Electronic Journal of Polish Agricultural Universities is the very first Polish scientific journal published exclusively on the Internet, founded on January 1, 1998 by the following agricultural universities and higher schools of agriculture: University of Technology and Agriculture of Bydgoszcz, Agricultural University of Cracow, Agricultural University of Lublin, Agricultural University of Poznan, Higher School of Agriculture and Teacher Training Siedlce, Agricultural University of Szczecin, and Agricultural University of Wroclaw.

ELECTRONIC JOURNAL OF POLISH AGRICULTURAL UNIVERSITIES

2003
Volume 6
Issue 2
Series AGRONOMY

SZULC P.M., DROZDOWSKA L., KACHLICKI P. 2003. EFFECT OF SULPHUR ON THE YIELD AND CONTENT OF GLUCOSINOLATES IN SPRING OILSEED RAPE SEEDS **Electronic Journal of Polish Agricultural Universities**, Agronomy, Volume 6, Issue 2.
Available Online http://www.ejpau.media.pl

EFFECT OF SULPHUR ON THE YIELD AND CONTENT OF GLUCOSINOLATES IN SPRING OILSEED RAPE SEEDS

Piotr Mirosław Szulc[1], Lucyna Drozdowska[1], Piotr Kachlicki[2]
[1]*Department of Plant Physiology, University of Technology and Agriculture in Bydgoszcz, Poland*
[2]*Institute of Plant Genetics, Polish Academy of Sciences in Poznań, Poland*

ABSTRACT
INTRODUCTION
MATERIAL AND METHODS
RESULTS
DISCUSSION
CONCLUSIONS
REFERENCES

ABSTRACT

The aim of the present research was to define the effect of sulphur nutrition on the seed yield of 'Star' spring oilseed rape and the content of glucosinolates. Sulphur was applied in different forms (elemental or ionic), in different ways (through soil or leaves) and doses (0, 20, 60 $kg \cdot ha^{-1}$). The laboratory research material involved seeds from a three-year field experiment set up on degraded black earth containing 1.93 mg $SO_4 \cdot kg^{-1}$ of soil. The content of glucosinolates in seeds was determined with the HPLC according EN ISO 9167-1. The application method and sulphur forms and doses increased the oilseed rape seed yield. The highest mean seed yield was obtained from plants exposed to foliar fertilisation with elemental sulphur at the dose of 60 $kg \cdot ha^{-1}$. In this case the content of glucosinolates amounted to 10.78 $\mu M \cdot g^{-1}$ of dry matter and was lower as compared to objects non-fertilised with sulphur. A total content of glucosinolates and the sum of alkenyl glucosinolates, most represented by progoitrin and gluconapin, were significantly highest in oilseed rape seeds fertilised with elemental sulphur at the dose of 60 $kg \cdot ha^{-1}$ applied into soil.

Key words: oilseed rape, fertilisation, sulphur, glucosinolates

INTRODUCTION

The yield of spring oilseed rape seeds and chemical composition depend on the cultivar, environmental conditions, nitrogen fertilisation and sowing date [11,14]. The oilseed rape cultivation technology also depends much on sulphur fertilisation, especially in the regions of deficit of this macroelement [23].

Wielebski and Wójtowicz [22] observed for winter oilseed rape that the seed yield of 3.5 $t \cdot ha^{-1}$ requires 88 kg of sulphur. Schnug and Haneklaus [15] showed that the sulphur uptake by oilseed rape took place especially in spring from the beginning of vegetation period to the end of flowering at the amount of 15-20 $kg \cdot t^{-1}$ of seeds produced. According to these authors, fertilising plants with this macroelement enhances the yield, content of fat and sulphur aminoacids. However it can also increase a total content of glucosinolates in seeds [2,8,16,24]. Glucosinolates are secondary metabolites containing sulphur, generally occurring in *Brassicaceae* family plants. They are non-toxic substances; however the products of their enzymatic break-down are biologically active compounds. The animal feeding experiments showed severe anti-nutritional effects of the glucosinolate derived compounds, so their level decides about the seeds technological value and the feed value of meal [7,13]. Both the sowing seeds and seeds for consumption of double-improved oilseed rape cultivars must comply with the Polish standard: 15 µM glucosinolates per g of seeds for sowing seeds and 25 µM per g of defatted seed meal for seeds to be processed [19].

The present research aimed at:

- evaluation of the effect of sulphur on the total glucosinolates content as well as their qualitative and quantitative composition in oilseed rape seeds,
- assessment of the influence of different methods, forms and doses of sulphur application on the seed yield with the optimal share of glucosinolates.

Bearing in mind the essential role of sulphur in oilseed rape agro-ecosystem and metabolism, a working hypothesis has been formulated which assumes that similarly as for winter oilseed rape, sulphur fertilisation will affect yielding and utility value of spring oilseed rape.

