Nutrient content, fat yield and fatty acid profile of winter rapeseed (*Brassica napus* L.) grown under different agricultural production systems

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ABSTRACT

Quality features of rapeseeds (*Brassica napus* L.) and potential for high yielding to a major extent may be defined by improvements in agricultural engineering methods that encompass biological progress. However, this is associated with fertilization and application of pesticides, which may negatively impact on environment and quality. It is thus essential to develop and improve edible oil production systems to satisfy farmer and non-threatening consumer. The aim of this study was to evaluate content of nutrients, fat yield and fatty acid profile of rapeseed grown in two crop rotation system with three levels of agricultural inputs. Three levels of technologies were used: economically (low-input), moderately intensively (medium-input) and intensively (high-input), varied in N amount and S fertilization as well as protection against pests. The medium- and high-input technologies applied in the monoculture contributed to an increased oleic acid in rapeseeds (by 5.7% and 5.5%), whereas low-input and high-input technologies resulted in an increased proportion of linoleic (by 11.6% and 2.1%) and linolenic acid (by 6.6% and 5.0%) in the monoculture rapeseeds. The medium-input level generated an increased proportion of arachidic (from 6.9% to 15.0%), octadecanoic (by 4.9%), linoleic (by 7.0%), linolenic (by 5.1%) and eicosadienoic fatty acids (by 17.7%) in rapeseeds cultivated in the crop rotation system. The increase in technological input level changed the ratio of polyunsaturated fatty acids to linoleic and linolenic acids by 5.1% and 7.4% ($p < 0.05$) in both crop rotation and by 4.2% and 7.9% monoculture systems. In general, the impact of winter rapeseed in crop sequence systems was found to have an insignificant impact on the content of macronutrients and trace elements in seeds. The highest fat yield was generated with the crop rotation system at the highest input level, whereas the lowest yield was recorded in the low-input monoculture technology.

Key words: Cropping system, integrated management, level of technology, rapeseed cultivars.

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INTRODUCTION

Oil and protein are the basic raw materials derived from rapeseeds (*Brassica napus* L.) Rapeseed oil is an important source of energy in human nutrition (Omidi et al., 2010) and degreased rapeseeds are used as feedstuffs (Baltrukoniene et al., 2015). Rapeseed oil is a distinguished edible oil, which is also determined by a relatively high proportion of unsaturated fatty acids such as linoleic acid (C18:2) and α-linolenic acid (C18:3) that are classified as essential unsaturated fatty acids (EFAs) and have been associated with blood lipid profiles associated with a lower risk of coronary heart disease (Narits, 2010; Ntawubizi et al., 2010). According to Zatonski et al. (2008), rapeseed oil has a very low content of saturated fatty acids than other oil plants and a relatively high content of the basic fatty acids (C18:2) and (C18:3) at optimal 2:1 ratios. The value of rapeseed, as a source of vegetable oils and proteins, may be improved by: increasing the content of oil, modifying the composition of fatty acids in oil, and reducing the anti-nutritional compounds, mainly fiber and glucosinolates, in rapeseed meal (Liersch et al., 2013).

The quality features of rapeseeds and the potential for high yielding to a major extent may be defined by improvements in agricultural engineering methods that encompass biological progress. However, this is associated with intense fertilization and the application of large amounts of pesticides, which may negatively impact the consumer. It is thus essential to develop and improve edible oil production systems to make them both satisfying to the farmer and non-threatening to the consumer (Velicka et al., 2016). Fertilizer applications, especially on nutrient deficient soils, can therefore increase crop yields and quality (Albert et al., 2012; Malhi, 2012). Both macro and micronutrients are essential to proper crop growth, but N and S are the most limiting nutrients (Ngezimana and Agenbag, 2014). Hegewald et al. (2016) noted the importance of crop rotation to maintain seed yield and oil yield of oilseed rape, and to maximize the response to applied N. A reduced N-rate increased N-use efficiency and reduced the risk of high-N surpluses without a significant/equivalent decrease in the seed yield when the rotation was optimized.

New rapeseed cultivars characterized by high and reliable yields and improvements in agronomic practices increase profits, contribute to faster crop rotation and enable growing crops in monocultures (Cwalina-Ambroziak et al., 2016). Despite the above, intensive rotation of the same crop could have negative effects, such as frequent pest infestations, including plant pathogens (Mohammadi and Rokhzadi, 2012). This problem

RESEARCH

can be addressed by reversing soil fatigue through the introduction of new cultivars and technologies suited to their requirements (Sieling and Christen, 2015). An increased level of fertilization, especially with N, is always associated with a need to improve the efficacy of plant protection (Cwalina-Ambroziak et al., 2016). Crop rotation and optimal rates of N (Rathke et al., 2006) and S fertilization (Sienkiewicz-Cholewa and Kieloch, 2015) are of key importance in reducing pathogenic infections in rapeseed.

