms. Hence, an adequate supply for plants with $S\text{-}SO_4$ affects their normal development, and consequently the yield and quality of harvested plant materials [16, 17].

Among the cultivated crops, the greatest demand for sulphur is from rape and *Brassicaceae* plants. Rape uptakes an average of 1.5 to 2 kg $S \cdot 100\ kg^{-1}$ seeds and straw, and the greatest demand for this nutrient is usually in spring from the start of the growing season until the end of florescence. Such large nutritional requirements for rape can often exceed the amount of available sulphur in the soil [2, 18, 19].

An analysis of plant material collected at designated points in the Lubelski region shows a clear relationship between the level of soil sulphur fertility, and the amount of spring rapeseed yield (Table 4).

The highest yields of oilseed rape within the limits of 2.07–2.41 1000 $kg \cdot ha^{-1}$ was observed in the Jablonna-Majatek village and Nosow (locality 2). In these localities, the level of sulphur sulphate in the soil was determined as a natural level. This may indicate that plants grown in these two test points, along with other climatic factors and cultivation used sufficient amounts of $S\text{-}SO_4$ to allow an appropriate yield.

Table 4

Yields of spring oilseed rape grown under different conditions of soil sulphur fertility

No. attempt	Locality	Yield [1000 kg · ha^{-1}]	
		straw	seeds
1	Nosow	3.76	1.54
2	Nosow	5.08	2.07
3	Halasy	0.78	0.32
4	Jablonna-Majatek	5.89	2.41

Slightly lower yields of spring rapeseeds were found in the Nosow (locality 1). The amount of seeds produced here were 1.3–1.6 times lower compared with the yield obtained in Jablonna-Majatek and Nosow (locality 2).

The least favourable conditions for growth and development of oilseed rape was found in Halasy, where the amount of $S\text{-}SO_4$ in the soil was determined as a result of increased antropogenic impact. In the analysed locality, the spring rapeseed yield was only 0.32 1000 kg · ha^{-1} and was 4.8–7.5 times lower than in the other experimental points. This may indicate that both a deficiency and excess of sulphur in crop production negatively affects the growth and yield of crops. Plants grown under excessive environmental conditions of sulphur usually uptake it in large quantities [20, 21]. In such conditions, the amount of organic sulphur in the dry weight of plants increases only slightly, and as a result the remaining quantity of this component accumulates in various tissues in the form of sulphates. These processes may affect the ionic imbalance in plants in addition to the violation of cell sap buffer systems. This in turn influences the amount and quality of harvested crops [7, 22].

The level of $S\text{-}SO_4$ soil fertility in soil of Lubelski region also affected the quality of the harvested plant material. The main criterion in assessing the quality of rapeseeds was their content of fat and protein and the presence of antinutritional substances, such as glucosinolates. The content of these compounds depends mainly on the variety, but the environmental conditions (weather, soil) and agronomic also play a role. Among the agronomic factors on the chemical composition of rapeseed, fertilization has the greatest impact. An important macroelement in nutrition of brassicacea plants is sulphur [23]. A deficiency in sulphur strongly influences the ability to acquire nitrogen from the soil, and hence the biosynthesis of protein nitrogen compounds. In addition, sulphur fertilization increases the percentage of fat and vegetable fats involved in *essential fatty acids* (EFA), thereby improving the nutritional value of oil. It should be noted, that too higher dosage will usually increase the sulphur content of alkenyl glucosinolates in rapeseed, which may worsen the nutritional value of the solvent extracted meal [24–26].

In the conducted research, the fat content of spring rapeseeds developed within 44.70–45.38 % (Table 5).

Table 5

Overall fat content in rapeseed

No. attempt	Locality	Fat content [%]
1	Nosow	45.38
2	Nosow	45.06
3	Halasy	45.35
4	Jablonna-Majatek	44.70

Standards adopted in 2007 by the *Polish Central Crop Variety Research Centre* (COBORU), specifies that the optimal fat content in dry matter of spring oilseed rapeseed should be at 45.0 % [27].

The highest content of fat were measured for spring rapeseeds collected in Nosow (locality 1) and Halasy, where the level of soil fertility of sulphur sulphate was determined as the average or had increased due to antropogenic impact. The lowest percentage of fat was found in the seeds from plants grown in Jablonna-Majatek. The amount of fat found there was at a level of 44.70 % and was slightly lower than the value adopted by COBORU as optimal.