MATERIAL AND METHODS

The results which cover the seed yield and glucosinolates content were obtained from a three-year (1997-1999) field experiment of the Department of Plant Cultivation of the Faculty of Agriculture, the Bydgoszcz University of Technology and Agriculture. The experiment was set up as a split-plot-split-block in four replications on degraded black earth of a wheat defective complex. A complete content of sulphur in soil ranged from 0.03 to 0.08% S_{total} and the mean content of sulphate sulphur amounted to 1.93 mg $SO_4 \cdot kg^{-1}$ of soil. The other soil properties are given in Table 1.

Table 1. Selected soil properties over the 1997-1999 research years

	Content		Mean
Granulometric fractions mm	2.00-0.05	56 – 68%	
	0.05-0.002	20 – 25%	
	< 0.002	12 – 19%	
$CaCO_3$, %	0.46 – 0.90		0.68
S_{total}, %	0.03 – 0.08		0.05
C_{org}, $g \cdot kg^{-1}$	11.50 – 18.50		15.0
humus, $g \cdot kg^{-1}$	19.80 – 31.90		25.8
P_2O_5, $mg \cdot kg^{-1}$	230 – 246		238
K_2O, $mg \cdot kg^{-1}$	125 – 225		175
Mg, $mg \cdot kg^{-1}$	35 – 38		36.5
pH_{KCl}	6.5 – 7.1		6.8

'Star' spring oilseed rape was sown at the beginning of the second decade of April on experimental plots of 18 m^2. In each research year sugar beet constituted a forecrop for spring oilseed rape. NPK ($N = 120\ kg \cdot ha^{-1}$, $P_2O_5 = 60\ kg \cdot ha^{-1}$, $K_2O = 120\ kg \cdot ha^{-1}$) fertilisation was applied pre-sowing.

Elemental sulphur was obtained from a fungicide preparation, known under brand name of 'Siarkol', while crystalline Na_2SO_4 was used as the source of ionic sulphur. Foliar fertilisation involved the usage of 6.7% water solution of Siarkol or Na_2SO_4. The dose of 20 kg $S \cdot ha^{-1}$ was applied before oilseed rape sowing (soil fertilisation) or over the rosette phase (foliar fertilisation). As for plant fertilisation with a dose of 60 kg $S \cdot ha^{-1}$, it was divided into three parts (Table 2). The control was made up of plots not fertilised with sulphur.

Table 2. Experiment design

Sulphur application method	Sulphur form	Dose kg S· ha^{-1}	Fertilisation date
Soil	Elemental (Siarkol)	20	Pre-sowing
		60 (3 x 20)	Pre-sowing
			Beginning of shoot elongation
			Beginning of flowering
	Ionic (Na_2SO_4)	20	Pre-sowing
		60 (3 x 20)	Pre-sowing
			Beginning of shoot elongation
			Beginning of flowering
Foliar	Elemental (Siarkol)	20	Rosette phase
		60 (3 x 20)	Rosette phase
			Beginning of shoot elongation
			Beginning of flowering
	Ionic (Na_2SO_4)	20	Rosette phase
		60 (3 x 20)	Rosette phase
			Beginning of shoot elongation
			Beginning of flowering

The date of two-phase seed harvest coincided with a turn of the first and second decade of August. The seed yield was measured and the seed content of alkenyl glucosinolates (progoitrin, gluconapin, glucobrassicanapin, napoleiferin) and indolyl glucosinolates (4-hydroxyglucobrassicin, glucobrassicin) were analysed using the HPLC of desulphoglucosinolates according to the EN ISO 9167-1 method. The chromatographic analysis was carried out using Merck Hitachi HPLC instrument with Spherisorb ODS2 ≤ 5 µm (250 × 4.6 mm) column.

The seed yield results and the content of glucosinolates in seeds were verified with variance analysis in a fixed model. The synthesis of the variance analysis was carried out in a mixed model. Mean values for the combination both for the seed yield and the content of glucosinolates were compared with a multiple Tukey test at p = 95%. In a search for variation in the values of the characteristics researched in objects fertilised with sulphur against the control (without sulphur), the Dunnet test was applied.

RESULTS

The observed effects of sulphur application methods, forms and doses on the spring oilseed rape yield varied over the successive research years (Table 3). The highest seed yield, 4.06 and 4.01 t·ha^{-1}, was obtained in 1997 following the foliar fertilisation with sulphur at the dose of 60 kg·ha^{-1} in ionic or elemental form, respectively, and it was 0.76-0.71 t·ha^{-1} higher than the seed yield from the control plots. Over 1998-1999 oilseed rape seed yields from all the plots covered by the fertilisation combinations were lower as compared with those of 1997, however, the highest yields were recorded for oilseed rape foliar-fertilised with sulphur in elemental form at the dose of 60 kg·ha^{-1}. Mean seed yield obtained over 1997-1999 for that experiment variant amounted to 3.23 t·ha^{-1} and was 0.81 t·ha^{-1} higher than the control. Variance analysis for mean seed yields confirmed the effect of the application method on oilseed rape yield and showed that foliar fertilisation was more effective. Comparing the yields obtained from the control and those fertilised sulphur, it was noticed that an increase in the sulphur dose from 20 to 60 kg·ha^{-1} increased the yield significantly. Foliar fertilisation of plants with ionic sulphur was the only one for which increasing the dose from 20 to 60 kg·ha^{-1} decreased the yield. An interaction was also shown between the application method and fertilisation form. As for soil fertilisation, the plants grown on plots fertilised with ionic sulphur yielded significantly higher than those with elemental sulphur. Foliar fertilisation with sulphur, however, showed better results when sulphur was applied in elemental form.