The aim of this study was to evaluate the content of nutrients, fat yield and fatty acid profile in a 5-yr monoculture and after a 4-yr break in the crop rotation system of rapeseed with three levels of agricultural inputs.

MATERIALS AND METHODS

Site and experimental set-up

The research facility is located in the Central European Lowlands, the sub-area of the South Baltic Lagoon, in the Ilawa Lake District. The study area is characterized by a young glacial landscape within the range of the ice sheet of the Pomeranian glaciation of the Vistula. Winter rapeseed (*Brassica napus* L.) was grown in monoculture and in crop rotation in Balcyny (53°36' N, 19°51' E), Poland, in 2009-2013. The field experiment was set up on loess soil, class IIIa soil/arable soil of good quality Topsoil (Ap) was made up of heavy loamy sand, and the E-horizon consisted of clay underlain by light loam in the illuvial horizon (Bt). According to the World Reference Base for Soil Resources (WRB, 2014), this corresponds to a Luvisol. Soil was slightly acidic (in KCl solution with pH 6.6), and its total N content was determined at 0.95 g kg^{-1} and total organic C content at 10.05 g kg^{-1}. Soil concentrations of plant-available macronutrients (mg kg^{-1}) were 93.3 mg P kg^{-1}, 185.4 mg K kg^{-1}, 58.5 mg Mg kg^{-1}, and 550 mg Ca kg^{-1}. The concentrations of soil nutrients were according to the valid standards and standard methods applied in Poland. The contents of macronutrients were determined: Total N by the Kjeldahl method, P and available K by the Egner-Riehm method in calcium-lactate extract ($(CH_3CHOHCOO)_2Ca$) acidified with hydrochloric acid to pH 3.6, available Mg was assayed after the extraction of 0.01 mol $CaCl_2 \times 10^{-3}$ m^3 from soil, using the Atomic Absorption Spectrometry (AAS) and Ca by universal method of extraction with 0.003 N acetic. Soil pH was determined electrometrically in a solution of 1 M KCl and humus content by the Tiurin method.

Before the experiment, a mixture of spring cereals (oats, barley, wheat) was sown in all plots for green fodder, without fertilization. The results presented in this study were noted in the fifth year of the experiment in the rapeseed monoculture (2013) and in crop rotation: 2009 winter rapeseed, 2010 winter wheat (*Triticum aestivum* L.), 2011 field bean (*Vicia faba* L.), 2012 spring wheat (*T. aestivum*), and 2013 winter rapeseed. The open-pollinated rapeseed 'Californium' was grown, seeds (4.5 kg ha^{-1}) were sown in 20 August and dressed with insecticides imidacloprid 200 g and cypermethryna 50 g (Brasikol C 250 FS, Z.P.U.H. "Best-Pest" – Jaworzno, Poland) and fungicide tiuram 332 g and karbendazym 148 g (Funaben T 480 FS, Organika-Azot S.A. Jaworzno, Poland). Plants were harvested in the first half of July. Three levels of technologies were used: economically (low-input), moderately intensively (medium-input) and intensively (high-input), varied in amount of N and S fertilization as well as protection against pests. The applied fertilizer and pesticide treatments are given in Table 1. The experiment had a randomized block design with three replicates. The plot size was 12.0 m^2, the harvested plot area was 9.0 m^2.

Yield and content of macro and microelements

At the end of the experiment seeds were collected, dried and purified. Rapeseed seed were collected from the experimental field (9.0 m^2) and its yield was calculated in tons per hectare at 15% humidity.

Seed samples (1 kg) were taken from the plot and subjected to chemical analysis for the content of macro-

Table 1. Treatments carried out in winter rapeseed (*Brassica napus*) plots experiment.

