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ORIGINAL PAPER

EFFECTS OF NITROGEN FERTILISATION ON THE YIELD, MICRONUTRIENT CONTENT AND FATTY ACID PROFILES OF WINTER WHEAT (*TRITICUM AESTIVUM* L.) VARIETIES*

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Abstract

The nutritional and technological value of grains is determined mostly by genetic traits of crops, and also by environmental conditions, such as the weather, soil conditions and applied crop production technology. The aim of the study was to assess the effects of nitrogen fertilisation on the yield components, the yield of grains, grain mineral content and technological indicators, including fatty acid profiles, in grains of winter wheat. A field experiment was carried out in north-eastern Poland (53°72 N; 20°42 E), in 2013-2016. The aim was to examine the following two factors: I – two doses of nitrogen fertilisation (150 and 200 kg ha^{-1}); II – four wheat varieties (Bogatka, KWS Ozon, Sailor, and Smuga). The yield of grains of the tested winter wheat varieties ranged from 6.64 to 8.35 t ha^{-1}. A significant effect of the varieties on the yield of grains was noted, with the emphasis on the better yield of Bogatka and KWS Ozon varieties. Generally, a higher nitrogen dose resulted in an increase in the Fe content (by 10.0%) owing to its higher content in grains of the varieties Bogatka (by 27.3%), Sailor (by 16.7%), and Smuga (by 8.9%). Linoleic acid (57.9%), palmitic acid (23.0%), oleic acid and octadecanoic acid (12.1%), linolenic acid (4.0%) and stearic acid (1.2%) were quantitatively dominant in the fatty acid profile of the oil. Polyunsaturated fatty acids (PUFA) accounted for an over 60% share in the total fatty acid content. No significant average effect of the increase in nitrogen fertilisation on changes to the fatty acid content in wheat grains was demonstrated, which suggests that the percentage of fatty acids in lipids is dependent on the genetic factor rather than on fertilisation. High correlation was found between the monounsaturated fatty acid (MUFA) content and the amounts of Cu (r = 0.815) and Fe (r = 0.616). Adequate quality of wheat grains can be guaranteed by proper selection of a variety.

Keywords: fatty acid profiles, microelements, wheat varieties, nitrogen fertilisation.

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INTRODUCTION

It is important in wheat production to balance the expectations of farmers, processors and consumers regarding the quality requirements for the final product. Farmers would like to obtain the highest possible yield parameters (the weight of 1,000 grains, a low screening percentage), which ultimately determine the volume of yield. Cereal grains are a source of minerals valuable both nutritionally and technologically (Shewry, Hey 2015). Macronutrients are the structural elements of a plant, while the role of micronutrients is to participate in the regulation of biochemical processes occurring in plants during the growing season (Soetan et al. 2010). The bread-making quality of wheat mainly depends on amounts and composition of gluten storage proteins. Lipids incorporated in the protein matrix are essential as they shape the appropriate properties of gluten (Min et al. 2017). The quality of bakery products is also highly influenced by fats, particularly endogenous lipids (of the *n*-9: C18:1, C20:3, C22:1 *n*-9 family and of the *n*-7: C16:1 *n*-1 family) contained in grains (Gerits et al. 2014).

The nutritional and technological values of grains are determined mostly by genetic traits of crops (Ktenioudaki et al. 2010, Zecevic et al. 2014). Environmental conditions, such as the weather, soil conditions and applied crop production technology (Piekarczyk et al. 2011, Klikocka et al. 2016, Orzech et al. 2016), particularly nitrogen fertilisation (Wojtkowiak et al. 2017), are also significant modifying factors. Nitrogen is the key factor influencing the yield of cereals. In addition to the volume of yields, this element also modifies the quality of grains. Study results are available which demonstrate effects of agronomic factors on the lipid composition in oilseed crops (Bybordi 2012, Wielebski et al. 2017). Research has also been conducted on the effects of a variety on its lipid composition (Liu 2011, Stuper-Szablewska et al. 2014, Konopka et al. 2017). However, there are few studies concerning the effect of nitrogen on these parameters of wheat grains (Min et al. 2017).

