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ORIGINAL PAPERS

YIELD AND QUALITY OF WINTER OILSEED RAPE IN RESPONSE TO DIFFERENT SYSTEMS OF FOLIAR FERTILIZATION*

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Abstract

The aim of this study was to determine the effect of different systems of foliar fertilization on the yield of winter oilseed rape (*Brassica napus* L.), the mineral composition of post-harvest biomass and the processing suitability of seeds. In winter oilseed rape grown on boulder clay, intensified foliar fertilization increased seed yield (by 0.43-0.69 Mg ha^{-1} 87% dry matter, DM), straw yield (by 0.59-1.69 Mg ha^{-1} DM), and decreased the harvest index (by 2-3%). The seeds of winter oilseed rape accumulated more N, P, Ca, Zn, Cu, Mn and Fe than straw. The concentrations of P, Mg and S were higher in straw than in seeds. Foliar fertilization increased the N, P and K content (by 2.0, 0.35 and 1.15 g kg^{-1} DM, respectively) and decreased the Mg and S content of straw (by 2.08 and 0.77 g kg^{-1} DM, respectively). A chemical analysis of seeds revealed significant changes only in the concentrations of K, S (increase by 0.57 and 0.55 g kg^{-1} DM, respectively) and P (decrease by 0.90 g kg^{-1} DM, respectively) under the influence of foliar fertilization. Intensified foliar fertilization increased the concentrations of Cu and Zn and decreased the levels of Mn and Fe in straw and seeds. The nutritional value of seeds deteriorated (crude fat content decreased by around 5.5 g kg^{-1} DM, but the composition of fatty acids (FAs), and the proportions of saturated FAs, monounsaturated FAs and polyunsaturated FAs were not significantly altered) with an increase in foliar fertilization levels. Foliar application of macronutrients and micronutrients improved the feed value of winter oilseed rape seeds. Intensified foliar fertilization reduced the content of alkenyl (by approx. 47%) and indole (by approx. 6%) glucosinolates in seeds, mostly due to a decrease in the concentrations of progoitrin, gluconapin and 4-OH-glucobrassicin.

Keywords: *Brassica* crops, productivity, mineral composition, fat, protein, fatty acids, fiber, glucosinolate.

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INTRODUCTION

Winter oilseed rape is the main source of edible oil and vegetable protein in the European Union. The seeds of double-low varieties of winter oilseed rape (canola type, characterized by low levels of erucic acid and glucosinolates, GLS), accumulate 440-490 g kg^{-1} dry matter (DM) of crude fat (CF) and 190-260 g kg^{-1} DM of total protein (TP) (Jankowski et al. 2015*a*). Oilseed crops of the family *Brassicaceae* are capable of GLS biosynthesis. In plants, GLS are synthesized from amino acids: methionine, alanine, valine, leucine, isoleucine (aliphatic GLS), tyrosine, phenylalanine (alkenyl GLS) and tryptophan (indole GLS) (Zukalová, Vašák 2002). The anti-nutritional effects of GLS can be attributed to the most active isothiocyanates derivatives which are released during the hydrolysis of selected alkenyl GLS (Verkerk et al. 2009). For this reason, the concentration of alkenyl GLS in the seeds of *Brassica* plants limits their suitability for use in animal nutrition, and it is one of the key criteria during registration and cultivation of double-low varieties in the European Union (25 μmol g^{-1} 91% DM seeds) (OJEC 1999). Recent research has shown that GLS degradation products, such as isothiocyanates and indole compounds, may deliver health benefits to humans and animals owing to their anti-carcinogenic activity (Verkerk et al. 2009).

