Fatty Acids Composition of Mustard Oil from Two Cultivars and Physico-chemical Characteristics of the Seeds

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Abstract: Analyses of fatty acids were carried out in oil samples derived from white mustard. Two cultivars of white mustard (Sinapis alba L.) were evaluated: ‘Borowska’, and ‘Bamberka’. The oil content in the seeds of the tested cultivars was 276 and 290 g/kg, respectively. The oils obtained differed significantly in the composition of fatty acids. The oil from ‘Borowska’ contained less saturated fatty acids (4.86%) in comparison to ‘Bamberka’ (10.36%). The content of erucic acid was 22.2% in the ‘Borowska’ oil, while the oil from ‘Bamberka’ contained only 3.8% of this component. The research shows that the oil pressed from ‘Borowska’ can be used for technical purposes, and the oil derived from the cultivar ‘Bamberka’ can be used for food purposes due to the low content of erucic acid in the fatty acid composition and the beneficial fatty acid composition. As a component of diet, the low-erucic acid oil from the cultivar ‘Bamberka’ can be a source of unsaturated fatty acids (total 67.25%). The lower levels of linoleic (9.46%) and linolenic (8.35%) acid, compared with ‘Borowska’ (respectively: 12.5 and 10.5%), may contribute to increased oil oxidative stability during storage.

Key words: erucic acid, mustard seed, mustard oil, fatty acids, Sinapis alba

1 Introduction

White mustard (Sinapis alba L.) is an oily spring plant species with approx. 25-30% fat content in seeds. Erucic acid prevails among mustard oil fatty acids. It is regarded as an anti-nutritional component; hence, mustard oil cannot be used for consumption¹. Kotiuk and Sawicka¹ as well as Rudko et al.⁷ indicate the possibility to apply the oil for technical purposes as a lubricant for sows and an additive to bio-diesel fuels⁹. Furthermore, the oil is biodegradable. In the USA, virgin oils including esters obtained from a variety of agricultural products such as mustard seeds are used to produce bio-diesel fuels⁹. At the same time, research aimed at the use of seeds as a source of edible oil is carried out. It is accompanied by work leading to an increase in the fat percentage in the seeds and modification of the fatty acid composition, i.e. increasing the levels of oleic acid, while reducing the content of linoleic, linolenic, and erucic acids⁶,⁷,⁹-¹³. The breeding work carried out in Poznan IHAR (Poland) resulted in a new variety of white mustard with double improved chemical composition of seeds accepted to the registering procedures by COBORU in 2009 under the provisional designation POH-209 (Warta). Seeds of this variety are completely devoid of sinalbin, with only residual contents of olefin, in dole, and aromatic glucosinolates. In addition, erucic acid has also been removed from the seeds. With these changes in the chemical composition, white mustard was transformed into a valuable protein-oil plant species. The composition of the oil made from the seeds of the POH-209 variety corresponds almost perfectly to the conditions of edible fats posed by the science on human nutrition. In particular, it can play a role in the prevention of atherosclerosis, cardiovascular diseases, and even cancer¹⁴-¹⁷. Therefore, the aim of this study was to analyze the fatty acid composition of
the oil from the selected varieties of white mustard, including the improved ‘Bamberka’ variety. In addition, attempts to define the relationship between the fatty acid composition and selected physical and chemical characteristics of the raw material were undertaken.

2 Experimental

2.1 Plant material

The raw material for the oil production was obtained from the field canopy experiment performed in three replicates in the randomized blocks pattern in Motwica (51°43′N 23°19′E) in 2017. Two white mustard varieties were tested: a) traditional high-erucic ‘Borowska’ and b) low-erucic ‘Bamberka’. The experiment was established in the soil with a granulometric composition of light dusty loam, boronization class IVb of good rye complex, with the acidic reaction (5.0 pH in 1n KCl). The soil abundance in available nutrients was as follows: phosphorus – low (34.5 mg P/kg soil), potassium – low (49.7 mg K/kg soil), magnesium – low (27 mg Mg/kg soil), copper – low (3.1 mg Cu/100 mg soil), zinc – medium (5.7 mg Zn/kg soil), cadmium – below 0.27 mg Cd/kg soil, and lead – 18.9 mg Pb/kg of soil. The average humus proportion in the arable layer of the soil amounted to 1.8 g/kg. The seeds were harvested at day 115 after sowing. Subsequently, 30-g seed samples were collected for the following physicochemical determinations: moisture, fat content, acid number, peroxide number, contents of total ash, insoluble ash, sulfur, as well as heavy metals (cadmium, lead, zinc, and copper). The tests were performed in 10 replicates.