Level of technology	Fertilization treatments	Protection against pests
Low-input	Autumn (before sowing): 30 kg N ha^{-1} (NH_4NO_3), 40 kg P ha^{-1} (40% P_2O_5), 60 kg K (60% K_2O) Spring: 160 kg N (NH_4NO_3), 1st dose (BBCH 30) 120 kg N ha^{-1}, 2nd dose (BBCH 50) 40 kg N ha^{-1}	Weeds (autumn, before sowing): clomazone and metazachlor (2.5×10^{-3} m^3 ha^{-1}) Pathogens: (BBCH 50-59, 65-69)*: dimoxystrobin and boscalid (0.5×10^{-3} m^3 ha^{-1}) Pests (BBCH 50-59): chlorpyrifos and cypermethrin (0.6×10^{-3} m^3 ha^{-1}), acetamiprid (0.12 kg ha^{-1})
Medium-input	Autumn (before sowing): 30 kg N ha^{-1} (NH_4NO_3), 60 kg P (40% P_2O_5), 120 kg K ha^{-1} (60% K_2O) Spring: 180 kg N (NH_4NO_3) 1st dose (BBCH 30) 120 kg N ha^{-1}, 2nd dose (BBCH 30) 60 kg N ha^{-1}, 45 kg S ha^{-1} ($(NH_4)_2SO_4$ (BBCH 30)	Weeds (autumn, before sowing): metazachlor and chinomerak (3.0×10^{-3} m^3 ha^{-1}), haloxyfop-R (0.5×10^{-3} m^3 ha^{-1}) Pathogens (BBCH 50-59, 65-69): flusilazole and carbendazim (1.2×10^{-3} m^3 ha^{-1}), tebuconazole (1.25×10^{-3} m^3 ha^{-1}) Pests (BBCH 50-59): chlorpyrifos and cypermethrin (0.6×10^{-3} m^3 ha^{-1}), acetamiprid (0.12 kg ha^{-1})
High-input	Autumn (before sowing): 30 kg N ha^{-1} (NH_4NO_3); 80 kg P ha^{-1} (40% P_2O_5), 150 kg K ha^{-1} (60% K_2O) Spring: 200 kg N ha^{-1} (NH_4NO_3) – 1st dose (BBCH 30) 120 kg N, 2nd dose (BBCH 50) 80 kg N ha^{-1}, 60 kg S ha^{-1} $(NH_4)_2SO_4$ (BBCH 30)	Weeds (autumn, before sowing): metazachlor and chinomerak (3.0×10^{-3} m^3 ha^{-1}), haloxyfop-R (0.5×10^{-3} m^3 ha^{-1}) Pathogens (BBCH 50-59, 65-69): dimoxystrobin and boscalid (0.5×10^{-3} m^3 ha^{-1}), azoxystrobin (1.0×10^{-3} m^3 ha^{-1}) Pests (BBCH 50-59): chlorpyrifos and cypermethrin (0.6×10^{-3} m^3 ha^{-1}), deltamethrin (0.2×10^{-3} m^3 ha^{-1}), acetamiprid (0.12 kg ha^{-1})

*BBCH Monograph (2001).

and micronutrients according to the methods used in agricultural chemistry. The seeds was mineralized in the acid mixture of HNO_3 and $HClO_4$ (4:1). The content of Cu, Zn, Mn and Fe was determined in the extract and mineralizate with the use of atomic absorption spectrometry (AAS) (Hitachi Z-8200 Polarized Zeeman Atomic Absorption Spectrophotometer, Hitachi, Tokyo, Japan). Total N was determined using the Kjeldahl method, P was determined with vanadium-molybdenum method, while K and Ca with atomic emission spectrometry (AES), and Mg with AAS in the material previously mineralized in H_2SO_4 with addition of H_2O_2 as an oxidizer.

Oil extraction and analysis

Fat content was determined with the use of near-infrared spectroscopy (NIR) (Infratec 1241 Grain Analyzer, Foss, Hillerod, Denmark), which takes measurements of transmission waves from the near-infrared region (570-1050 nm). Analysis of the fatty acids was done following the cold extraction of rape oil with chloroform/methanol (2:1 v/v). Fatty acid methyl esters (FAME) were prepared according to Zadernowski and Sosulski (1978) using a mixture of chloroform:methanol:sulphuric acid (100:100:1, v/v/v). Chromatographic separation was performed using a gas chromatograph (Agilent 7890A, Agilent Technologies Wilmington, Delaware, USA) with a flame-ionization detector (FID) and a 30 m 0.32 mm internal diameter capillary column. The liquid phase was Supelcowax 10 and the film thickness was 0.25 μm.

The conditions of separation were as follows: helium was used as a carrier gas; flow rate 1 mL min^{-1}; detector temperature 250 ºC; injector temperature 230 ºC; column temperature 195 ºC. The different acids were identified by comparing retention times with standards from Supelco (Bellefonte, Pennsylvania, USA). The fatty acid content is presented as the relative percentage (% total fatty acids) in rape oil.