The varied content of sulphur sulphate in the soils of the Lubelski region has also been reflected in the composition of fatty acids in seeds of spring oilseed rape (Table 6).

Table 6

Changes in fatty acid composition in seeds of spring rape

No. attempt	Percentage of fatty acids in the crude fat [%]											
	12:0	14:0	16:0	16:1	18:0	18:1 cis	18:2	18:3 Σ	20:0	20:1	22:0	22:1
1	—	0.08	4.45	0.22	1.94	58.97	22.26	10.30	0.36	1.13	0.30	—
2	—	0.06	4.53	0.11	1.99	57.97	22.51	10.55	0.56	1.41	0.31	—
3	—	0.06	4.52	0.14	1.86	59.08	22.19	10.26	0.53	1.06	0.29	—
4	0.03	0.07	4.61	0.29	1.95	58.20	22.22	10.44	0.55	1.19	0.39	0.07

Explanation of table: (–) – no value; Σ – total acids 18:3 alpha and gamma 18:3; 12:0 – capric acid; 18:3 – α-linolenic acid; 14:0 – myristic acid; 18:3 – γ-linolenic acid; 16:0 – palmitic acid; 20:0 – arachidic acid; 16:1 – palmitoleate acid; 20:1 – eicosenoic acid; 18:0 – stearic acid; 22:0 – behenic acid; 18:1 – oleic acid; 22:1 – erucic acid; 18:2 – linoleic acid.

The content of rapeseed fatty acids in oil with varying levels of saturation determines its relevance and use in human nutrition [28].

For cooking and the production of biofuels purposes, the desirable content of oil should be with high oleic acid ($C_{18:1}$) to over 75 % and with a reduced content of polyunsaturated linolenic acid ($C_{18:3}$) – less than 4 %.

Salad dressings oil, and oils typically used as a liquid part of the carcass to produce margarines should be characterised by increased linoleic acid content ($C_{18:2}$) up to 26 % and with reduced content of linolenic acid – below 4 %.

The oil contains large amounts of saturated fatty acids such as lauric ($C_{12:0}$) and palmitic ($C_{16:0}$) can be used in the manufacture of margarine. Short sequence saturated fatty acids may also be a valuable raw material for the cosmetics industry, baking, confectionery and food industry.

In the production of anti-foaming thickeners for solid lubricants and factices, the most desirable are rape varieties with very high erucic acid ($C_{22:1}$) above 90 %. It should be noted however, that the demand for this type of oil is quite low [10].

In spring, rapeseeds collected from the Lubelski region, the share of oleic acid in relation to the total content of all detected fatty acids ranged between 57.97–59.08 % (Table 6). The highest content of this acid were characterised by rapeseed harvested in Halasy. In this locality, the amount of $S\text{-}SO_4$ in the soil samples was very high and amounted to 52.5 mg $S\text{-}SO_4 \cdot kg^{-1}$ soil. In contrast, the lowest percentage of oleic acid was observed in dry seeds from Nosow (locality 2), where the amount of sulphate sulphur in the soil was low and stood at 8.5 mg $S\text{-}SO_4 \cdot kg^{-1}$ soil. In the other two localities, the share of acid in the raw fat stood at 58.20 % and 58.97 %. This may indicate that the increase in sulphur content in the soil in a form directly available to plants was accompanied by oleic acid content in seeds of spring rape. This is also confirmed by the earlier studies Kaczor and Kozlowska [8]. This is undoubtedly a major impact on the quality of harvested vegetable fat. The high content of oleic acid ($C_{18:1}$) in rape oil is relatively close to the prized olive oil. In addition, the high content of oleic acid in rapeseed oil is also healthy, because it decreases the amount of LDL fraction (*Low-Density-Lipoprotein*), which are considered the most dangerous in the development of atherosclerosis [29].

Another point of view was presented in the work of Krauze and Bowszys [4] and Szulc et al [28]. They point out that the fertilization of various sulphur compounds can lead to a decrease in fatty acid content for the polyunsaturated fatty acids.

In terms of health benefits, rapeseed oil is also appropriate as an important part in vegetable fat and other essential fatty acids (EFA). They are an important component of all membranes of the body and are involved in the regulation of vital functions by increasing the levels of prostaglandins. In addition, this affects the activity of metyloglutanylo-CoA reductase, which in turn affects the reduction of cholesterol synthesized by the liver [28, 30].