2.2 Seed characteristics

Moisture content was analyzed by the oven-drying method at 105°C in a Memmert GmbH & Co. KG drying oven (Germany) according to ISO 6946:1999[27]. Oil content was determined in approx. 30-g seed sample in accordance with the extraction-gravimetric method[18]. The seed characteristics were determined with the following methods: total ash – PN-ISO 928:1999[39]; ash insoluble in 10% HCl according to PN-A-74014:1994[20]; acid number – PN-ISO 660:1998[41]; peroxide number – PN EN ISO 3960:1996[22]; sulfur content – PB-33/ICP; lead, cadmium, zinc, and copper contents – PN-EN 14082:2004[21] with modifications at point 6.3. – AAS technique combustion.

2.3 Oil extraction and fatty acid composition

The technological tests, including partial seed oil removal, were performed in Vinegar and Mustard Factory in Parczew during production of mustard meal – a semiproduct for mustard condiment production. The tests consisted of partial de-oiling the seeds (residual oil in the meal was 15%), and the extracted oil was the by-product. The 02PV0 screw press with capacity of up to 100 kg·h⁻¹ was used. To analyze the fatty acid composition of the oil samples, approx. 10 g-oil samples were collected. Fatty acid profiles were measured by gas chromatography according to ISO standards[24, 25]. The oil samples (100 ml each) were converted to their fatty acid methyl esters (FAME). The fatty acid methyl ester samples were analysed in a gas chromatograph (Shimadzu GC-2010 PLUS) equipped with a flame ionisation detector. A highly polar BPX 70 capillary column (60 m x 0.25 mm, 25 μm) was used for the separation. The column was programmed in a temperature range from 140 to 210°C, the dosing temperature was 210°C, and the detector temperature was set to 250°C. The carrier gas was 6.0 helium with a constant flow rate of 2 mL/min.

2.4 Statistical analysis

Statistical processing of the results was performed applying variance, correlation, simple Pearson correlation, and polynomial regression analysis. The significance of variability sources was verified using the Fisher-Snedecor F test, while evaluation of the significance of differences between compared average values was performed using the Tukey multiple interval test. Based on simple correlation coefficients, variables to multiple polynomial regressions were selected. The stepwise method was used in the regression analysis. The algorithm was as follows: a full set of independent variables was the start. The model was estimated and the vector of empirical values of t-statistics for the hypotheses was determined. Then, the variable for which the lowest empirical value of t-statistics was obtained (referring to its absolute value) was removed from the model and re-estimated. This procedure was continued as long as the model contained only significant variables. Fitting the model to the empirical data was made by verifying the hypothesis about the significance of the determination coefficient. The procedure was terminated when the explaining variables were missing or addition of a new variable to the equation resulted in a significant loss of the parameters or the determination coefficient. The function parameters were determined by means of the least squares and significance was verified applying the Student t-test[26]. The following dependent variables (y) were assumed for the statistical processing: y1 = (16:0) palmitic acid, y2 = (18:0) stearic acid; y3 = (18:1cis11) cis-oleic acid; y4 = (18:2) linoleic acid; y5 = (18:3a) alpha-linolenic acid; y6 = (20:1) arachidic acid; y7 = (22:0) behenic acid; y8 = (22:1) erucic acid; y9 = (24:0) lignoceric acid; y10 = (24:1) nervonic acid; y11 = (20:1) eicosoenic acid. In turn, the independent variables included x1 = cadmium – mg/kg; x2 = lead – mg/kg; x3 = zinc – mg/kg; x4 = copper – mg/kg; x5 = moisture – %; x6 = total ash – %; x7 = ash insoluble in 10% HCl in %; x8 = oil content – g/kg; x9 = acid number – mgKOH/1g oil; x10 = peroxide number – in milligram equivalents of O₂/kg sample; x11 = sulfur.
content – mg/kg FW (Fresh Weight) of the sample. Regression equation presented in tables was calculated according to the formula: \( y = a + bx \), where \( y \) – dependent variable, \( a \) – constant, \( b \) – regression coefficient, \( x \) – independent variable. Partial regression coefficients \( (b_j) \) indicate to which extent the oil characteristic varies if a given factor is changed by a unit. The variability of the analyzed results was characterized using the following features: arithmetic mean, standard deviation, and variability coefficient calculated according to the formula:

\[
V = \frac{s}{x} \cdot 100\%
\]

where \( s \) – standard deviation, \( x \) – arithmetic mean (Table 2).

### 3 Results

#### 3.1 Seed properties

The genetic characteristics of the examined mustard varieties had a significant impact on the oil content and its quality features. The oil proportion in the evaluated mustard varieties differed significantly and averaged 275.6 g/kg – for ‘Borowska’ and 290.2 g/kg of seeds for ‘Bamberka’ (Table 1). The seeds of the ‘Borowska’ cultivar were characterized by higher content of zinc and water than ‘Bamberka’. Both cultivars had similar contents of total ash in the seeds, but the level of insoluble ash and the sulfur content were higher in ‘Bamberka’. The oil obtained from ‘Borowska’ seeds was characterized by a higher value of acid number and peroxide number, which indicated that oil from ‘Bamberka’ oil had better parameters.