The aim of the study was to assess the effects of nitrogen fertilisation on the yield components, the yield of grains, mineral content and technological indicators, including fatty acid profiles, in the grains of four winter wheat varieties.

MATERIAL AND METHODS

Winter wheat (*Triticum aestivum* L.) was cultivated in three growing seasons (2013/2014, 2014/2015, and 2015/2016) at the Educational and Experimental Station in Tomaszkowo (53°72 N; 20°42 E), Poland. The experiment was laid out according to the random block method with three replications, on grey-brown podzolic soil with the textural granulometric composition of silty clay loam, complex 4, (rye complex very good) class IIIb (in the Polish soil classification system). According to the World Reference Base for Soil Resources (IUSS Working Group WRB 2015, this corresponds to a soil profile called Haplic Cambisol. The soil was slightly acidic (in KCl solution with pH 5.7), its total N content was determined at 0.97 g kg^{-1} d.m. and the total organic C content was 10.12 g kg^{-1} d.m.

Winter wheat was subjected to one of the two nitrogen fertilisation regimes (Table 1):

Table1

Doses of N fertilisation

Type and dose of N fertilisation		Time of application/Growth stages (BBCH)			
		pre-sowing	tillering/ BBCH 25-29	stem elongation/ BBCH 30-31	heading/ BBCH 51-52
Type		urea 46% ($CO(NH_2)_2$)	ammonium nitrate 34% (NH_4NO_3)	ammonium nitrate 34% (NH_4NO_3)	urea 46% ($CO(NH_2)_2$), foliar application of a 10% solution
Dose ($kg\ ha^{-1}$)	150	40	70	30	10
	200	40	80	60	20

1) 150 kg N ha^{-1} – this is a standard N dose for medium-intensive technologies of wheat production in Poland (according to investigation years);
2) 200 kg N ha^{-1} – this is an N dose in intensive technologies of wheat production in Poland (according to investigation years).

Moreover, 70 kg ha^{-1} of phosphorus and 100 kg ha^{-1} of potassium were applied in all experimental variants.

Four wheat varieties (Bogatka, KWS Ozon, Sailor, and Smuga), which are recommended for the cultivation under the conditions of north-eastern Poland, were tested. Bogatka and KWS Ozon belong to bread varieties, while the varieties Sailor and Smuga are high quality ones. The grains of these varieties are well-filled, with high mass of a thousand grains and a small share of the screenings. The grains of these varieties are characterized by high levels of protein and gluten of good quality. Plants of these varieties are quite resistant to most wheat diseases.

A single plot measured 9.90 m^2, and an area for harvesting on a single plot was 8.00 m^2. Winter triticale was grown as the preceding crop. Winter wheat was sown at a density of 550 grains m^{-2} and spacing of 12 cm. Tillage included first ploughing performed immediately after the harvest of the preceding crop. Pre-sow ploughing and harrowing were carried out prior to the sowing of winter wheat. Immediately prior to the sowing, a combined cultivator and seed drill were used on all plots in order to mix mineral fertilisers, prepare the soil for sowing, and to sow the wheat seeds. Weeds were controlled with herbicides. Because the risk thresholds were not exceeded, no protection against pests and diseases was applied.

Each year, after the growing season, yields of wheat grains were harvested from the experimental plots (8.0 m^2) and converted to tonnes per ha, at the same humidity level of 15%. 1.0 kg samples were randomly sampled from harvested grains and used for further analyses. To determine the screenings, 100 g samples of grains were weighed, sifted (for 3 min) through a 2.0 mm Vogel screen and weighed again. The weight of a thousand grains was determined using an LN-S, 50A seed counter (Unitra, Szczytno, Poland).

The grains were mineralised in a mixture of acids HNO_3 and $HClO_4$ (4:1), and the Cu, Zn, Mn, and Fe content was determined in the mineralisate by atomic absorption spectroscopy (AAS) using a Hitachi Z-8200 spectrophotometer. The fat content and an analysis of fatty acids were completed following cold extraction 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 separation settings were as follows: helium was a carrier gas (flow rate-1 mL min^{-1}), detector temp. was 250°C, injector temp. was 230°C, and column temp. was 195°C. 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 wheat oil.

