VLIV JARNÍ APLIKACE LISTOVÝCH HNOJIV NA VÝNOS A KVALITU ŘEPKY OZIMÉ

The influence of spring foliar fertilization on the yield and quality of winter oilseed rape seeds

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Summary. This article presents the results of a three-year study investigating the influence of foliar application of macronutrients and micronutrients on the yield and quality of winter oilseed rape seeds. The field experiment was performed in 2012-2015 in the Agricultural Experiment Station in Bałcyny operated by the University of Warmia and Mazury in Olsztyn (north-eastern Poland). Foliar spring fertilization significantly increased (0.22 t/ha) the seed yield of winter oilseed rape by increasing the number of siliques per plant, the number of seeds per silique and 1000 seed weight. Intensified foliar fertilization improved the nutritional value of winter oilseed rape seeds by increasing their content of crude fat and polyunsaturated fatty acids. The feed value of fat-free residues of winter oilseed rape seeds deteriorated under the influence of foliar application of macronutrients and micronutrients by lowering the total protein content of seeds and increasing the concentrations of alkenyl glucosinolates, mainly progoitrin.

Keywords*: winter oilseed rape, foliar fertilization, yield, total protein, crude fat, glucosinolates*

Souhrn: Příspěvek prezentuje výsledky tříleté studie, zkoumající vliv listové aplikace makroprvků a mikroprvků na výnos a kvalitu řepky ozimé. Polní pokus byl založen v letech 2012 – 2015 na zemědělské pokusné stanici v Bałcyny, provozované Univerzitou Warminsko-Mazurskou v Olštyně (severo-východní Polsko). Jarní listové hnojení průkazně zvýšilo (0,22 t/ha) výnos ozimé řepky zvýšením počtu šešulí na rostlinu, počtu semen v šešulích a hmotnosti 1000 semen. Intenzivní hnojení na list zlepšilo nutriční hodnotu semen ozimé řepky zvýšením obsahu tuku a nenasycených mastných kyselin v semenech. Krmná hodnota extrahovaného šrotu se zhoršila vlivem listové aplikace makroprvků a mikroprvků snížením obsahu bílkovin a zvýšením koncentrace glukosinolátů, zejména progoitrinu v semenech.

Klíčová slova: *řepka ozimá, hnojení na list, výnos, bílkoviny, tuk, glukosinoláty*

Introduction

The macronutrient uptake of winter oilseed rape per 1 ton of seeds and straw has been estimated at 50-73 kg N, 9-20 kg P, 33-89 kg K, 4-11 kg Mg, 14-20 kg S (Grzebisz, 2011). Such a high demand for nutrients can be satisfied only if they are applied to the soil. Foliar fertilizers are applied to crops with symptoms of macronutrient deficiency, and they are the main source of micronutrients for field crops (Jankowski et al., 2016abc). Foliar-applied nutrients are more effectively absorbed by plants. Foliar fertilization also delivers environmental benefits by limiting fertilizer runoff to water and preventing the eutrophication of water bodies (Sharpley et al., 1994). In agricultural practice, foliar fertilizers are applied in various doses depending on their form (salts, chelates), chemical composition (macronutrients and micronutrients) and the number of treatments (Jankowski et al., 2016c). Foliar fertilizers can increase seed yields by 0.3-0.7 t/ha on sandy loam soils (Grzebisz et al., 2010; Sienkiewicz-Cholewa and Kieloch, 2015; Jankowski et al., 2016ab) to 1.3 t/ha on sandy soils (Yang et al., 2009).

Productivity and the processing suitability of seeds are very important parameters in the cultivation of winter oilseed rape. Seed quality is determined mainly by their crude fat content, total protein content and the concentrations of biologically active components, mostly glucosinolates (GLS). Regardless of the genetic factors that determine the technological properties of seeds, seed quality is also influenced by habitat and climatic conditions and agronomic factors. In oilseed crops of the family *Brassicaceae*, fertilization significantly influences the biosynthesis of nutrients and bioactive components (Jankowski et al., 2015).