#### 3.2 Fatty acid composition

The results of the fatty acid profile determination showed that the oils obtained from mustard seeds were characterized by different contents of saturated as well as mono and poly-unsaturated fatty acids (Table 2).

The oil obtained from white mustard seeds contained the following average levels of saturated fatty acids (SFA) expressed in g/100 g of fresh weight: palmitic – 2.91, stearic – 1.83, arachidic – 1.41, behenic – 1.32, and lignoceric – 0.16. The white mustard cultivars significantly differed in their contents of individual saturated fatty acids. ‘Bamberka’ was characterized by a higher content of palmitic, stearic, arachidic, and behenic acids than ‘Borowska’, while the latter exhibited a higher level of lignoceric acid than ‘Bamberka’ (Table 2).

Monounsaturated (MUFA) fatty acids were dominated by cis-o-leinolic acid, whereas nervonic acid made up the lowest proportion. Varietal properties greatly determined the composition of monounsaturated fatty acids in the mustard oil. The seeds of the ‘Bamberka’ cultivar were characterized by significantly higher content of cis-oleic acid and significantly lower content of erucic acid than seeds of the traditional high-erucic ‘Borowska’ cultivar. In turn, the latter cultivar exhibited the presence of eicosenoic and nervonic acids as well as a higher proportion of erucic acid and a lower level of cis-o-leanolic acid in the seeds, compared to those of ‘Bamberka’. The analysis of polyunsaturated fatty acids (PUFA) in the evaluated product revealed that the content of linoleic acid and \( \alpha \)-linoleic acid was at the level of 11 g/100 g FW and 9.4 g/100 g FW of oil, respectively (Table 2). The oil derived from the seeds of ‘Borowska’ appeared to have higher amounts of both linoleic acid and \( \alpha \)-linoleic acid than the ‘Bamberka’ oil.

#### 3.3 Statistical analysis

The statistical characteristics of the dependent variables \( (y) \) showed greater stability of features of oil produced from the seeds of ‘Borowska’ than ‘Bamberka’ (Tables 1 and 2). Behenic acid content turned out to be a most stable feature in the product with coefficients \( V = 0.0 \) and 1.35% for ‘Bamberka’ and ‘Borowska’, respectively.

| Seed components: | Cultivars: | ‘Borowska’ | ‘Bamberka’ |
|------------------|------------|------------|------------|
|                  | Mean ± SD  | CV [%]     | Mean ± SD  | CV [%]     |
| Oil [g/kg]       | 275.6 ± 3.43 | 1.21       | 290.2 ± 4.33 | 1.49      |
| Zinc [mg/kg]     | 63.1 ± 1.73  | 2.75       | 59.00 ± 0.87 | 1.47      |
| Water [%]        | 13.01 ± 0.26 | 2.00       | 11.69 ± 0.17 | 1.48      |
| Total ash [%]    | 4.42 ± 0.09  | 1.96       | 4.33 ± 0.08  | 2.00      |
| Insoluble ash [%]| 0.53 ± 0.03  | 4.90       | 0.68 ± 0.02  | 2.54      |
| Sulfur [mg/kg]   | 7.98 ± 0.03  | 0.43       | 8.15 ± 0.03  | 0.32      |

Oil properties:

| Acid number [mg KOH/g] | 8.6 ± 0.17 | 2.01       | 6.9 ± 0.09  | 1.26      |
| Peroxide number [mgO₂/kg] | 4.90 ± 0.07 | 2.11 | 4.60 ± 0.17 | 3.77      |

SD - standard deviations; CV - coefficient of variation

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**Table 2** Seed components of two cultivars white mustard.
Stearic acid content was the most variable feature, which was proved by variability coefficients $V = 6.61\%$ for 'Borowska' and $V = 3.7\%$ for the 'Bamberka' cultivar.

The characteristics of the independent variables $x$ showed that the most stable feature of mustard oil quality was the peroxide number of oil derived from the seeds of 'Borowska' (the most variable feature – the content of ash insoluble in 10% HCl in seeds of the same cultivar; $V = 4.90\%$) (Table 1).

The correlation coefficient is a measure of the strength of the relationship between random variables. The empirical correlation coefficient $r$ has all properties defined for the correlation coefficient. The correlation coefficient also determines the direction of the relationship. Pearson correlation coefficients determine the extent to which variables as a measure of the correlation of two (or more) variables are interdependent. In the case of palmitic, stearic, $cis$-oleic, arachidic, and behenic acids, the strongest positive relationship was found with the content of insoluble ash, while a negative correlation was determined for erucic, lignoceric, and nervonic acids. A very high negative correlation was related to the seed moisture content, zinc, total ash, and sulfur in seeds, as well as ascorbic acid number in oil. The increase in the contents of these fatty acids in the oil by values shown in Table 4. The evaluated regression models explained 86.1%, 87.9%, and 99.4% of the variability of dependent variables, respectively. The determination coefficient indicates to which extent the variability of a given feature can be explained by another one. In addition, it shows how much of the total variability of the random variable $y$ is explained by the linear regression of $x$.