Among the essential fatty acids found in rapeseed oil linoleic acid ($C_{18:\,2}$) and alpha-and gamma-linolenic acid ($C_{18:3}$) are considered noteworthy (Table 6).

The share of linoleic acid in crude fat was between 22.22–22.51 % and was hardly dependant on the fertility of soil for sulphur sulphate in the Lubelski region. At the same time, it is worth highlighting, that the highest acid content of the seeds were in rapeseed from Nosow (locality 2), although the soil samples from this village reported the lowest content of $S\text{-}SO_4$, compared with other soil tests. Similar dependencies were also found in the case of linolenic acid ($C_{18:3}$) where the percentage of crude fat was between 10.26–10.55 %.

Due to stipulated quality requirements that are set for rapeseeds; in determining the fatty acid content we should also consider the content of undesirable erucic acid ($C_{22:1}$), in terms of nutritional value. In accordance with accepted standards, the contribution of erucic should not exceed 2 % [31]. None of the analysed samples were found to exceeded the standard. A small quantity of the fatty acid was observed only in the dry weight of rapeseeds coming from Jablonna-Majatek. In the analysed sample, the level of erucic acid in the crude fat was only at 0.07 %. Similar observations were also made by Kaczor and Kozlowska [8], which in their study found no effect on the sulphur fertilisation part of erucic acid in rapeseed oil.

Among other fatty acids found in spring rapeseeds, the percentage of palmitic acid ($C_{16:0}$) was at 4.45–4.61 %. The highest percentage share of that acid were characterised by rapeseed grown in Jablonna-Majatek, where the amount found in the soil $S\text{-}SO_4$ was determined as low.

The percentage of stearic acid ($C_{18:0}$) in the crude fat also, to some extent, depends on the sulphur sulphate soil fertility in the Lubelski region. The highest content of this acid at 1.94–1.99 % was found in spring rapeseeds coming from Nosow (locality 1 and 2) and Jablonna-Majatek. The lowest level of stearic acid was recorded in rapeseed grown in Halasy. The contribution of this fatty acid in crude fat was at 1.86 %. It should be noted that in the soil samples originating from this locality, the amount of $S\text{-}SO_4$ was very high and amounted to 52.5 mg $\cdot$ kg^{-1}. It can be assumed therefore that such a high level of sulphur in the form available to plants directly affects the quality of harvested vegetable fat.

The eicosenoic acid content ($C_{20:1}$) ranged between 1.06–1.41 %. The largest decrease in the percentage of this acid was also found in samples of rapeseed collected in Halasy. In our study, the quantity of plant fatty acid was 1.1–1.3 times lower compared with the values found in rapeseed grown in other localities.

In contrast to the participation of these fatty acids, the lowest percentage of acid, arachidic ($C_{20:0}$) was found in spring rapeseeds, which were collected in Nosow (locality 1). In the plant material from this locality, the quantity of the fatty acid was 0.36 % while the $S\text{-}SO_4$ content in the soil was defined as the average.

In all samples of rapeseed grown under different conditions of soil fertility with the sulphur sulphate, a small percentage of behenic acid ($C_{22:0}$) was recorded. It levelled off at 0.29-0.39 %.

The palmitoleate acid content ($C_{16:1}$) also to some extent depends on the $S\text{-}SO_4$ in the soil material originating from the Lubelski region. The highest share of that acid was characterised by rapeseed collected from Jablonna-Majatek and Nosow (locality 1). In the case of plant samples collected in Nosow (locality 2), where the amount of $S\text{-}SO_4$ in the soil was low and amounted to only 8.5 mg $S\text{-}SO_4 \cdot kg^{-1}$ soil, the percentage of palmitoleate acid was the lowest and amounted to 0.11 %.

In the collected oil low levels of myristic acid ($C_{14:0}$) were found which amounted to 0.06–0.08 %.

Concerning the effect of the sulphur sulphate content in the soil on the quantity and quality of oil obtained from seeds of spring rape, it should be stressed that this was just one of many factors influencing the quality parameters of *Brassicaceae* plants. One cannot forget very important factors in the cultivation of oilseed rape, cultivar characteristics, climatic conditions (humidity, temperature) and other agronomic treatments [1, 10].