The Polish climate can be described as temperate, strongly 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 average air temperature during the three years of the study (2013/2014, 2014/2015, and 2015/2016) from September to August was similar (8.5°C), and higher by 0.6°C than the multi-annual average temperatures (1981-2010). Significant differences were noted as regards the precipitation levels. During the growing season of 2014/2015, the precipitation levels were the lowest (429.1 mm) compared to the other years of the study and to the multi-annual average values. Precipitation deficits were noted in the autumn season (from September to November 2014) as well as in the spring and summer season (from May to June 2015). Total monthly precipitation levels significantly lower than the multi-annual average values were also noted from April to August 2014.

The results were statistically processed in Statistica 10.0 (StatSoft, Tulsa, Oklahoma, USA) with the use of two-way ANOVA. Basic parameters and homogenous groups were determined by the Tukey's test at $P \leq 0.05$. Relationships between the grain yields, weight of a thousand grains, percentage of screenings and the Cu, Fe, Zn, and Mn content as well as the content of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), and the C18:2/C18:3 acid ratio, were also determined and expressed with the Pearson's correlation coefficients (*r*).

RESULTS AND DISCUSSION

The yield of grains of the tested winter wheat varieties ranged from 6.64 to 8.35 t ha^{-1} (Table 2). A significant effect of the varieties on the yield of grains was noted, with an emphasis on the better yield of Bogatka and KWS Ozon varieties.

On average, an increase in nitrogen fertilisation to 200 kg N ha^{-1} only resulted in an increase in the weight of a thousand grains (by 8.1%). However, the varieties did not respond to the shaping of these characteristics in terms of nitrogen fertilisation in the same way. Only the Bogatka variety responded by significantly increasing the weight of a thousand grains (by 23.5%) as a result of the increase in the N dose. Similar to studies by other authors (Brzozowska et al. 2008, Haliniarz et al. 2013), a low relationship between the thousand seed weight and the N dose was demonstrated. According to Zecevic et al. (2014), the weight of a thousand grains is a component of the yield which is, to a large extent, determined genetically.

The rate of the uptake of minerals (macro- and micronutrients) depends on a crop species (Ciołek et al. 2012), variety (Korzeniowska et al. 2015), habitat conditions (Gao et al. 2012), and agronomic factors. As regards micronutrients, a particularly important physiological role in plants and in human nutrition is played by Zn, Fe, Mn and Cu (Soetan et al. 2010). According to Ciołek et al. (2012), the grains of wheat cultivated using a medium intensive technology contain 2.55 mg Cu kg^{-1}, 25.6 mg Mn kg^{-1}, 22.9 mg Fe kg^{-1}, and 21.6 mg Zn kg^{-1}. In our study, the content of these elements in wheat grains was as follows: from 1.81 to 2.20 mg Cu kg^{-1}, from 40.7 to 54.5 mg Fe kg^{-1}, from 19.1 to 25.6 mg Zn kg^{-1}, and from 24.6 to 29.0 mg Mn kg^{-1} (Table 3). Of the wheat varieties under assessment, the highest levels of Fe and Zn were found in grains of the variety Smuga. Generally, a higher nitrogen dose resulted in an increase in the Fe content (by 10.0%) as a consequence of its higher content in grains of the varieties Bogatka (by 27.3%), Sailor (by 16.7%), and Smuga (by 8.9%).

The fat content of the grains of the analysed wheat varieties ranged from 1.38% to 1.55%, and was similar to the values obtained in the study by Ciołek et al. (2012), but was lower than that obtained (for six varieties) by Konopka et al. (2016). In the author's own study of the wheat varieties under assessment, the Bogatka and Smuga varieties were characterised by the