The processing suitability of seeds is determined primarily by crop variety, climate and farming operations, mainly fertilization (Rathke et al. 2005, Balík et al. 2006, 2007, Jankowski et al. 2015*a*,*b*). Higher levels of N fertilization in winter oilseed rape decrease the content of CF and alkenyl GLS and increase the concentrations of TP and indole GLS in seeds (Zhao et al. 1994, Rathke et al. 2005). Sulfur fertilization generally increases TP levels in seeds by raising the concentrations of nutritionally important exogenous amino acids (Grant et al. 2012) and by strongly stimulating the biosynthesis of alkenyl GLS (Zhao et al. 1994, Zukalová, Vašák 2002, Jankowski et al. 2015*a*). Micronutrient fertilization increases CF levels in seeds by 0.5-1% (Lääniste et al. 2004, Sienkiewicz-Cholewa, Kieloch 2015) to 4% (Yang et al. 2009) and improves their feed value by lowering total GLS concentrations, by 7-27% (Yang et al. 2009).

The macronutrient uptake of winter oilseed rape in terms of 1 Mg ha^{-1} of seed and straw yield reaches 50-73 kg N, 9-20 kg P, 33-89 kg K, 4-11 kg Mg and 14-20 kg S (Grzebisz 2011). In agricultural practice, such quantities of nutrients can be supplied effectively to plants only through soil fertilization. Foliar fertilization, an alternative method of supplying macronutrients, can only be used to reverse the effects of nutritional deficiencies, and it can serve as the main fertilization technique only to supply plants with the required micronutrients.

Most research into foliar fertilization of oilseed rape focuses on the influence of individual nutrients on seed yield and quality. In agricultural practice, foliar fertilization systems differ in their intensity (chemical composition and form of fertilizers, number of applications). This study evaluates the effects of four systems of foliar fertilization with macronutrients and micronutrients (1, 2, 4 and 6 applications) on the seed yield and straw yield of winter oilseed rape, the mineral composition of post-harvest biomass, and the nutritional and feed value of seeds.

MATERIALS AND METHODS

Field experiment

A field experiment on winter oilseed rape was conducted in 2012-2015, at the Agricultural Experiment Station in Bałcyny (latitude 53°35′42″ N, longitude 19°51′20″ E, north-eastern Poland). Winter oilseed rape was grown in four systems of foliar fertilization with macronutrients and micronutrients, and the results were compared with the control treatment (without foliar fertilization) – Table 1.

Table 1

Intensity of foliar application of macronutrients and micronutrients in winter oilseed rape

Date of application (BBCH*)	Foliar fertilizer**				
12-14	—	—	—	FoliQ Mikromax	FoliQ Mikromax
16-18	—	—	—	—	FoliQ Mikromax
30	—	—	FoliQ AscoVigor	FoliQ AscoVigor + FoliQ Kombimax	FoliQ AscoVigor + FoliQ Kombimax
35-37	—	—	—	—	FoliQ 36 Azotowy + FoliQ Bor
50-52	—	FoliQ 36 Azotowy + FoliQ Bor	FoliQ 36 Azotowy + FoliQ Bor	FoliQ 36 Azotowy + FoliQ Bor	FoliQ AminoVigor
55-57	—	—	—	FoliQ 36 Azotowy	FoliQ 36 Azotowy + FoliQ Bor
Treatment	A	B	C	D	E

* Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie;
** FoliQ 36 Azotowy (5 dm^3 ha^{-1}) = 1800 g ha^{-1} N; 124 g ha^{-1} Mg; 1.1 g ha^{-1} micronutrients;
FoliQ AscoVigor (2 dm^3 ha^{-1}) = 63 g ha^{-1} N; 32 g ha^{-1} K; 26 g ha^{-1} Ca; 20 g ha^{-1} S; 76.2 g ha^{-1} B; 20.4 g ha^{-1} Mn; 12.8 g ha^{-1} Zn; 0.12 g ha^{-1} Fe. Fertilizer with stimulating effects, enriched with *Alcophyllum* sea algal extract, natural growth hormones (cytokinins, auxins, gibberellins, betanins), vitamins and amino acids.
FoliQ Bor (1 dm^3 ha^{-1}) = 150 g ha^{-1} B;
FoliQ Mikromax (1 dm^3 ha^{-1}) = 120 g ha^{-1} N; 125 g ha^{-1} K; 25 g ha^{-1} Mg; 28 g ha^{-1} S; 4.4 g ha^{-1} B; 7.3 g ha^{-1} Cu; 14.5 g ha^{-1} Fe; 21.8 g ha^{-1} Mn; 0.2 g ha^{-1} Mo; 14.5 g ha^{-1} Zn;
FoliQ Kombimax (3 dm^3 ha^{-1}) = 840 g ha^{-1} N; 523 g ha^{-1} K; 112 g ha^{-1} Mg; 8.4 g ha^{-1} B; 2.1 g ha^{-1} Cu; 4.1 g ha^{-1} Fe; 2.1 g ha^{-1} Mn; 2.1 g ha^{-1} Zn