The linoleic acid content was related to the seed moisture content, zinc, total and insoluble ash, oil, and sulfur in seeds, as well as peroxide number in oil. The increase in the contents of these fatty acids in the oil by values shown in Table 2. The evaluated regression models explained 100% ($R^2 = 1.0$) of the variability of dependent variables.

α-Linolenic acid appeared to be associated with almost

### Table 2 Composition of major fatty acid in oils from two cultivars white mustard[g/100 g oil].

| Fatty acid         | Cultivars: | 'Borowska' | 'Bamberka' | LSD_{0.05} |
|--------------------|------------|------------|------------|------------|
|                    | Mean ± SD  | CV [%]     | Mean ± SD  | CV [%]     |           |
| Palmitic (16:0)    | 2.44 ± 0.10 | 3.90       | 3.37 ± 0.10| 3.08       | 0.26       |
| Stearic (18:0)     | 1.31 ± 0.09 | 6.61       | 2.34 ± 0.09| 3.70       | 0.23       |
| Arachidic (20:0)   | 0.72 ± 0.09 | 1.20       | 2.09 ± 0.09| 0.41       | 0.02       |
| Behenic (22:0)     | 0.07 ± 0.00 | 0.00       | 2.56 ± 0.04| 1.35       | 0.06       |
| Lignoceric (24:0)  | 0.32 ± 0.00 | 0.00       | 0.00 ± 0.00| 0.00       | 0.00       |
| $\sum$ SFA        | 4.86       | —          | 10.36      | —          | —          |
| $cis$-oleic (18:1cis)| 25.05 ± 0.04| 0.17       | 45.64 ± 0.16| 0.34       | 0.30       |
| Eicosenic (20:1)   | 8.64 ± 0.09 | 1.00       | 0.00 ± 0.00| 0.00       | 0.16       |
| Erucic (22:1)      | 22.22 ± 0.09| 0.39       | 3.80 ± 0.02| 0.46       | 0.16       |
| Nervonic (24:1)    | 2.28 ± 0.02 | 0.76       | 0.00 ± 0.00| 0.00       | 0.03       |
| $\sum$ MUFA       | 58.19      | —          | 49.44      | —          | —          |
| Linoleic (18:2)    | 12.53 ± 0.09| 0.69       | 9.46 ± 0.13| 1.37       | 0.29       |
| $\alpha$-linolenic (18:3a)| 10.45 ± 0.04| 0.41       | 8.35 ± 0.13| 1.56       | 0.25       |
| $\sum$ PUFA       | 22.98      | —          | 17.81      | —          | —          |

SD - standard deviations; CV - coefficient of variation; LSD_{0.05} – low significant differences;

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Table 3  Pearson correlation coefficients.

|       |    y₁  |    y₂  |    y₃  |    y₄  |    y₅  |    y₆  |    y₇  |    y₈  |    y₉  |    x₁  |    x₂  |    x₃  |    x₄  |    x₅  |    x₆  |    x₇  |    x₈  |    x₉  |    x₁₀|    x₁₁|
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|
| y₁    | 1.00   | 1.00   | 1.00   | 1.00   | 1.00   |
| y₂    | 0.98   | 0.99   | 1.00   | 1.00   | 1.00   |
| y₃    | -0.97  | -0.98  | -1.00  | -1.00  | 1.00   |
| y₄    | -0.99  | -1.00  | -1.00  | 0.99   | 1.00   |
| y₅    | 0.98   | 0.99   | 1.00   | -1.00  | -1.00  | 1.00   |
| y₆    | 0.98   | 0.99   | 1.00   | -1.00  | -1.00  | 1.00   |
| y₇    | 0.98   | 0.99   | 1.00   | -1.00  | -1.00  | 1.00   |
| y₈    | 0.98   | 0.99   | 1.00   | -1.00  | -1.00  | 1.00   |
| y₉    | 0.98   | 0.99   | 1.00   | -1.00  | -1.00  | 1.00   |
| x₁    | 0.01   | 0.00   | 0.01   | 0.07   | 0.00   | 0.01   | 0.01   | 0.01   | 0.01   | 1.00  |
| x₂    | -0.03  | 0.00   | 0.08   | -0.07  | 0.05   | 0.09   | 0.08   | -0.08  | -0.08  | -0.07  | -0.09  | 0.35   |
| x₃    | -0.86  | -0.85  | 0.88   | 0.84   | -0.84  | -0.84  | 0.85   | 0.85   | 0.84   | 0.51   | 0.20   |
| x₄    | -0.28  | -0.29  | 0.36   | 0.25   | -0.29  | -0.28  | 0.30   | 0.29   | 0.28   | 0.96   | 0.31   | 0.73   |
| x₅    | -0.94  | -0.95  | 0.97   | 0.94   | -0.95  | -0.95  | 0.96   | 0.95   | 0.96   | 0.95   | 0.96   |
| x₆    | -0.47  | -0.48  | 0.54   | 0.45   | -0.48  | -0.47  | 0.49   | 0.48   | 0.49   | 0.47   | 0.88   |
| x₇    | 0.94   | 0.94   | 0.96   | 0.94   | 0.97   | 0.96   | 0.96   | 0.96   | 0.96   | 0.96   | 0.96   |
| x₈    | -0.95  | -0.95  | 0.96   | -0.95  | 0.96   | 0.95   | 0.96   | 0.95   |
| x₉    | 0.55   | 0.54   | 0.54   | 0.54   | 0.54   | 0.54   | 0.54   |
| x₁₀   | 0.55   | 0.54   | 0.54   | 0.54   | 0.54   | 0.54   |
| x₁₁   | 0.55   | 0.54   | 0.54   | 0.54   | 0.54   | 0.54   | 0.54   |