Weather conditions

Poland's climate can be described as a temperate climate, which is greatly influenced by oceanic air currents from the west, cold polar air from Scandinavia and Russia, as well as warmer, sub-tropical air from the south.

The mean monthly air temperatures (from winter rapeseed sowing till the end of November) were on a similar level as the analogous annual periods (Table 2). The drought recorded in August (with precipitation lower by 44.9 mm than in the annual periods) might have hindered seed germination, but the precipitation levels in the following months secured good plant growth before wintering. During the wintering period (December-March), when water resources should be accumulated for spring growth, precipitation was lower by 41.5 mm in comparison with the analogous periods in 1981-2010.

Following melts, there were ground frosts in March, which presented a risk of potential plant damage due to thin snow cover. Weather conditions did also not favor plant development and growth at the stages from budding to silique formation – BBCH 53-79 (BBCH Monograph, 2001). The recorded precipitation volumes between April and June were lower by 50.9 mm (lower by 30.8% as compared to the annual periods) and remained below the requirements of winter rapeseed.

Statistical analyses

The results were statistically processed in Statistica 10.0 (StatSoft, Tulsa, Oklahoma, USA) with the use of one-way ANOVA. Basic parameters and homogenous groups were determined by Tukey's test at $p = 0.05$. The relationships between yield of seeds, content of fat, N, P, K, Mg, Ca, Cu, Fe, Zn, Mn and yield of fat: saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), were described by linear regression analysis.

RESULTS AND DISCUSSION

Content of macro and microelements

The chemical analysis of winter rapeseeds demonstrated that, regardless of production technology, the average content of minerals in the fifth year of monoculture was as follows: 29.9 g N kg^{-1}, 0.595 g P kg^{-1}, 1.12 g K kg^{-1}, 0.298 g Mg kg^{-1}, 0.55 g Ca kg^{-1}, 3.18 mg Cu kg^{-1}, 115.6 mg Fe kg^{-1}, 42.8 mg Zn kg^{-1}, and 38.2 mg Mn kg^{-1}. In the fifth crop rotation year there was a year break in rapeseed: 29.2 g N kg^{-1}, 0.562 g P kg^{-1}, 1.12 g K kg^{-1}, 0.302 mg Mg kg^{-1}, 0.392 mg Ca kg^{-1}, 3.47 mg Cu kg^{-1}, 113.3 mg Fe kg^{-1}, 44.6 mg Zn kg^{-1}, and 42.4 mg Mn kg^{-1} (Table 3). These results are comparable in their P and Cu contents with a higher amount of N, Mg, Fe, Mn and Zn, although they have a lower content of other elements compared to the data reported by Fordonski et al. (2015).

The content of N, P, K, and Mg in rapeseed did not differ significantly depending on its proportion in a crop rotation.

Table 2. Weather conditions in 2012-2013 and the multi-annual average of 1981-2010.

Years	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug-July average
						Temperature, ºC							
2012-2013	17.9	14.0	7.9	4.9	-3.3	-4.5	-0.8	-4.0	6.3	15.0	17.4	17.9	7.4
1981-2010	17.7	13.0	8.1	2.8	-1.0	-2.4	-1.6	1.8	7.7	13.2	15.8	18.3	7.8
						Rainfall, mm							Aug-July Sum
2012-2013	25.7	41.0	57.6	48.5	15.1	34.6	21.3	14.0	22.5	46.2	45.4	163.8	535.7
1981-2010	70.6	56.2	51.2	46.1	42.6	30.1	23.1	30.7	29.8	62.3	72.9	81.2	596.8

Table 3. Macro and microelements content in seeds of winter rapeseed grown under different agricultural production systems.