Table 2

Grain yield and grain yield components, means from 2014-2016

Variables	Dose of N (kg ha^{-1})	Varieties				Average for varieties
		Bogatka	KWS Ozon	Sailor	Smuga	
Yield of grain (t ha^{-1})	150	$7.85^{a} \pm 2.28$	$7.73^{a} \pm 1.42$	$6.69^{b} \pm 0.65$	$6.64^{b} \pm 0.72$	$7.22^{A} \pm 0.89$
	200	$7.92^{a} \pm 2.15$	$8.35^{a} \pm 1.84$	$7.00^{ab} \pm 1.50$	$7.22^{ab} \pm 1.45$	$7.62^{A} \pm 1.52$
	av. for N	$7.88^{A} \pm 1.45$	$8.04^{A} \pm 1.49$	$6.84^{B} \pm 1.08$	$6.94^{B} \pm 1.12$	-
Weight of 1000 grains (g)	150	$39.5^{c} \pm 10.81$	$43.5^{bc} \pm 1.00$	$43.4^{bc} \pm 2.13$	$42.7^{bc} \pm 1.81$	$42.2^{B} \pm 4.97$
	200	$48.8^{a} \pm 3.02$	$45.4^{ab} \pm 2.07$	$44.3^{abc} \pm 2.14$	$44.1^{bc} \pm 3.20$	$45.6^{A} \pm 3.44$
	av. for N	$44.1^{A} \pm 8.71$	$44.5^{A} \pm 1.50$	$43.8^{A} \pm 1.94$	$43.4^{A} \pm 2.33$	-
Content of screenings (%)	150	$0.199^{b} \pm 0.01$	$0.371^{a} \pm 0.06$	$0.127^{b} \pm 0.08$	$0.231^{ab} \pm 0.04$	$0.232^{A} \pm 0.16$
	200	$0.128^{b} \pm 0.05$	$0.246^{ab} \pm 0.12$	$0.217^{b} \pm 0.08$	$0.222^{b} \pm 0.04$	$0.203^{A} \pm 0.09$
	av. for N	$0.163^{B} \pm 0.01$	$0.308^{B} \pm 0.14$	$0.171^{B} \pm 0.01$	$0.227^{AB} \pm 0.04$	-

a, *b*, *c*, ...*A*, *B*... values with the same letter are not significantly different according to the Tukey's test ($p \leq 0.05$), ± SD (standard deviation)

Table 3

Content of micronutrients in grain, means from 2014-2016

Variables	Dose of N (kg ha^{-1})	Varieties				Average for varieties
		Bogatka	KWS Ozon	Sailor	Smuga	
Cu (mg kg^{-1} d.m.)	150	$1.83^{a} \pm 0.12$	$1.98^{a} \pm 0.06$	$2.20^{a} \pm 0.06$	$1.97^{a} \pm 0.10$	$1.99^{A} \pm 0.28$
	200	$1.81^{a} \pm 0.18$	$2.00^{a} \pm 0.11$	$1.97^{a} \pm 0.05$	$2.20^{a} \pm 0.05$	$1.99^{A} \pm 0.31$
	av. for N	$1.82^{A} \pm 0.14$	$1.99^{A} \pm 0.14$	$2.09^{A} \pm 0.17$	$2.08^{A} \pm 0.08$	-
Fe (mg kg^{-1} d.m.)	150	$40.7^{b} \pm 1.06$	$46.7^{ab} \pm 0.26$	$46.7^{ab} \pm 0.64$	$49.7^{ab} \pm 2.25$	$45.9^{B} \pm 4.17$
	200	$51.8^{ab} \pm 2.51$	$41.6^{b} \pm 1.00$	$54.5^{a} \pm 0.53$	$54.1^{a} \pm 1.10$	$50.5^{A} \pm 7.83$
	av. for N	$46.2^{AB} \pm 2.99$	$44.1^{B} \pm 1.32$	$50.6^{AB} \pm 6.67$	$51.9^{A} \pm 1.62$	-
Zn (mg kg^{-1} d.m.)	150	$21.6^{ab} \pm 0.10$	$23.7^{ab} \pm 0.64$	$19.1^{b} \pm 0.81$	$24.1^{ab} \pm 0.72$	$22.1^{A} \pm 2.91$
	200	$21.8^{ab} \pm 0.06$	$22.0^{ab} \pm 0.55$	$22.8^{ab} \pm 0.64$	$25.6^{a} \pm 0.53$	$23.0^{A} \pm 1.15$
	av. for N	$21.7^{A} \pm 0.48$	$22.9^{A} \pm 1.44$	$20.9^{A} \pm 2.50$	$24.8^{A} \pm 0.64$	-
Mn (mg kg^{-1} d.m.)	150	$28.2^{a} \pm 0.36$	$26.7^{a} \pm 0.06$	$25.6^{a} \pm 0.57$	$27.8^{a} \pm 0.21$	$27.1^{A} \pm 1.44$
	200	$28.7^{a} \pm 0.72$	$24.6^{a} \pm 1.51$	$29.0^{a} \pm 1.89$	$26.3^{a} \pm 0.21$	$27.2^{A} \pm 2.23$
	av. for N	$28.5^{A} \pm 1.58$	$25.7^{A} \pm 1.79$	$27.4^{A} \pm 2.99$	$27.0^{A} \pm 0.19$	-