The experiment had a randomized complete block design with three replications. The plot size was 15 m^2 (1.5 × 10). Each year, the experiment was established on Haplic Luvisol developed from boulder clay (IUSS 2006). The soil had a slightly acidic pH ranging from 5.36-6.51 in 1 mol L^{-1} KCl. Soil nutrient levels were as follows: 1.02–2.06% C_{org} (Kurmies method), 56-72 mg kg^{-1} P (Egner-Riehm method), 104-133 mg kg^{-1} K (Egner-Riehm method), 49-63 mg kg^{-1} Mg (atomic absorption spectrometry, AAS, Carl Zeiss Jena, Germany), 3.8-8.9 mg kg^{-1} (Bardsley and Lancaster method), 0.48-0.52 mg kg^{-1} B (colorimetry, Specol 11 spectro-colorimeter, Carl Zeiss Jena, Germany), 1.9-2.7 mg kg^{-1} Cu (AAS), 8.4-14.4 mg kg^{-1} Zn (AAS), 131-184 mg kg^{-1} Mn (AAS), and 2100-2450 mg kg^{-1} Fe (AAS).

The preceding crops were cereals and legumes grown for green fodder. Before sowing, the plots were fertilized with 30 kg ha^{-1} N (urea, 46%), 35 kg ha^{-1} P (granular triple superphosphate, 20%) and 100 kg ha^{-1} K (potassium chloride, 50%). In spring, soil was fertilized with 180 kg ha^{-1} N (ammonium nitrate, 34%) in two applications of 120 kg ha^{-1} (BBCH 30) and 60 kg ha^{-1} (BBCH 52). Each year, winter oilseed rape of the double-low variety SY Kolumb was sown in the second half of August, at 60 dressed (thiuram) seeds m^{-2}, with inter-row spacing of approx. 19 cm. Weeds, diseases and pests were controlled throughout the growing season in accordance with the integrated pest management (IPM) principles (OJEC 2009). Winter oilseed rape was harvested at physiological maturity using a small-plot harvester with a cutting height of 8-10 cm. Each year, winter rapeseed was harvested in the first half of July.

Biomass yield

The major yield components were measured directly before the harvest of winter oilseed rape: plants m^{-2}, siliques $plant^{-1}$, seeds $silique^{-1}$, and 1000-seed weight with 87% DM content. The yield of winter oilseed rape from each plot was determined by weight after threshing and conversion to 87% DM content. Straw yield was given on a dry weight basis. Dry matter content was estimated by drying a subsample of 1 kg at 105°C in a ventilated oven (FD 53, Binder GmbH, Germany) to constant weight. The harvest index (HI) was calculated with the use of the below equation:

$$HI = \frac{\text{seed yield (Mg ha}^{-1}\text{ DM)}}{\text{seed and straw yield (Mg ha}^{-1}\text{ DM)}}.$$

Determination of macronutrient and micronutrient concentrations in biomass

Macronutrient and micronutrient content was determined in the straw and seeds of winter oilseed rape on a dry weight basis. Samples of dried straw and seeds were ground in a laboratory mill (GM 300, Retsch, Germany). Phosphorus content was determined by the vanadium-molybdenum method, Ca and K – by atomic emission spectrometry (AES, Jenway LTD PFP 7, UK), Mg – by AAS, total N – by the hypochlorite method. Total S was determined turbidimetrically in plant material that had been digested with nitric acid and magnesium nitrate to the sulfate form. The concentrations of Cu, Zn, Mn and Fe were determined by Flame-AAS.