Crop sequence	Level of technology: Low-input	Medium-input	High-input
	N (g kg^{-1})		
Fifth year of monoculture	30.3 ± 0.32a	29.3 ± 0.25ab	30.0 ± 0.55a
Fourth year break in rapeseed	29.0 ± 0.70ab	27.9 ± 0.90b	30.7 ± 0.85a
	P (g kg^{-1})		
Fifth year of monoculture	6.13 ± 0.35a	5.83 ± 0.35a	5.90 ± 0.56a
Fourth year break in rapeseed	5.70 ± 0.20a	5.53 ± 0.35a	5.63 ± 0.15a
	K (g kg^{-1})		
Fifth year of monoculture	12.0 ± 0.45a	10.6 ± 0.50a	11.0 ± 1.95a
Fourth year break in rapeseed	11.6 ± 0.75a	11.0 ± 1.05a	11.0 ± 1.85a
	Mg (g kg^{-1})		
Fifth year of monoculture	3.13 ± 0.25a	2.87 ± 0.45a	2.93 ± 0.35a
Fourth year break in rapeseed	3.13 ± 0.35a	3.13 ± 0.15a	2.80 ± 0.30a
	Ca (g kg^{-1})		
Fifth year of monoculture	3.10 ± 0.20c	4.13 ± 0.15b	3.43 ± 0.15c
Fourth year break in rapeseed	2.97 ± 0.21c	3.53 ± 0.25c	5.27 ± 0.25a
	Cu (mg kg^{-1})		
Fifth year of monoculture	3.13 ± 0.15a	3.23 ± 0.35a	3.17 ± 0.25a
Fourth year break in rapeseed	3.14 ± 0.15a	3.63 ± 0.25a	3.63 ± 0.35a
	Fe (mg kg^{-1})		
Fifth year of monoculture	120.4 ± 2.82a	115.6 ± 0.65ab	110.8 ± 4.25bc
Fourth year break in rapeseed	111.0b ± 1.20c	121.6 ± 2.15a	107.2 ± 3.39c
	Zn (mg kg^{-1})		
Fifth year of monoculture	41.3 ± 1.21c	40.8 ± 0.85c	46.5 ± 1.11a
Fourth year break in rapeseed	42.0 ± 1.55c	45.2 ± 1.15b	46.5 ± 1.35a
	Mn (mg kg^{-1})		
Fifth year of monoculture	34.4 ± 1.35d	35.3 ± 1.20cd	44.8 ± 0.92a
Fourth year break in rapeseed	38.0 ± 1.15c	41.6 ± 1.35b	47.6 ± 0.75a

Averages in two rows followed by the same letter are nonsignificant ($\alpha < 0.05$); ± standard deviation.

The level of Ca was higher (by 17.0%) in rapeseed produced with a medium-input monoculture system compared to crop rotation technology. However, the content of this element was lower (by 34.9%) in the high-input crop rotation system than in monoculture. Considering the intensity of agricultural engineering procedures, only the highest level (high-input) generated a significant increase (10.0%) of N accumulation in the rapeseed compared to medium-input technology. Similarly, Ca content in a crop rotation was significantly higher with the high-input compared to both the low-input and medium-input technology. In the fifth monoculture year, a higher Ca content was recorded in the medium-input technology than the other levels (26.5% on average).

Depending on a crop rotation method, a generally higher content of microelements was measured in rapeseeds grown in the crop rotation system. However, a significantly higher content of Mn was found only for the low-input crop rotation technology and of Zn and Mn in the medium-input system. The rapeseed low-input crop rotation system was an exception, with a significantly lower Fe content (by 7.8%).

The highest fertilization level (high-input) generated a significantly higher content of Zn and Mn in rapeseeds in both crop rotation systems. A significantly higher Fe level was recorded in rapeseeds grown in the medium-input crop rotation technology and in the low-input monoculture system.

Yielding, fat content

Winter rapeseed cultivated for a number of years in the same field reacts with a substantial reduction in seed yield, but when seeded occasionally 2 yr in a row or in a short monoculture system it may generate yields at a similar level as after cereal plants (Rozylo and Palys, 2011; Jaskulska et al., 2014). When cultivated in a monoculture and crop rotation system, winter rapeseed yielded high-level crops, from 4.04 to 6.25 t ha^{-1} (Table 4).

Regardless of the technology level, seed yield was higher by 18.6% with the crop rotation method than in the monoculture system. Significantly higher crops (by 47.3%) were obtained using low-input crop rotation technology compared to the low-input monoculture approach. The increase of agricultural engineering technologies contributed to diminishing differences in the yield between the crop rotation and monoculture systems. Increased intensity of agricultural technologies resulted in significantly higher seed crops only in the crop rotation system. Jarecki et al. (2013) found that higher level of agricultural engineering procedures, as compared with a lower input, generated a significant increase in seed yield by approximately 12%, which is a result of substantially higher number of siliques on the plant and thousand-seed weight. The level of oil in mature winter rapeseeds ranges between 45% and 50% on average (Liersch et al., 2013). In personal studies, winter rapeseeds 'Californium' contained 47.2% fat on average (Table 4). The crop rotation method did not substantially modify the fat content in rapeseeds. Moreover, the intensity level of agricultural procedures did not impact the fat content in rapeseeds, as reported in the studies performed by Jarecki et al. (2013).