The aim of this study was to evaluate the influence of foliar macronutrient and micronutrient fertilizers applied in BBCH stages 50-52, 55-57 and 75 on the yield components, seed yield, and the nutritional and feed value of winter oilseed rape seeds.

Materials and Methods

Winter oilseed rape (SY Kolumb F_1) was grown in a field experiment in the Agricultural Experiment Station in Bałcyny (latitude 53°35′42″ N, longitude 19°51′20″ E, north-eastern Poland) in 2012-2015. Liquid multi-nutrient fertilizer (FoliQ 36 N) was applied in 1, 2 and 3 treatments in BBCH stages 50-52, 55-57 and 75 (Table 1).

The experiment had a randomized complete block design with three replications. Plot size was 15 m^2 (10 m × 1.5 m). Each year, the experiment was established on Haplic Luvisol developed from boulder clay (IUSS, 2006). The soil had a slightly acidic pH ranging from 5.52-6.36 in 1 mol/L KCl. Soil nutrient levels were as follows: 0.89–1.08% Corg (Kurmies method), 60.1-77.2 mg/kg P (Egner-Riehm method), 98.9-212.4 mg/kg K (Egner-Riehm method), 62-90 mg/kg Mg (atomic absorption spectrometry, AAS, Carl Zeiss Jena, Germany), 7.5-11.1 mg/kg SO_4^{2-} (UV-1201V spectrophotometer, Shimadzu Corporation Kyoto, Japan), 2.0-3.8 mg/kg Cu (AAS), 17.9-21.6 mg/kg Zn (AAS), 189-198 mg/kg Mn (AAS), and 2200-2450 mg/kg Fe (AAS). The content of mineral nitrogen in soil was 4.19-9.88 mg/kg $N-NO_3$ and 1.57-5.05 mg/kg $N-NH_4$ at a depth of 0-30 cm, 0.29-7.41 mg/kg $N-NO_3$ and 0.75-1.73 mg/kg $N-NH_4$ at a depth of 31-60 cm, and 1.98-5.40 mg/kg $N-NO_3$ and 1.50-1.53 mg/kg $N-NH_4$ at a depth of 61-90 cm. The concentration of $N-NH_4$ in soil was determined colorimetrically with Nessler's reagent, and the concentration of $N-NO_3$ was determined colorimetrically with phenol diosulfonic acid (UV-1201V spectrophotometer, Shimadzu Corporation Kyoto, Japan).

Seed samples were scanned in the NIR 6500 monochromator (FOSS NIR Systems Inc., USA) equipped with a reflectance module. The results were predicted by partial least-squares (PLS) calibrations to determine the content of total protein (Kjeldahl method), crude fat (Soxhlet extraction method), acid detergent fiber (ADF) and neutral detergent fiber (NDF) (van Soest method). Glucosinolates were assayed by quantifying trimethylsilyl derivatives of desulfated GLS in the Agilent 6890 gas chromatography system (Agilent Technologies Inc., USA). The obtained fatty acid methyl esters (FAMEs) were analyzed by gas chromatography (HP 3390A, USA).

The results were analyzed by ANOVA, and treatment means were compared in Duncan's test at a probability level of 0.05 in Statistica 10.1 PL.

Table 1. Intensity of foliar application of macronutrients and micronutrients in winter oilseed rape.

Date of application (BBCH*)	Foliar fertilizer**			
50-52	—	FoliQ 36 N	FoliQ 36 N	FoliQ 36 N
55-57	—	—	FoliQ 36 N	FoliQ 36 N
75	—	—	—	FoliQ 36 N
Number of treatments	Control (without foliar fertilization)	1 treatment	2 treatments	3 treatments

** Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie;*
*** FoliQ 36 N (5 dm^3/ha), 1 treatment = 1800 g/ha N; 200 g/ha MgO; 0.65 g/ha B; 13.0 g/ha Cu; 1.35 g/ha Fe; 67.0 g/ha Mn; 0.05 g/ha Mo; 0.35 g/ha Zn.*