Conclusions

The results of preliminary studies to determine the relationship between sulphur sulphate soil fertility in the Lubelski region, and selected characteristics of rapeseed quality permit us to draw the following conclusions:

1. The sulphate sulphur soil fertility of the Lubelski region was clearly differentiated from the low fertility (Nosow – locality 2 and Jablonna-Majatek) by high (Nosow – locality 1) to very high (Halasy).
2. The level of fertility in the analysed soil in S-SO_4 had an influence on the yield and the total fat content in seeds of spring rape.
3. The amount of fat found in the seed samples was within the range for optimum values set by the Polish Central Crop Variety Research Centre.
4. The highest content of fat was characterised by a spring oilseed rapeseed grown in Nosow (locality 1) and Halasy, where the amount of sulphate sulphur in the soil was defined as high or very high fertility.
5. The amount of sulphate sulphur in soil samples also had an influence on the quality of the vegetable fat that was influencing the percentage of individual fatty acids in the crude fat.
6. The percentage of oleic acid ($C_{18:1}$ cis) clearly increased with increasing soil fertility in the sulphur absorbed by the plant and reached the highest value in Halasy, where the level of soil fertility in S-SO_4 was determined as level IV (very high fertility).
7. The content of essential fatty acids clearly reduces with increases of S-SO_4 content the soil. The highest percentages of these acids were found in seed samples collected from the locality with a natural amount of sulphur sulphate in soils (locality 2 and 4).
8. A high sulphate sulphur content in the analysed samples of soil resulted in a decrease in the percentage of fatty acids such as: stearic ($C_{18:0}$), eicosenoic ($C_{20:0}$) and behenic ($C_{22:0}$).
9. There were no relationships between the fertility of sulphur soil in Lubelski region, and participation in terms of arbitrary values of dietary erucic acid ($C_{22:1}$).
10. In addition to the soil's fertility in S-SO_4 to changes in total fat content and the percentages of individual fatty acids, other factors most probably also had an influence including, stress, varied varieties, climatic conditions, and other agrotechnical should be emphasised.

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ZAWARTOŚĆ TŁUSZCZU I SKŁAD KWASÓW TŁUSZCZOWYCH W NASIONACH RZEPAKU UPRAWIANEGO W WARUNKACH ZRÓŻNICOWANEJ ZASOBNOŚCI GLEB LUBELSZCZYZNY W SIARKĘ

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Abstrakt: Celem podjętych badań była próba oceny zależności pomiędzy zasobnością gleb Lubelszczyzny w siarkę a niektórymi cechami jakościowymi nasion rzepaku jarego. Materiał badawczy stanowiły próbki glebowe i roślinne pobrane z terenu województwa lubelskiego. Wybór gleb do badań uwzględniał ich kategorię agronomiczną oraz zawartość siarki siarczanowej. Rośliną testową był rzepak jary zbierany w fazie pełnej dojrzałości. Wybór rośliny do badań podyktowany był jej dużymi wymaganiami pokarmowymi w stosunku do siarki. Wyniki przeprowadzonych badań wskazują, że zasobność gleb Lubelszczyzny w siarkę cechowała duża zmienność, począwszy od zasobności niskiej do bardzo wysokiej. Rzutowało to na ogólną zawartość tłuszczu w nasionach oraz na skład kwasów tłuszczowych. Najmniejszą zawartością tłuszczu charakteryzowały się nasiona rzepaku zbieranego w miejscowościach o podwyższonej lub bardzo wysokiej zawartości siarki w glebie. Również procentowy udział kwasu oleinowego wyraźnie zwiększał się wraz ze wzrostem zasobności gleb w $S\text{-}SO_4$. Zawartość, cennych z punktu widzenia walorów zdrowotnych, niezbędnych nienasyconych kwasów tłuszczowych wyraźnie jednak malała w miarę zwiększania się w glebie zawartości siarki w formie bezpośrednio dostępnej dla roślin. Nie stwierdzono natomiast wyraźnej zależności pomiędzy zasobnością gleb Lubelszczyzny w siarkę a udziałem niepożądanego z punktu widzenia żywieniowego, kwasu erukowego.

Słowa kluczowe: rzepak jary, zawartość tłuszczu, skład kwasów tłuszczowych, zasobność gleb w $S\text{-}SO_4$