y₁ – (16:0) palmitic acid; y₂ – (18:0) stearic acid; y₃ – (18:1cis) – cis-oleic acid; y₄ – (18:2) linoleic acid; y₅ – (18:3α) – α-linolenic acid; y₆ – (20:0) arachidic acid; y₇ – (22:0) behenic acid; y₈ – (22:1) erucic acid; y₉ – (24:0) – lignoceric acid; y₁₀ – (24:1) nervonic acid; y₁₁ – (20:1) eicosenic acid; x₁ – Cd [mg/kg]; x₂ – Pb [mg/kg]; x₃ – Zn [mg/kg]; x₄ – Cu [mg/kg]; x₅ – water [%]; x₆ – total ash [%]; x₇ – insoluble ash [% 10% HCl]; x₈ – content of oil – g/kg; x₉ – acid number [mg KOH/1 g oil]; x₁₀ – peroxide numer [meqO₂/kg]; x₁₁ – content of sulfur in mustard seeds [mg/kg]
all independent variables, with the exception of total ash and oil in the mustard seeds. The increasing zinc and sulfur contents in the seeds as well as peroxide and acid numbers by a unit, within limits of standard deviation from the arithmetic mean, contributed to reduction of the accumulation of the acid. In turn, the increase in the seed moisture content and insoluble ash content in the seeds by a unit, within limits of standard deviation from the arithmetic mean, resulted in an increased share of α-linolenic acid by values presented in Table 4. The model explained 99.1% \((R^2 = 0.991)\) of the variability of dependent variables.

Arachidic, behenic, erucic, lignoceric, eicosenoic, and nervonic acids were associated with the moisture content in seeds, insoluble ash content in seeds, as well as acidic and peroxide numbers in oil. In the case of arachidic and behenic acids, the increase in seed moisture content, insoluble ash content, along with the decrease in acid and peroxide numbers by a unit (within the standard deviation from the arithmetic mean) caused a change in these characteristics by values shown in Table 1. The developed regression models explained 100% of the variability of dependent variables \((R^2 = 1.0)\).

In the case of erucic, lignoceric, eicosenoic, and nervonic acids, the decrease in seed moisture as well as insoluble ash content, along with the increase in acid and peroxide numbers by a unit, within the limits of standard deviation from the arithmetic mean, caused a change in the profile of fatty acids in oil by values indicated in Table 4. The estimated models explained 92.6%, 97.7%, 81.5%, and 100% of the variability of dependent variables, respectively \((R^2 = 0.926, 0.977, 0.815, \text{and 1.00})\). This means that more than 81% of the variability is explained by this model. The significance of equations presented in Table 4 was very high, i.e. at a level of \(p = 8.7E-118 - 8.1E-151\).

### 4 Discussion

#### 4.1 Oil content

Sharafia et al.\(^{27}\), who examined the fatty acid composition of 20 cultivated species and five wild relatives, showed that the oil content ranged from 21 \((B. \text{ nigr})\) to 46% \((B. \text{ napus})\). The main fatty acids, i.e. oleic, linoleic, linolenic, erucic, palmitic, and stearic acids, constituted 89-94% of all fatty acids in all species. Cultivated \(B. \text{ napus}\) species had the highest content of oleic acid \((61%)\) and the lowest level of erucic acid \((1%)\) in comparison to the other species tested. \(Brassica \text{ rap}a\) and \(B. \text{ oleracea}\) had the highest level of erucic acid \((41\text{ and }46\%)\), respectively. The highest content of linolenic \((20\%)\) and linoleic acid \((19\%)\) was observed in \(B. \text{ juncea}\) seeds. Zannatul et al.\(^{4}\) and Sharafia et al.\(^{27}\) showed high genetic variability in terms of the oil content and fatty acid composition among the tested species. This indicates that the seed oil of these species is probably suitable for both human consumption and industrial purposes. The oil content in the evaluated white mustard varieties was at a similar level, although higher than that found by Piętka and Krzymański\(^{35}\) and Piętka et al.\(^{41}\).