Results and discussion

Seed yield

In soils with an average content of available nutrients and balanced soil fertilization, foliar fertilization has a weak influence on winter oilseed rape (White et al., 2015). In the present study, the yield of winter oilseed rape was determined at 6.8-7.1 t/ha. The yield potential of winter oilseed rape was effectively utilized, and spring foliar fertilization improved seed yield by only 0.22 t/ha (by 3%). It should be noted that foliar macronutrient fertilizers deliver much greater benefits when the yield potential of winter oilseed rape is less effectively utilized. In a study by Kwiatkowski (2012), foliar fertilization increased the yield of winter oilseed rape by around 0.5 t/ha (16%). The improvement in seed yield induced by foliar application of macronutrients and micronutrients results mainly from a higher number of siliques per plant (Grzebisz et al., 2010), higher number of seeds per silique (Jankowski et al. 2016b), higher 1000 seed weight (Jankowski et al., 2016a) and greater increase in all yield components (Kwiatkowski, 2012) (Table 2).

Table 2. The influence of spring foliar application of macronutrients and micronutrients on the yield components and seed yield of winter oilseed rape (across years).

Parameter	Spring foliar fertilization			
	Control	1 treatment	2 treatments	3 treatments
Number of plants per 1 m^2	43.8	43.9	42.4	44.1
Number of siliques per plant	113.5	111.6	116.1	114.2
Number of seeds per silique	27.0	27.4	27.4	27.3
1000 seed weight (g, 87% DM)	5.22	5.21	5.29	5.23
Seed yield (t/ha 87% DM)	6.86^b	6.83^b	7.01^a	7.08^a

Processing suitability of winter oilseed rape seeds

Foliar application of macronutrients and micronutrients enhances crude fat biosynthesis in the seeds of winter oilseed rape (Kwiatkowski, 2012; Jankowski et al., 2016b). In the current study, three applications of liquid multi-nutrient fertilizer in BBCH stages 50-52, 55-57 and 75 contributed to a significant increase in the crude fat content of seeds by around 8 g/kg DM (Table 3). Foliar feeding has a multidirectional influence on the fatty acid composition of seeds. In a study by Spychaj-Fabisiak et al. (2011), foliar application of macronutrients and micronutrients induced a minor decrease in the concentration of the C18:1 fatty acid and an increase in the concentration of the C18:2 fatty acid. According to Jankowski et al. (2016a), the fatty acid composition of seeds was not significantly modified by higher rates of foliar fertilization with macronutrients and micronutrients. In the present study, a higher number of foliar fertilization treatments in spring increased PUFA concentrations, in particular the content of the C18:2 fatty acid (Table 3).

Table 3. The influence of spring foliar application of macronutrients and micronutrients on the nutritional value of seeds of winter oilseed rape (across years).

Parameter	Spring foliar fertilization			
	Control	1 treatment	2 treatments	3 treatments
Crude fat content of seeds				
g/kg DM	493.7^{b}	494.0^{b}	500.7^{a}	501.7^{a}
Fatty acid content of seeds				
C_{16} (%)	4.8^{b}	4.9^{a}	4.8^{b}	4.8^{b}
C_{18} (%)	1.7	1.7	1.7	1.7
$C_{18:1}$ (%)	63.3	63.4	62.6	62.4
$C_{18:2}$ (%)	18.3^{b}	18.4^{b}	18.7^{a}	18.5^{ab}
$C_{18:3}$ (%)	10.5	10.5	11.0	10.8
$C_{20:1}$ (%)	1.1^{b}	1.1^{b}	1.2^{b}	1.4^{a}
$\frac{C_{18:2}\ (\omega-6)}{C_{18:3}\ (\omega-3)}$	1.76	1.76	1.70	1.71
Total saturated FAs (%)	6.5	6.6	6.5	6.5
Total MUFAs (%)	64.4	64.5	63.8	63.8
Total PUFAs (%)	28.8^{b}	28.9^{b}	29.7^{a}	29.3^{ab}

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

C_{16} – palmitic acid; C_{18} – stearic acid; $C_{18:1}$ – oleic acid; $C_{18:2}$ – linoleic acid; $C_{18:3}$ – linolenic acid; $C_{20:1}$ – eicosanoic acid; FA - fatty acids; MUFA - monounsaturated fatty acid; PUFA - polyunsaturated fatty acid

Table 4. The influence of spring foliar application of macronutrients and micronutrients on the feed value of seeds of winter oilseed rape (across years).