a, *b*, *c*, …*A*, *B*… values with the same letter are not significantly different according to the Tukey's test ($p \leq 0.05$), ± SD (standard deviation) highest fat content. An increase in nitrogen fertilisation to 200 kg N ha^{-1} resulted in a slight increase (by 4.2%) in the fat content of grains.

In the oil obtained from wheat grains, 17 fatty acids were assayed, including 8 saturated fatty acids (C12:0 – lauric acid; 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). There was no occurrence of the following fatty acids: eicosatrienoic acid (C20:3*n*6), erucic acid (C22:1*n*9), cis-13,16-docosadienoic acid (C22:2), lignoceric acid (C24:0) and nervonic acid (C24:1*n*9) – Figure 1.

In the fatty acid profile of the oil, linoleic acid – C18:2 (57.9%), palmitic acid – C16:0 (23.0%), oleic acid – C18:1 c9 and octadecanoic acid – C18:1 c11 (12.1%), linolenic acid C18:3 *n*-3 + *n*-6 (4.0%), and stearic acid – C 18:0 (1.2%) were quantitatively dominant (Table 4). No significant differences in other fatty acids under the influence of the experimental factors applied were demonstrated (C12:0; C14:0; C15:0; C16:1; C17:0; C17:1; C20:0; C20:1; C20:2; C22:0) and their percentages amounted to a total of 2.0%.

No statistically significant effect of the increase in nitrogen fertilisation on changes to the fatty acid content in wheat grains was demonstrated, which suggests that the percentage of fatty acids in lipids is primarily determined by the genetic factor and not the fertilisation factor. Of the wheat varieties under assessment, the highest content of C16:0 and C18:3 *n*-3+*n*-6 acids was found in grains of the variety KWS Ozon, that of C18:0 acid in the

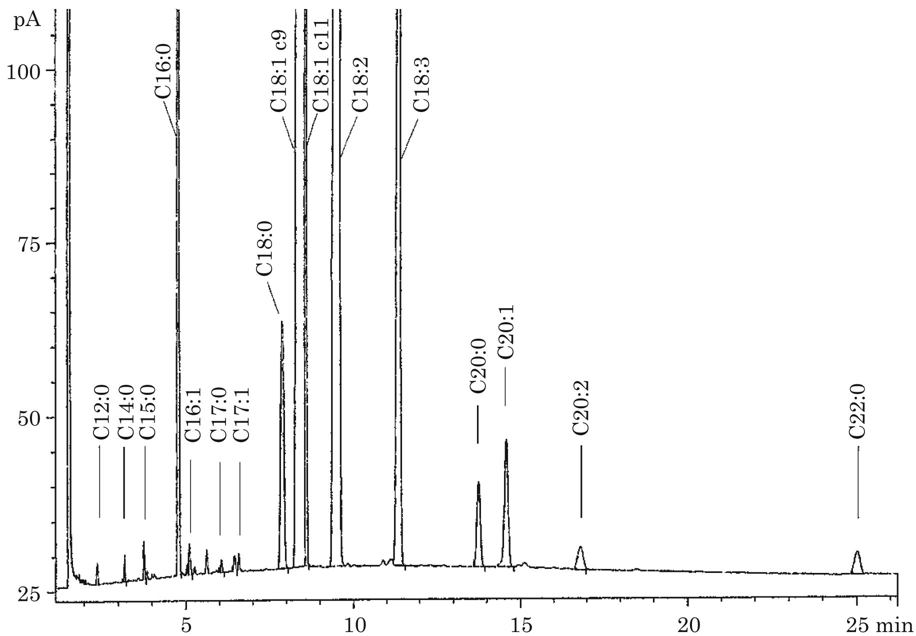

Fig. 1. Representative chromatogram of the fatty acid profile of a winter wheat sample