#### 4.2 Fatty acid composition

The percentage of palmitic, stearic, oleic, eicosenoic, linolenic, and α-linolenic acids was at a level similar to that obtained in the study by Piętka et al.\(^{41}\), while the erucic acid content was half higher. Differentiation of the fatty acid profile in mustard oil in terms of the contents of palmitic, oleic, linoleic, linolenic, erucic, nervonic, and eicosenoic acids, depending on the type of the specimen, was also observed by Ciubota-Rosie et al.\(^{5}\). As suggested by Murawa et al.\(^{28}\), the percentage of saturated, monounsaturated, and polyunsaturated fatty acids in the oil from mustard seeds is determined by genetic features of cultivars. This

### Table 4

| Dependent variables | Free Word | Independent variables (x) | Determination coefficient [%] | Significance F |
|---------------------|-----------|---------------------------|-----------------------------|---------------|
| Palmitic            | -21.54    | -0.54  -2.19 -7.96 -0.07 -0.99 2.49 5.04 | 98.1 | 8.7E-118 |
| Stearic             | -15.47    | -0.43  -1.56 -5.07 -0.07 -1.08 2.17 4.00 | 87.9 | 6.4E-120 |
| cis-oleic           | -71.33    | 4.08  -16.79 -11.08 -0.49 -10.33 11.43 29.66 | 99.4 | 1.2E-122 |
| Linoleic            | 38.74     | -1.02  353 -5.77 3.48 0.08 4.21 | -4.84 | 100.0 | 6.4E-119 |
| α-linolenic         | 31.55     | -0.47  2.57 0.10 -0.53 -2.42 -4.96 | 99.1 | 9.0E-121 |
| Arachidic           | 16.65     | 0.19  5.23 -0.65 -0.16 | 100.0 | 1.3E-149 |
| Behenic             | 35.90     | 0.63  9.97 -1.53 -0.02 | 100.0 | 1.2E-148 |
| Erucic              | -222.51   | -3.26  -69.63 9.93 0.94 | 92.6 | 2.2E-149 |
| Lignoceric          | -3.99     | 0.06  -1.24 0.17 0.02 | 97.6 | 2.9E-149 |
| Nervonic            | -22.33    | -0.28  -7.81 1.13 0.08 | 81.5 | 8.1E-151 |
| Eikosenic           | -101.29   | -1.95  -33.79 4.8 0.91 | 100.0 | 3.5E-149 |

\(\text{Values}\) were very high;

\(R^2\) values are shown in Table 1.
was confirmed in the present study. The oil extruded from the traditional 'Borowska' cultivar was characterized by a typical fatty acid composition and percentage as that specified in the Codex Alimentarius\[29]. Only the oleic acid (18:1) content was slightly above the upper limit of the range (23%), while the quantity of behenic acid (22:0) was below the specified range (0.2%). In their study, Piętka et al.\[14\] detected no arachidic, behenic, lignoceric, and nervonic acids in oil obtained from 'Borowska' seeds, although these acids were present in the oil analyzed in the present study. The fatty acid composition in the oil from the improved 'Bamberka' variety tested in the present study was significantly different from that specified in the Codex Alimentarius\[20\] in terms of oleic and erucic acids. Some significant differences in the amounts of these fatty acids were found between the assessed cultivars. According to the National Nutrient Database for Standard Reference\[33\], the content of saturated fatty acids in mustard oil amounts to the average of 11.58 g/100 g. However, it varied in the present study depending on the cultivar and ranged from 4.86 g/100 g in 'Borowska' to 10.36 g/100 g in the case of 'Bamberka'. The level of both monounsaturated and polyunsaturated acids in the oil extruded from 'Borowska' was more similar to the standard than that produced from 'Bamberka'.

The higher erucic acid content in the analyzed oil, compared to the value reported by Piętka et al.\[14,15\] and Bartkowiak-Broda et al.\[30\], may result from numerous events of crossbreeding with traditional cultivars having high levels of this acid, since white mustard is both self-pollinated and allogamous. Paszkiewicz-Jasińska\[32\] indicated some significant differences between 'Borowska' and Ascot cultivars of white mustard related to the fatty acid profile. The varietal differences were found for all unsaturated fatty acids and two saturated ones – stearic and behenic. The author did not identify any diversity in the contents of palmitic and arachidic acids in oil produced from the seeds of these varieties, whereas the largest differences between the cultivars were recorded referring to the content of oleic and erucic acids. Ascot contained by 6.7% more erucic acid in oil, while 'Nakielska' had by approx. 7.4% more oleic acid. The differences in the accumulation of fatty acids in seeds also exist among 'Nakielska', and 'Borowska'\[14,29\]. The largest difference in this respect was observed for erucic acid\[14,31,33\]. Kaczor and Kozłowska\[31\] analyzed the effect of sulfur fertilization and liming on the overall oil content and fatty acid composition in white mustard seeds. They found that sulfur fertilization slightly increased the amount of oil in seeds, but did not cause any significant changes in the composition of saturated fatty acids. As suggested by the authors, the profile of fatty acids in the seeds was influenced by fertilization with calcium. Sulfur supplementation toplants as well as soil liming resulted in an increase in the contents of erucic, linoleic, oleic, myristoleic, palmitoleic, linoleic, and eicosenoic acids in relation to the control not fertilized with these nutrients.