Parameter	Spring foliar fertilization			
	Control	1 treatment	2 treatments	3 treatments
Total protein content of seeds				
g/kg DM	200.1^{a}	193.7^{b}	191.0^{b}	192.7^{b}
Concentrations of ADF and NDF				
NDF (%)	29.1	28.9	28.7	29.3
ADF (%)	23.0	23.5	22.9	23.2
GLS content (μmol/g) of seeds				
Gluconapin	1.1^{a}	0.9^{b}	0.5^{d}	0.6^{c}
Glucobrassicanapin	0.2^{b}	0.3^{a}	0.3^{a}	0.3^{a}
Progoitrin	2.7^{c}	3.1^{b}	3.9^{a}	2.2^{d}
Napoleiferin	0.1	0.1	0.1	0.1
Glucobrassicin	0.2	0.2	0.2	0.2
4-OH-glucobrassicin	3.3^{a}	3.2^{b}	3.1^{b}	3.4^{a}
Alkenyl GLS	4.0^{c}	4.3^{b}	4.6^{a}	3.1^{d}
Indole GLS	3.6^{a}	3.5^{b}	3.4^{b}	3.7^{a}
$\frac{\text{Alkenyl GLS}}{\text{Indole GLS}}$	1.1^{c}	1.2^{b}	1.4^{a}	0.9^{d}

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

ADF - acid detergent fiber; NDF - neutral detergent fiber; GLS – glucosinolates; alkenyl GLS: gluconapin, glucobrassicanapin, progoitrin; indole GLS: napoleiferin, glucobrassicin, 4-OH-glucobrassicin

The influence of foliar fertilization on the total protein content of winter oilseed rape seeds is strongly differentiated by habitat and climatic conditions. In experiments conducted by Kwiatkowski (2012) and Jankowski et al. (2016a), foliar fertilization did not affect the total protein content of winter oilseed rape seeds. In the current study, the total protein content of seeds was reduced by 9.1 g/kg DM as a result of intensified foliar fertilization with macronutrients and micronutrients (Table 3). Jankowski et al. (2016b) reported an increase in the total protein content of winter oilseed rape seeds under the influence of foliar fertilization.

The seeds of double-low varieties of winter oilseed rape registered in Poland contain mainly progoitrin, gluconapin and 4-hydroxy-glucobrassicin (Jankowski et al., 2015). In a study by Jankowski et al. (2016a), intensified foliar fertilization led to a considerable decrease in the concentrations of alkenyl GLS, mainly progoitrin and gluconapin. The concentrations of indole GLS in the seeds of winter oilseed rape decreased significantly with an increase in the intensity of foliar fertilization, mainly due to a decrease in the content of 4-OH-glucobrassicin. Kwiatkowski (2012) demonstrated that foliar application of macronutrients and micronutrients decreased the GLS content of seeds and improved the feed value of fat-free residues. The cited findings do not corroborate our results (Table 4). In the present study, a higher number of foliar fertilization treatments deteriorated the feed value of the fat-free residues of winter oilseed rape seeds by increasing the concentrations of alkenyl GLS and decreasing the content of indole GLS.

Conclusions

1. Spring foliar fertilization significantly increased (0.22 t/ha) the seed yield of winter oilseed rape by increasing the number of siliques per plant, number of seeds per silique and 1000 seed weight.
2. Intensified foliar fertilization in spring improved the nutritional value of the seeds of winter oilseed rape. Spring foliar fertilization significantly increased the crude fat content of seeds and the concentrations of polyunsaturated fatty acids, mainly linoleic acid.
3. The feed value of the fat-free residues of winter oilseed rape seeds deteriorated under the influence of foliar application of macronutrients and micronutrients. Foliar fertilization decreased the total protein content of seeds and increased the concentrations of alkenyl glucosinolates, mainly progoitrin, in the seeds of winter oilseed rape.

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