The content of fat in seeds is mainly determined by genetics (Tanska et al., 2009; Wittkop et al., 2009; Ambrosewicz-Walacik et al., 2015), although it may change being influenced by habitat conditions (Ozturk, 2010; Spychaj-Fabisiak et al., 2011; Faraji, 2012; Varényiová and Ducsay, 2016). The fat yield was strongly correlated with seed yield (r = 0. 929) but was independent of fat content (Table 7). According to Narits (2010), N fertilization had a positive effect on seed yield and seed protein content. On the other hand, N fertilization, especially in higher rates, had a negative effect on oil content.

Table 4. Seed and fat yield and fat content in seeds of winter rapeseed grown under different agricultural production systems.

Crop sequence	Level of technology: Low-input	Medium-input	High-input
	Seed yield (t ha^{-1})		
Fifth year of monoculture	4.04 ± 0.39c	4.63 ± 0.53ab	5.78 ± 0.59ab
Fourth year break in rapeseed	5.95 ± 0.39a	4.97 ± 0.62abc	6.25 ± 0.19a
	Fat content (%)		
Fifth year of monoculture	46.5 ± 1.40a	48.1 ± 1.19a	46.7 ± 2.51a
Fourth year break in rapeseed	46.0 ± 1.37a	49.1 ± 1.19a	46.9 ± 1.47a
	Fat yield (t ha^{-1})		
Fifth year of monoculture	2.13 ± 0.35b	2.62 ± 0.45ab	3.19 ± 0.43ab
Fourth year break in rapeseed	3.03 ± 0.19ab	2.89 ± 0.59ab	3.40 ± 0.25a

Averages in two rows followed by the same letter are nonsignificant ($\alpha < 0.05$); ± standard deviation.

Fatty acid profile

The analysis of fatty acid composition demonstrated a high proportion of oleic (C18:1 c9), linoleic (C18:2) and linolenic (C18:3) acids (Table 5). There was no occurrence of the following fatty acids: erucic (C22:1n9), cis-13,16-docosadienoic (C22:2), lignoceric (C24:0), and nervonic (C24:1n9). In general, the proportion of winter rapeseed in the seeding structure had a varied effect on the fatty acid proportions. In rapeseeds from the monoculture, low-input and medium-input technologies resulted in a higher percentage contribution of oleic acid (C18:1 c9) while the high-input approach generated a reduction of its level. Low-input and high-input technologies contributed to an increase in the percentage proportion of C18:2 and C18:3 fatty acids in rapeseeds from the monoculture. The medium-input technology resulted in increased levels of C20:0, C18:1 c11, C18:2, C18:3, and C20:2 fatty acids in the crop rotation system rapeseeds.

Table 5. Fatty acid profile (%) in seeds of winter rapeseed grown under different agricultural production systems.

Fatty acid profile[a]	Crop sequence[b]	Level of technology		
		Low-input	Medium-input	High-input
C14:0	M	0.068 ± 0.003a	0.064 ± 0.002a	0.064 ± 0.002a
	Cr	0.068 ± 0.007a	0.061 ± 0.006a	0.069 ± 0.009a
C15:0	M	0.026 ± 0.004a	0.022 ± 0.005a	0.025 ± 0.05a
	Cr	0.052 ± 0.068a	0.019 ± 0.002a	0.023 ± 0.004a
C16:0	M	4.93 ± 0.650a	4.58 ± 0.105b	4.55 ± 0.090b
	Cr	5.02 ± 0.160a	4.62 ± 0.085b	4.53 ± 0.055b
C17:0	M	0.044 ± 0.005a	0.054 ± 0.005a	0.052 ± 0.002a
	Cr	0.043 ± 0.004a	0.047 ± 0.007a	0.052 ± 0.003a
C18:0	M	1.54 ± 0.045bc	1.71 ± 0.075abc	1.68 ± 0.085abc
	Cr	1.50 ± 0.045c	1.78 ± 0.125a	1.74 ± 0.085ab
C20:0	M	0.521 ± 0.003d	0.530 ± 0.007cd	0.548 ± 0.005bc
	Cr	0.526 ± 0.015cd	0.605 ± 0.009a	0.566 ± 0.011b
C22:0	M	0.355 ± 0.006b	0.364 ± 0.005b	0.389 ± 0.007a
	Cr	0.348 ± 0.014bc	0.345 ± 0.009bc	0.331 ± 0.007c
C16:1	M	0.251 ± 0.006a	0.232 ± 0.004a	0.233 ± 0.007a
	Cr	0.258 ± 0.019a	0.238 ± 0.012a	0.235 ± 0.011a
C17:1	M	0.066 ± 0.006a	0.081 ± 0.002a	0.082 ± 0.004a
	Cr	0.091 ± 0.125a	0.069 ± 0.011a	0.079 ± 0.020a
C18:1 c9	M	57.8 ± 2.050e	61.1 ± 2.560b	60.4 ± 1.050c
	Cr	57.3 ± 2.191f	59.6 ± 1.150d	61.6 ± 2.850a
C18:1 c11	M	3.32 ± 0.045ab	2.99 ± 0.055c	2.99 ± 0.095c
	Cr	3.35 ± 0.055a	3.19 ± 0.152b	3.04 ± 0.025c
C20:1	M	1.18 ± 0.110ab	1.05 ± 0.045ab	1.26 ± 0.045a
	Cr	1.19 ± 0.055ab	1.13 ±0.020ab	1.21 ± 0.026ab
C18:2	M	21.2 ± 0.025a	19.0 ± 0.105e	19.4 ± 0.055d
	Cr	20.6 ± 0.145b	19.8 ± 0.090c	18.5 ± 0.025f
C18:3	M	8.61 ± 0.440a	8.08 ± 0.085c	8.48 ± 0.090ab
	Cr	8.34 ± 0.600b	8.44 ± 0.090ab	8.03 ± 0.115c
C20:2	M	0.069 ± 0.002a	0.057 ± 0.002c	0.061 ± 0.003bc
	Cr	0.065 ± 0.002ab	0.067 ± 0.001ab	0.057 ± 0.003c