As demonstrated by Murawa et al.\[28\], the fatty acid profile in white mustard seeds, in particular the proportions of saturated acids and oleic acid, is determined by herbicides applied. Piętka et al.\[14\], Piętka and Krzyżański\[35\], Bartkowiak-Broda\[31\], and Piętka et al.\[35\] reported that 'Bamberka' had substantially lower content of erucic acid (<1.5%) than traditional cultivars but higher concentrations of oleic acid. The quantity of erucic acid obtained in this study was 3.80 g/100 g FW of oil, which was higher than during tests of this cultivar performed by breeders\[29\]. Nevertheless, it did not exceed the permissible level (5% with respect to fatty acids) specified for cooking oil\[38\]. The low productivity associated with elimination of erucic acid and sinablin (main white mustard glucosinolate) has been overcome in a new variety, which is characterized by a very low acid content erucic acid in oil (less than 1.5%), no sinablin, and very low content of other glucosinolates in seeds (less than 15 μg/g). These types of white mustard may contribute to reducing the European deficit of vegetable protein\[39\]. As suggested by Ciubota-Rosie et al.\[5\], the composition of fatty acids in oil depends on the environmental conditions, cultivation of raw material, and in particular on the temperature and isolation. Lower air temperatures during the growing season favor the accumulation of polyunsaturated fatty acids accelerating seed maturation, which contributes to an increase in the content of monounsaturated fatty acids to a higher degree than polyunsaturated acids.

Mukherjee and Kiewitt\[30\] reported that the fatty acid composition depended on the phase of plant maturity. Mainly the maturation of Sinapis alba seeds was affected by a rapid fall in the amount of lipids, including palmitic and linoleic acids, up to six weeks after flowering. At the same time, there was an increase in the oleic acid concentration, reaching its maximum at 4 WAF, followed by extension of the oleic acid chain and formation of gad oleic acid and erucic acid. Changes in the fatty acid composition of individual lipid classes indicate that the very long chains of monounsaturated fatty acids (C16 and C22), as opposed to long-chain ones (C15 and C18), are metabolized mainly to triacylglycerols and formed by esterification to diacylglycerols and monoacylglycerols rather than to glycerol-3-phosphate acids. The research conducted by Brown et al.\[37\] upon the modification of fatty acids composition in white mustard seeds indicated a negative correlation between the content of erucic and oleic acid in oil (a decrease in the erucic acid content contributes to an increase in the amount of oleic acid). These authors also observed a high correlation between the contents of oleic vs. palmitic, stearic, linolenic, and eicosenoic acids in oil. Similarly, the present findings indicate a negative relationship of the contents of oleic acid vs. linoleic, α-linolenic, erucic, lignoceric, nervonic, and eicosenoic acids. Potts and Males\[10\].
Potts et al., and Raney et al. investigated changes in the amount of individual fatty acids in low-erucic Indian mustard. They were related to reduction of the amounts of linoleic and linolenic acids and an increase in the oleic acid content. As suggested by these authors, despite their high nutritional value, the acids reduce the oxidative stability of the oil and its consumption quality, especially during long-term storage.

4.3 Nutritional and technical value of mustard oils

Polyunsaturated fatty acids are essential components of diet and constituents of cell membrane lipids. They are involved in the transport and oxidation of cholesterol and are a substrate for the synthesis of eicosanoids. In the classical sense, essential unsaturated fatty acids (EUFA’s), e.g., linoleic (n-6) and α-linolenic (n-3) acids, cannot be synthesized by the human organism, and the nutritional value of oils is dependent on their contents and the n-6 to n-3 ratio. According to the Confederation of the Food and Drink Industries of the EU (CFDI), the recommended daily intake (RFI) of α-linolenic acid (n-3) is 20 g for women and 25 g for men, whereas that of n-6 acids is 14 g and 18 g, respectively. Consumption of a single tablespoon of low-erucic mustard oil (12 g) provides 1 g α-linolenic acid, an average of 45% of RDI, and 1.1 g of linoleic acid, an average of 6.98% RDI. The assessed mustard oil obtained from the seeds of the ‘Bamberka’ cultivar exhibited the n-6 to n-3 ratio of 9.46:8.35 (i.e., 13:1). Minkowski as well as Maszewska and Gańko considered 4:1 the optimal proportion of these acids. As reported by Minkowski, epidemiological studies suggest a positive effect of replacing dietary saturated fatty acids with monounsaturated oleic acid, because it lowers the cholesterol level in blood plasma and LDL. Furthermore, monounsaturated fatty acids do not reduce the concentration of cholesterol in high-density lipoproteins (HDL) and do not affect the concentration of triacylglycerols. The Recommended Daily Intake (RFI) of monounsaturated fatty acids amounts to 34 g for women and 29 g for men. One tablespoon (12 g) of oil extruded from the improved white mustard cultivar ‘Bamberka’ provides 5.48 g of oleic acid.