Processing suitability of seeds

Seed samples were scanned in the NIR Systems 6500 monochromator (FOSS NIR Systems Inc., USA) equipped with a reflectance module. Intact seeds (approx. 5 g) were placed in a standard ring cup and scanned. The results were predicted by partial least squares (PLS) calibrations established for total protein (reference data from the Kjeldahl method), crude fat (Soxhlet extraction method), acid detergent fiber (ADF) and neutral detergent fiber (NDF) (van Soest method). Glucosinolates were assayed by gas chromatography of trimethylsilyl derivatives of desulfated GLS in the Agilent 6890 gas chromatograph (Agilent Technologies Inc., USA) equipped with a 15 m HP-5 column, according to the method proposed by Raney and modified by Michalski et al. (1995). The fatty acid methyl esters (FAMEs) were analyzed by gas chromatography (HP type 3390A, USA). A DB-23 capillary column (30 m in length) with an operating temperature of 200°C was used (injector and detector temperature was 220°C), with hydrogen as the carrier gas.

Statistical analysis

Data were analyzed by ANOVA, and treatment means were compared with the Duncan's test at a probability level of 0.05 in Statistica 10.1 PL (StatSoft. Inc. 2011). The foliar fertilization system and experimental year were the fixed effects, and the replications were the random effects.

RESULTS AND DISCUSSION

Biomass yield

In medium-rich soils with a balanced fertilization regime, foliar application of macronutrients to winter oilseed rape produces weak results, seed yield increased by 0.09 to 0.22 Mg ha^{-1} (White et al. 2015). When the yield potential of winter oilseed rape is low, a foliar supply of macronutrients could lead to a greater increase in seed yield at 0.46 to 0.54 Mg ha^{-1} (Kwiatkowski 2012). Foliar application of micronutrients generally induces a higher increase in seed yield than foliar supply of macronutrients. Foliar fertilization with micronutrients increases seed yield by 10-16% (medium-rich soils) (Grzebisz et al. 2010, Sienkiewicz-Cholewa, Kieloch 2015) to even 46-67% (sandy soils) (Yang et al. 2009). In this study, where winter oilseed rape was grown on boulder clay soil, standard foliar application of N and B at the beginning of inflorescence did not improve productivity. A significant increase in seed yield (0.27 Mg ha^{-1}) was observed only after the application of a micronutrient fertilizer with stimulating effects (Ascovigor). A further increase in the intensity of foliar fertilization improved seed yield by 0.43 (4 fertilizer applications) to 0.69 Mg ha^{-1} (6 fertilizer applications) – Table 2. In winter oilseed rape, foliar fertilizers generally improve seed yield by increasing the number of siliques (GRZEBISZ et al. 2010) or the number of siliques and the number of seeds per silique (YANG et al. 2009, KWIATKOWSKI 2012). In our study, seed yield increased due to the beneficial effects foliar of fertilizers on 1000-seed weight (Table 2). In winter oilseed rape, intensified foliar fertilization often leads to a greater increase in straw yield (BOWSZYS, KRAUZE 2000, Table 2) than seed yield, which decreases the values of the harvest index (BOWSZYS, KRAUZE 2000, WHITE et al. 2015, Table 2).