Averages in two rows followed by the same letter are nonsignificant ($\alpha < 0.05$); ± standard deviation.

[a]C14:0 myristic acid; C15:0 pentadecanoic acid; C16:0 palmitic acid; C17:0 margaric acid; C18:0 stearic acid; C20:0 arachidic acid; C22:0 behenic acid; C16:1 palmitoleic acid; C17:1 margaric-oleic acid; C18:1 oleic acid c9; C18:1 octadecanoic acid c11; C20:1 eicosenic acid; C18:2 linoleic acid; C18:3 linolenic acid; C20:2 eicosadienoic acid.

[b]M: Fifth year of monoculture (monoculture), Cr: fourth year break in rapeseed (crop rotation).

According to nutritional studies, a proper ratio of n-6 to n-3 polyunsaturated fatty acids in the daily ration should range from 6:1 to 4:1, although according to the experts of the International Society for the Study of Fatty Acids and Lipids (ISSFAL), the n-6 PUFA to n-3 PUFA ratio in the diet should not exceed 4 (Ntawubizi et al., 2010). The percentage changes in the proportions of polyunsaturated fatty acids such as linoleic acid (C18:2) and linolenic acid (C18:3) did not exert any significant impact on the C18:2/C18:3 ratio in rapeseed from either crop rotation systems (Table 6). Greater differences in the C18:2/C18:3 acid ratio were reported with a varied level of agricultural engineering technology. An increased intensity of the technology significantly reduced the ratio of these acids both in the crop rotation and monoculture system. The recorded proportions of linoleic acid-to-linolenic acid approximated the levels reported by Tanska et al. (2009).

The average content of SFA in rapeseed oil was 7.41%, PUFA was approximately 28.2%, and MUFA was approximately 64.3%. Neither the level of technology nor the crop sequence impacted the content of SFA with C14, C15, C16, C17, C18, C20, and C22 atoms. The highest content of MUFA (66.1%) was recorded with the highest level of technology in the crop rotation system, and of PUFA (29.9%) with the low-input monoculture system. Rapeseed oil from the monoculture system contained a significantly higher amount of MUFA (medium-input) and PUFA (low- and high-input). Depending on the level of rapeseed saturation in crop rotation and technology, the MUFA:PUFA ratio ranged from 2.1:1 to 2.5:1 and was similar to typical rapeseed oil. According to Liersch et al. (2013), oil with the monounsaturated-to-polyunsaturated fatty acid ratio of 2:1 perfectly fits into the nutritional recommendations.

A correlation analysis shows a negative relation between seed yield and content of P (r = -0.535) (Table 7).

Table 6. Saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) and C18:2/C18:3 in seeds of winter rapeseed grown under different agricultural production systems.