The high content of erucic acid in the oil extruded from the seeds of ‘Borowska’ white mustard disqualifies it from consumption. Instead, it is an advantage when the oil is used for technical purposes. Hemingway, Rudko, Sawicka and Kotiuk, Rudko, Hassan and Khaleda, suggest a possibility of using the high-erucic mustard oil as a lubricant for chain saws. Its additional asset consists in its environmentally friendly character. The kinematic viscosity of mustard oil at 100°C, viscosity index, density, melting and ignition points, as well as sulfur content, proportion of impurities, and acid number are similar to that for mineral oil, which is widely used in motor saws. Significant differences between mustard and mineral oils were observed in relation to kinematic viscosity at 40°C and viscosity index. The susceptibility of mustard oil to oxidation and solidification at −13°C (while this value for mineral oil is approx. −27°C) is a disadvantage. Therefore, further studies of the use of mustard oil for technical purposes are focused on slowing down the oxidative changes in the oil and lowering the freezing point, which is essential when working in forest ecosystems.

The determination coefficients of the equation systems discussed in the present study were high, and even very high (D = 100%) in the case of linoleic, arachidic, behenic, and eicosenoic acids. This suggests that the fatty acid composition is influenced by moisture content in seeds, level of ash insoluble in 10% HCl, as well as acid and peroxide numbers. In the case of regression models for erucic, palmitic, stearic acid, cis-oleic, lignoceric, and nervonic acids in oil, the determination coefficient value was high and met the level of 60% postulated by Kranz and Royal. At divergent influences of meteorological factors, this suggests that the content of these acids in mustard oil is affected by other factors, not included in the model function. However, as suggested by Neter et al., the R² value should be interpreted with caution, since it does not have a clear interpretation for the WSL estimator. The use of regression in practice, as shown by Belsley et al. and Smith, can be simplified to the following two phases: construction of the model, i.e., a function describing the dependence of expected values of the expected variable on the explaining variables. This feature, however, can be set not only in a form of a simple mathematical formula, but also in the whole algorithm, e.g., as a neural network, regression trees, etc. The model is to be constructed in a way allowing more close fitting of the experimental data containing both explaining and explained variables. The use of the model (scoring) can consist in applying the calculated model to experimental data in which only explaining variables are known in order to define the expected value of the explained variable. Designated polynomial regression models can be used to predict values that would be accepted by variable $y$ at fixed values of independent variable $x$. It is an issue of prediction or forecasting. However, the more different the value of $x$ (for which the prediction procedure is applied) from the average of the sample, the lower the accuracy of the forecast. Estimation of the regression function is a difficult issue, because there is no assurance that the set of the analyzed independent variables is complete and the type of regression function is not known in advance. Hence, there is a problem of selecting the shape of the regression function and a set of independent variables. Some comparable "accuracy of the model fitting", the correlation coefficient or R² for different types of regression functions, and a set of independent variables can be achieved in the present study.

The science progress provides opportunities to develop...
particular functional characteristics of plants, depending on their intended use. A conscious choice of materials with defined and improved features for food processing may contribute to the development of by-products that arise from the use of traditional cultivars and thus widening the product range of a given company and achieving a better economic effect. On the other hand, random and unconscious purchase of raw materials with characteristics that are different from the original sample can result in defects of the final product. Double improved cultivars may cause defects of mustard flavor due to the lack of glucosinolates. It is therefore important to plan the resource management and to cooperate with manufacturers of plant material, especially in the case of production for food processing.

5 Conclusions
1. Due to the high content of erucic acid, the oil extruded from 'Borowska' mustard seeds can be used for technical purposes to produce biodegradable lubricants.
2. With its low level of erucic acid and advantageous fatty acid profile, the oil made from 'Bamberka' white mustard seeds can be applied for consumption and as a source of unsaturated fatty acids, whereas the lower contents of linoleic and linolenic acids, compared to 'Borowska', can ensure higher oxidative stability of the oil during storage.
3. The polynomial regression analysis between dependent and independent variables allow better explanation of the causes of diversity in the fatty acid composition of the white mustard oil, which in future will facilitate prediction of its quality characteristics on the basis of the chemical composition of raw material.
4. Further studies focused on determination of detailed usefulness features of the analyzed oil types, both for technical and consumption purposes, are necessary.

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