Table 2

The effect of foliar fertilization intensity on yield components and biomass yield of winter oilseed rape (across years)

Parameter	Foliar fertilization system				
	A	B	C	D	E
Plants m^{-2}	37.4	35.9	35.8	35.9	37.5
Siliques plants^{-1}	128.4	134.8	135.7	138.0	134.5
Seeds silique^{-1}	26.4	26.7	26.8	26.7	26.9
1000-seed weight (g, 87% DM)	5.23^{d}	5.30^{c}	5.33^{bc}	5.37^{b}	5.43^{a}
Seed yield (Mg ha^{-1} 87% DM)	6.48^{d}	6.60^{d}	6.75^{c}	6.91^{b}	7.17^{a}
Straw yield (Mg ha^{-1} DM)	7.79^{c}	7.71^{c}	7.87^{c}	8.38^{b}	9.48^{a}
Harvest index	0.454^{a}	0.461^{a}	0.463^{a}	0.452^{a}	0.431^{b}

Values marked with the same letter do not differ significantly at $P \leq 0.05$.

Chemical composition of biomass

In this study, the seeds of winter oilseed rape accumulated 8-fold more N, 6-fold more P and 4.5-fold more Ca than straw. The concentrations of P, Mg and S were 1.9-, 2.1- and 1.2-fold higher in straw than in seeds, respectively (Table 3). Seeds accumulated significantly more Cu (2.6-fold), Zn (9.1-fold), Mn (2.8-fold) and Fe (1.7-fold) than straw (Table 4). The changes in macronutrient and micronutrient levels induced by foliar fertilization depend on the biomass type. According to SIENKIEWICZ-CHOLEWA and KIELOCH (2015), foliar application of macronutrients and micronutrients contributes to a higher increase in their concentrations in the vegetative than in generative parts of winter oilseed rape plants. In this study, foliar fertilization also induced a more pronounced increase in macronutrient levels in straw than in seeds. Foliar application of macronutrients and micronutrients significantly increased N, P and K levels (by 2.0, 0.35 and 1.15 g kg^{-1} DM, respectively)

Table 3

The effect of foliar fertilization intensity on the macronutrient content (g kg^{-1} DM) of winter oilseed rape straw and seeds (across years)

Macronutrients	Foliar fertilization system				
	A	B	C	D	E
Straw					
N	3.05^{e}	3.35^{d}	3.80^{c}	4.60^{b}	5.05^{a}
P	1.00^{b}	1.00^{b}	1.05^{b}	1.00^{b}	1.35^{a}
K	13.95^{b}	14.15^{b}	14.95^{a}	15.10^{a}	15.10^{a}
Ca	0.65	0.65	0.65	0.65	0.65
Mg	10.28^{a}	10.25^{a}	10.10^{a}	8.75^{b}	8.20^{c}
S	3.02^{a}	2.95^{a}	2.90^{a}	2.60^{b}	2.25^{c}
Seeds					
N	32.15	32.34	32.03	31.78	31.72
P	7.15^{a}	6.95^{a}	6.55^{b}	6.50^{b}	6.25^{b}
K	7.23^{b}	7.60^{ab}	7.60^{ab}	7.75^{a}	7.80^{a}
Ca	2.98	2.95	2.95	2.90	2.90
Mg	4.45	4.45	4.40	4.40	4.50
S	2.00^{e}	2.15^{cd}	2.25^{bc}	2.35^{b}	2.55^{a}

Values marked with the same letter do not differ significantly at $P \leq 0.05$.

Table 4

The effect of foliar fertilization intensity on the micronutrient content (mg kg^{-1} DM) of winter oilseed rape straw and seeds (across years)

Micronutrients	Foliar fertilization system				
	A	B	C	D	E
Straw					
Cu	1.02^{c}	1.00^{c}	1.40^{b}	1.50^{b}	1.75^{a}
Zn	3.50^{c}	3.90^{b}	3.98^{b}	3.95^{b}	4.35^{a}
Mn	14.82^{a}	14.60^{a}	13.10^{b}	13.00^{bc}	12.60^{c}
Fe	88.67^{a}	82.90^{b}	57.70^{d}	69.80^{c}	52.00^{e}
Seeds					
Cu	3.47	3.50	3.40	3.50	3.60
Zn	34.38^{c}	34.50^{c}	33.90^{c}	37.10^{b}	39.40^{a}
Mn	40.18^{a}	38.10^{ab}	38.30^{ab}	36.10^{bc}	35.40^{c}
Fe	125.55^{a}	124.30^{a}	114.90^{b}	108.50^{c}	106.70^{c}