Crop sequence	Level of technology		
	Low-input	Medium-input	High-input
	SFA (%)		
Fifth year of monoculture	7.48 ± 0.12a	7.32 ± 0.20a	7.31 ± 0.18a
Fourth year break in rapeseed	7.55 ± 0.30a	7.47 ± 0.24a	7.32 ± 0.16a
	MUFA (%)		
Fifth year of monoculture	62.7 ± 2.21c	65.5 ± 1.32a	64.8 ± 1.67b
Fourth year break in rapeseed	62.2 ± 3.26c	64.2 ± 1.75b	66.1 ± 0.37a
	PUFA (%)		
Fifth year of monoculture	29.9 ± 1.60a	27.2 ± 1.92d	27.9 ± 1.48c
Fourth year break in rapeseed	29.0 ± 2.70b	28.3 ± 1.81c	26.6 ± 1.42e
	C18:2/C18:3 (%)		
Fifth year of monoculture	2.46 ± 0.14b	2.36 ± 0.12c	2.28 ± 0.18e
Fourth year break in rapeseed	2.47 ± 0.10a	2.35 ± 0.14d	2.30 ± 0.03c

Averages in two rows followed by the same letter are nonsignificant ($\alpha < 0.05$); ± standard deviation.

Table 7. Correlations between seed yield, fat content, macro and micronutrients in seeds and fat yield, saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) in seeds of winter rapeseed grown under different agricultural production systems.

Specification	Seed yield	Fat yield	SFA	MUFA	PUFA
Seed yield	-	0.929	ns	ns	-0.472
Fat content	ns	ns	ns	ns	ns
N	ns	ns	ns	ns	ns
P	-0.535	-0.596	ns	0.604	ns
K	ns	ns	0.800	ns	ns
Mg	ns	ns	0.920	ns	0.514
Ca	ns	ns	ns	0.876	-0.835
Cu	ns	ns	ns	0.487	ns
Fe	ns	-0.669	ns	ns	0.553
Zn	ns	ns	ns	0.511	ns
Mn	ns	0.623	ns	0.585	-0.578

ns: Nonsignificant differences.

There was a positive relation between fat yield and seed yield (r = 0.929) and Mn level (r = 0.623) and a negative relation between P (r = -0.596) and Fe content (r = -0.669). The increase in SFA was closely correlated with K (r = 0.800) and Mg (r = 0.920) contents. There was a positive correlation between the MUFA content and the level of P (r = 0.604), and Ca (r = 0.876) with the content of Cu, Zn, and Mn (r = 0.487, r = 0.511 and r = 0.585, respectively). As the only lipid fraction, PUFAs were correlated with seed yield (r = -0.472). Together with the increase in Mg and Fe content, the amount of PUFA increased (r = 0.514 and r = 0.553, respectively) whereas the PUFA fractions decreased together with increasing Ca and Mn levels (r = -0.835 and r = -0.578, respectively).

CONCLUSIONS

In general, the impact of winter rapeseed in crop sequence systems was found to have an insignificant impact on the content of macronutrients and trace elements in seeds, except for the higher levels of Ca (high-input), Mn (low-input and medium-input) and Zn (medium-input) in rapeseeds from the crop rotation system and higher contents of Ca (medium-input) and Fe (low-input) in the monoculture system.

The highest level of agricultural technology (high-input method) in both systems resulted in a significant increase of Zn and Mn content in seeds and N and Ca level in the crop rotation system.

The medium-input and high-input technologies applied in the monoculture contributed to an increased percentage of oleic acid (C18:1 c9) in rapeseeds, whereas the low-input and high-input technologies resulted in an increased percentage proportion of C18:2 and C18:3 acids in the monoculture rapeseeds. The medium-input level generated an increased proportion of C20:0, C18:1 C11, C18:2, C18:3 and C20:2 fatty acids in rapeseeds cultivated in the crop rotation system.

The increase in the level of technological input significantly changed the ratio of polyunsaturated fatty acids to linoleic (C18:2) and linolenic acids (C18:3) in both the crop rotation and monoculture systems.

The proportion of saturated fatty acids was positively correlated with the content of K and Mg. The level of monounsaturated fatty acids was positively correlated with P and Ca content and with levels of Cu, Zn and Mn. The proportion of polyunsaturated fatty acids was positively correlated with the level of Mg and Fe, although it was negatively correlated with the seed yield and the content of Ca and Mn.

The oil content in winter rapeseeds ranged from 46.0% to 59.1%. The fat yield was strongly correlated with the seed yield (r = 0.929) although it was independent of the fat content. The highest fat yield was generated with the crop rotation system at the highest input level, whereas the lowest yield was recorded in the low-input monoculture technology.

Continuous rape cultivation does not have negative effects on seed yield and quality. Because of the technological quality of the seed, which is determined by the amount of polyunsaturated fatty acid, it is advisable to use low-input technology.

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