Table 4

Fatty acid profile (%) in grain, means from 2014-2016

Fatty acid profile*	Dose of N (kg ha^{-1})	Varieties				Average for varieties
		Bogatka	KWS Ozon	Sailor	Smuga	
C16:0	150	$22.8^{abc} \pm 0.34$	$24.0^{ab} \pm 0.74$	$23.5^{abc} \pm 0.21$	$21.8^{c} \pm 1.37$	$23.0^{A} \pm 1.09$
	200	$22.2^{bc} \pm 0.55$	$24.3^{a} \pm 0.38$	$23.3^{abc} \pm 0.42$	$22.5^{abc} \pm 0.58$	$23.1^{A} \pm 0.92$
	av. for N	$22.5^{BC} \pm 0.50$	$24.1^{A} \pm 0.55$	$23.4^{AB} \pm 0.32$	$22.2^{C} \pm 1.02$	-
C18:0	150	$1.00^{b} \pm 0.08$	$1.15^{ab} \pm 0.09$	$1.30^{a} \pm 0.04$	$1.15^{ab} \pm 0.06$	$1.15^{A} \pm 0.12$
	200	$1.04^{b} \pm 0.15$	$1.16^{ab} \pm 0.07$	$1.21^{ab} \pm 0.02$	$1.34^{a} \pm 0.11$	$1.19^{A} \pm 0.14$
	av. for N	$1.02^{b} \pm 0.11$	$1.15^{ab} \pm 0.07$	$1.26^{a} \pm 0.06$	$1.25^{a} \pm 0.13$	-
C18:1 c9 + C11	150	$11.8^{cd} \pm 0.59$	$10.4^{de} \pm 0.73$	$12.4^{bc} \pm 0.45$	$14.4^{a} \pm 0.71$	$12.2^{A} \pm 1.59$
	200	$11.8^{cd} \pm 0.62$	$9.9^{e} \pm 0.87$	$12.1^{c} \pm 0.22$	$13.8^{ab} \pm 0.19$	$11.9^{A} \pm 1.54$
	av. for N	$11.8^{B} \pm 0.54$	$10.1^{C} \pm 0.77$	$12.3^{B} \pm 0.37$	$14.1^{A} \pm 0.55$	-
C18:2	150	$58.9^{a} \pm 3.44$	$58.3^{a} \pm 4.22$	$56.7^{a} \pm 4.11$	$57.1^{a} \pm 4.29$	$57.8^{A} \pm 3.56$
	200	$59.4^{a} \pm 5.54$	$58.4^{a} \pm 2.32$	$57.1^{a} \pm 4.49$	$56.7^{a} \pm 4.78$	$57.9^{A} \pm 3.96$
	av. for N	$59.2^{A} \pm 4.13$	$58.4^{A} \pm 3.05$	$56.9^{A} \pm 3.86$	$56.9^{A} \pm 4.07$	-
C18:3 n-3 + n-6	150	$3.67^{a} \pm 0.44$	$4.50^{a} \pm 0.40$	$4.16^{a} \pm 0.11$	$3.78^{a} \pm 0.25$	$4.03^{A} \pm 0.44$
	200	$3.73^{a} \pm 0.51$	$4.45^{a} \pm 0.28$	$4.32^{a} \pm 0.26$	$3.67^{a} \pm 0.34$	$4.04^{A} \pm 0.47$
	av. for N	$3.70^{B} \pm 0.42$	$4.48^{A} \pm 0.32$	$4.24^{B} \pm 0.20$	$3.72^{B} \pm 0.27$	-
Others	150	$2.10^{a} \pm 0.67$	$1.95^{a} \pm 0.21$	$1.96^{a} \pm 0.25$	$1.71^{a} \pm 0.21$	$1.96^{A} \pm 0.35$
	200	$1.79^{a} \pm 0.17$	$1.85^{a} \pm 0.16$	$2.27^{a} \pm 0.75$	$2.13^{a} \pm 0.41$	$2.01^{A} \pm 0.43$
	av. for N	$1.94^{A} \pm 0.47$	$1.90^{A} \pm 0.17$	$2.11^{A} \pm 0.53$	$1.97^{A} \pm 0.34$	-