Values marked with the same letter do not differ significantly at $P \leq 0.05$.

and decreased Mg and S concentrations in straw (by 2.08 and 0.77 g kg^{-1} DM, respectively). A chemical analysis of seeds revealed significant changes only in the concentrations of K and S (increase by 0.57 and 0.55 g kg^{-1} DM, respectively) and P (decrease by 0.90 g kg^{-1} DM, respectively) – Table 3. In the work of Grzebisz et al. (2010), macronutrient levels (Cu, Fe, Mn, Zn, Mo) increased significantly in both vegetative tissues of the main shoot and branches and in generative parts (seeds) under the influence of foliar fertilization.

In our study, similar results were noted only in respect of Cu and Zn whose concentrations in straw and seeds increased with a rise in the intensity of foliar fertilization. In contrast, the Mn and Fe content of straw and seeds decreased with an increase in the intensity of foliar fertilization (Table 4).

Processing suitability of seeds

Studies conducted in various climates and agricultural conditions (Estonia, Poland, China) revealed that foliar fertilization increased CF levels in winter oilseed rape (Lääniste et al. 2004, Yang et al. 2009, Sienkiewicz-Cholewa, Kieloch 2015). In the present study, intensified foliar fertilization lowered CF concentrations in seeds by 5.5 g kg^{-1} DM (Table 5). Those differences could be attributed to variations in yield potential (dilution effect) of winter oilseed rape between the experiments. In this study, seed yield reached 6.5-7.2 Mg ha^{-1}, whereas in other experiments, it did not exceed 5.0 Mg ha^{-1} (Sienkiewicz-Cholewa, Kieloch 2015). In the work of Spychaj-Fabisiak et al. (2011), foliar application of macronutrients (S and Mg) and micronutrients (B) led to a minor decrease in the content of C18:1 and an increase in the concentrations of C18:2. Yang et al. (2009) demonstrated that foliar fertilization with B lowered the content of C22:1. In our study, intensified foliar fertilization with macronutrients and micronutrients did not exert a significant effect on the composition of fatty acids (FAs) or the proportions of saturated FAs, monounsaturated FAs (MUFAs) and polyunsaturated FAs (PUFAs) – Table 5.

Foliar application of macronutrients and micronutrients does not lead to significant differences in the TP content of winter oilseed rape (Harasim, Filipek 2009, Kwiatkowski 2012, Table 5). This biological process requires significant amounts of energy (Bhatia, Rabson 1976) and N, which is difficult to supply in effective quantities through foliar fertilization.

The seeds of double-low varieties of winter oilseed rape contain mainly progoitrin, gluconapin (alkenyl GLS) and 4-hydroxyglucobrassicin (indole GLS) which account for 84-93% of total GLS (Jankowski et al. 2015*a*) – Table 6. In our study, intensified foliar fertilization substantially decreased the concentrations of alkenyl GLS, mainly progoitrin (by 41%) and gluconapin (by 46%). The content of indole GLS in seeds decreased (by 6%) with an increase in the intensity of foliar fertilization, mainly due to a decline in the concentrations of 4-OH-glucobrassicin (Table 6). The results of studies performed in other climates and agricultural conditions (China, southern Poland) also indicate that foliar application of macronutrients and micronutrients improves the feed value of non-fat seed residues by lowering their GLS content (Yang et al. 2009, Kwiatkowski 2012).