* C16:0 palmitic acid; C18:0 stearic acid; C18:1 oleic acid c9; C18:1 octadecanoic acid c11; C18:2 linoleic acid; C18:3 n-3 α-linolenic acid; C18:3 n-6 linoleic acid;
others – C12:0; C14:0; C15:0; C16:1: C17:0; C17:1; C20:0; C20:1; C20:2; C22:0;
a, *b*, *c*, …*A*, *B*… values with the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$), ± SD (standard deviation).

varieties Sailor and Smuga, and the highest content of C18:1 c9 + C11 was in the variety Smuga, while a high (but not statistically significantly) content of C18:2 was detectd in grains of the variety Bogatka. Studies by Stuper-Szablewska et al. (2014) and Konopka et al. (2017) also demonstrated differences in fatty acid profiles in grains of various wheat varieties.

Polyunsaturated fatty acids (PUFA), accounting for over 60% share in the total fatty acid content, were dominant in wheat grains (Table 5). This may indicate very good quality of grains owing to the healthful properties of these acids, which are beneficial to the human health (Abedi, Sahari 2014, Lee et al. 2016).

The results indicate a moderate, statistically unconfirmed effect of nitrogen fertilisation on the percentages of SFA (saturated fatty acids), MUFA (monounsaturated fatty acids) and PUFA (polyunsaturated fatty acids).

Table 5

SFA, MUFA and PUFA and C18:2/C18:3, % in seeds of winter wheat grown under different agricultural production systems, means from 2014-2016

Fatty acids	Dose of N (kg ha^{-1})	Varieties				Average for varieties
		Bogatka	KWS Ozon	Sailor	Smuga	
SFA	150	$25.0^{ab} \pm 0.97$	$26.3^{ab} \pm 0.97$	$25.8^{ab} \pm 0.36$	$23.9^{b} \pm 1.56$	$25.2^{A} \pm 1.30$
	200	$24.2^{ab} \pm 0.79$	$26.5^{a} \pm 0.54$	$25.8^{ab} \pm 1.04$	$25.1^{ab} \pm 0.42$	$25.4^{A} \pm 1.09$
	av. for N	$24.6^{B} \pm 0.91$	$26.4^{A} \pm 0.71$	$25.8^{AB} \pm 0.70$	$24.5^{B} \pm 1.22$	-
MUFA	150	$12.5^{cd} \pm 0.64$	$11.0^{de} \pm 0.77$	$13.3^{abc} \pm 0.56$	$15.1^{a} \pm 0.76$	$13.0^{A} \pm 1.65$
	200	$12.5^{cd} \pm 0.67$	$10.5^{e} \pm 0.90$	$13.0^{bc} \pm 0.33$	$14.6^{ab} \pm 0.25$	$12.6^{A} \pm 1.61$
	av. for N	$12.5^{B} \pm 0.59$	$10.7^{C} \pm 0.80$	$13.1^{B} \pm 0.45$	$14.8^{A} \pm 0.58$	-
PUFA	150	$62.8^{a} \pm 3.92$	$62.9^{a} \pm 4.67$	$61.0^{a} \pm 4.25$	$61.0^{a} \pm 4.57$	$61.9^{A} \pm 3.84$
	200	$63.3^{a} \pm 6.08$	$63.0^{a} \pm 2.64$	$61.6^{a} \pm 4.79$	$60.5^{a} \pm 5.16$	$62.1^{A} \pm 4.28$
	av. for N	$63.0^{A} \pm 4.58$	$63.0^{A} \pm 3.39$	$61.3^{A} \pm 4.06$	$60.8^{A} \pm 4.37$	-
C18:2/ C18:3	150	$16.1^{a} \pm 0.98$	$13.0^{b} \pm 0.22$	$13.6^{b} \pm 0.61$	$15.1^{a} \pm 0.14$	$14.5^{A} \pm 1.40$
	200	$16.0^{a} \pm 0.67$	$13.1^{b} \pm 0.34$	$13.2^{b} \pm 0.25$	$15.5^{a} \pm 0.12$	$14.5^{A} \pm 1.39$
	av. for N	$16.1^{A} \pm 0.75$	$13.1^{B} \pm 0.28$	$13.4^{B} \pm 0.47$	$15.3^{A} \pm 0.22$	-

SFA – Saturated Fatty Acids, MUFA – Monounsaturated Fatty Acids, PUFA – Polyunsaturated Fatty Acids;
a, *b*, *c*, …*A*, *B*… values with the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$), ± SD (standard deviation).

Of the analysed wheat varieties, the variety KWS Ozon was characterised by the significantly highest percentage of SFAs and the lowest percentage of MUFAs. The variety Smuga was characterised by the significantly highest percentage of MUFAs.

An important indicator of the good quality of oil is an appropriate C18:2/C18:3 acid ratio, which ensures the proper synthesis of long chain polyunsaturated fatty acids (Abedi, Sahari 2014). FAO/WHO's nutritional recommendations (Simopoulos et al. 2002) indicate that the C18:2/C18:3 acid (omega-6/omega-3) ratio in foods should be from 5/1 to 10/1. A study by Candela et al. (2011) demonstrated that an excess of C18:2 and very low levels of C18:3 lead to an unfavourable ratio of these acids (which may go as high as 20-30/1) and this may adversely affect human metabolism. A high C18:2/C18:3 acid ratio was found (on average, from 13.0/1 to 16.1/1) in the current study, and it resembles that obtained in a study by Ciołek et al. (2012). The varieties Smuga and Bogatka were characterised by a significantly broader ratio between these acids.

Correlation analysis demonstrated a positive relationship between the fat content and acids C18:2/C18:3 (r = 0.798) – Table 6. Moreover, a relationship was noted between the MUFA content and the content of the micronutrients Cu (r = 0.815) and Fe (r = 0.616).

Table 6

Correlations between grain yield, weight of 1000 grains, content of screenings, content of fat, micronutrients in grain and content of SFA, MUFA and PUFA in grain of winter wheat, means from 2014-2016

Features	Content of fat	SFA	MUFA	PUFA	C18:2/C18:3
Yield of grain	ns	ns	ns	ns	ns
Weight of 1000 grains (g)	ns	ns	ns	ns	ns
Content of screenings (%)	ns	0.452	-0.470	ns	-0.525
Content of fat	ns	-0.538	ns	ns	0.798
Cu	ns	ns	0.815	ns	ns
Fe	ns	ns	0.616	ns	ns
Zn	ns	ns	ns	ns	ns
Mn	ns	ns	ns	ns	ns

SFA – Saturated Fatty Acids, MUFA – Monounsaturated Fatty Acids, PUFA – Polyunsaturated Fatty Acids, ns – not significant differences

CONCLUSIONS

1. The yield of grains of the tested winter wheat varieties ranged from 6.64 to 8.35 t ha^{-1}. A significant effect of the varieties on the yield of grains was noted, notably better yields of the varieties Bogatka and KWS Ozon.

2. Generally, a higher nitrogen dose resulted in an increase in the Fe content (by 10.0%) owing to its higher content in grains of the varieties Bogatka (by 27.3%), Sailor (by 16.7%), and Smuga (by 8.9%).

3. Linoleic acid (57.9%), palmitic acid (23.0%), oleic acid and octadecanoic acid (12.1%), linolenic acid (4.0%) and stearic acid (1.2%) were quantitatively dominant in the fatty acid profile of oil. Polyunsaturated fatty acids (PUFA) composed a 60% share in the total fatty acid content. No significant average effect of the increase in nitrogen fertilisation on changes to the fatty acid content in wheat grains was demonstrated, which suggests that the percentage of fatty acids in lipids is determined by the genetic factor rather than by fertilisation.

4. High correlation was found between the monounsaturated fatty acid (MUFA) content and the amounts of Cu (r = 0.815) and Fe (r = 0.616).

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