Table 5

The effect of foliar fertilization intensity on the nutritional value of winter oilseed rape (across years)

Component	Foliar fertilization system				
	A	B	C	D	E
Crude fat content of seeds					
(g kg^{-1} DM)	494.5^{a}	494.3^{a}	488.3^{b}	488.7^{b}	489.7^{b}
Fatty acid content of oil					
C16 (%)	4.7	4.7	4.8	4.8	4.8
C18 (%)	1.6	1.6	1.7	1.7	1.6
C18:1 (%)	62.8	62.4	63.1	63.4	63.5
C18:2 (%)	18.1	18.3	18.5	18.1	18.9
C18:3 (%)	10.7	10.9	10.7	10.8	10.0
C20:1 (%)	1.7	1.7	1.2	1.2	1.2
C22:1 (%)	0.4	0.4	0.0	0.0	0.0
C18:2 (ω-6)/C18:3 (ω-3)	1.7	1.7	1.7	1.7	1.7
Total saturated FAs (%)	6.3	6.3	6.5	6.5	6.4
Total MUFAs (%)	64.9	64.5	64.3	64.6	64.7
Total PUFAs (%)	28.8	29.2	29.2	28.9	28.9

Values marked with the same letter do not differ significantly at $P \leq 0.05$.
FA – fatty acids, MUFA – monounsaturated fatty acid, PUFA – polyunsaturated fatty acid

Table 6

The effect of foliar fertilization intensity on the feed value of winter oilseed rape (across years)

Component	Foliar fertilization system				
	A	B	C	D	E
Total protein content of seeds					
(g kg^{-1} DM)	198.3	198.6	200.2	202.1	200.9
Content of acid detergent fiber (ADF) and neutral detergent fiber (NDF) in seeds					
NDF (%)	27.9	28.0	28.2	28.5	28.7
ADF (%)	22.4	22.5	23.0	23.4	23.2
GLS content (μmol g^{-1}) of seeds					
Gluconapin	1.76^{a}	0.98^{b}	0.98^{b}	1.02^{b}	0.80^{b}
Glucobrassicanapin	0.38	0.32	0.22	0.28	0.26
Progoitrin	4.65^{a}	4.12^{b}	3.46^{c}	3.25^{c}	2.76^{d}
Napoleiferin	0.10	0.10	0.09	0.10	0.09
Glucobrassicin	0.19	0.19	0.19	0.19	0.19
4-OH-glucobrassicin	3.35^{a}	3.32^{ab}	3.17^{bc}	3.05^{c}	3.12^{c}
Alkenyl GLS	6.79^{a}	5.42^{b}	4.66^{c}	4.55^{c}	3.82^{d}
Indole GLS	3.64^{a}	3.61^{a}	3.45^{b}	3.34^{b}	3.40^{b}

Values marked with the same letter do not differ significantly at $P \leq 0.05$.
GLS – glucosinolates; alkenyl GLS: gluconapin, glucobrassicanapin, progoitrin; indole GLS: napoleiferin, glucobrassicin, 4-OH-glucobrassicin

CONCLUSIONS

1. Intensified foliar fertilization of winter oilseed rape significantly increased seed yield and straw yield. The increase in straw yield, in response to foliar application of macronutrients and micronutrients, was higher than the increase in seed yield, which depressed the harvest index.

2. Seeds of winter oilseed rape accumulated more N, P Ca, Zn, Cu, Mn and Fe than straw. The concentrations of P, Mg and S were higher in straw than in seeds. Foliar application of macronutrients and micronutrients significantly increased the concentrations of N, P, K Cu and Zn, and decreased the levels of Mg, S, Mn and Fe in straw. A chemical analysis of seeds revealed significant changes in the concentrations of K, S, Cu and Zn (increase), and P, Mn and Fe (decrease) under the influence of foliar fertilization.

3. Intensified foliar fertilization of winter oilseed rape contributed to a significant decrease in the crude fat content of seeds (with no significant effect on fatty acid profile) and a decrease in the concentrations of alkenyl GLS (progoitrin and gluconapin).

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