Table 3. Effect of sulphur fertilisation on the 'Star' spring oilseed rape seed yield

Sulphur fertilisation			Yield, t·ha^{-1}			
Application method	Form	Dose kg·ha^{-1}	1997	1998	1999	Mean
Control			3.30	2.17	1.79	2.42
Soil	elemental	20	3.55	2.35	1.84	2.58
		60	3.88	2.50	1.86	2.75
		mean	3.71	2.42	1.85	2.66
	ionic	20	3.98	2.44	1.86	2.76
		60	4.00	2.58	2.01	2.86
		mean	3.99	2.51	1.93	2.81
	mean for the form	20	3.76	2.39	1.85	2.67
		60	3.94	2.54	1.93	2.80
Mean for the soil fertilisation			3.84	2.46	1.89	2.73
Foliar	elemental	20	3.85	2.42	2.10	2.79
		60	4.01	3.29	2.39	3.23
		mean	3.93	2.85	2.24	3.01
	ionic	20	3.47	2.88	2.18	2.84
		60	4.06	2.43	1.86	2.78
		mean	3.76	2.65	2.02	2.81
	mean for the form	20	3.66	2.65	2.14	2.82
		60	4.03	2.86	2.12	3.00
Mean for foliar fertilisation			3.84	2.75	2.13	2.91
Mean for fertilised objects			3.84	2.60	2.01	2.82
Annual mean			3.57	2.38	1.90	2.62
$LSD_{p=0.05}$ for fertilised objects:						
application method (A)			ns	0.09	0.04	0.06
fertilisation form (B)			ns	ns	ns	ns
fertilisation dose (C)			0.16	0.09	ns	0.12
interaction:						
A x B			0.28	ns	0.09	0.11
A x C			ns	0.13	ns	0.13
B x C			ns	ns	0.06	0.14
$LSD_{p=0.05}$ for the contrast:						
control – fertilisation object			ns	ns	ns	ns

ns – non-significant differences

Sulphur fertilisation modified also the content of glucosinolates in spring oilseed rape which differed over years (Table 4). The total content of glucosinolates in seeds was highest in the first year of the experiment and significantly depended on the fertilisation form and dose. However only foliar fertilisation with ionic sulphur at the dose of 60 kg·ha^{-1} increased the content of these compounds as compared with the control. Over the second experiment year all the factors studied as well as their interaction significantly affected the content of glucosinolates in seeds. Sulphur applied into soil increased the total content of glucosinolates as compared with the control; the highest content of glucosinolates was observed in seeds of plants fertilised with sulphur introduced into soil in elemental form. The foliar application of sulphur, irrespective of the form, did not increase the content of these compounds and it remained at the level of the control or was lower. The fertilisation with sulphur in the ionic form resulted in a lower content of glucosinolates then that observed in seeds of plants fertilised with elemental sulphur. In case of soil fertilisation with the elemental form of sulphur an increase of its dose did not influence the content of glucosinolates. In the other fertilisation variants a significantly higher total glucosinolate contents were recorded in seeds collected from plants fertilised with 20 kg S·ha^{-1} as compared to the sulphur dose of 60 kg·ha^{-1}. The 1998 most favourable fertilisation variant coincided with foliar fertilisation with elemental and ionic sulphur at the dose of 60 kg·ha^{-1} which did not increase the content of glucosinolates in seeds. The analysis of seeds collected in the 1999 experiment showed that the content of glucosinolates in seeds, just like in 1998, was significantly differentiated by the factors studied. The highest content of glucosinolates was observed in seeds of plants foliar-fertilised with ionic sulphur. An increase in sulphur dose from 20 to 60 kg·ha^{-1} irrespective of the application method significantly increased the total content of glucosinolates when the ionic form was applied. In that research year the most favourable fertilisation method was foliar fertilisation with elemental sulphur and soil fertilisation with ionic sulphur, which did not increase significantly the content of glucosinolates as compared with the control. Variance analysis which covered the three-year research period showed a significant effect of the interaction between the application method and the sulphur form applied on the total content of glucosinolates. The highest content of glucosinolates was recorded in seeds collected from objects soil-fertilised with elemental sulphur. However, there was noted no increased content of the compounds researched in seeds due to soil fertilisation with ionic sulphur and to foliar fertilisation with elemental sulphur.

Table 4. Effect of sulphur fertilisation on the content of glucosinolates in 'Star' spring oilseed rape seeds

Sulphur fertilisation			Content of glucosinolates, μM·g^{-1} of dry matter			
Application method	Form	Dose kg·ha^{-1}	1997	1998	1999	Mean
Control			14.2	12.6	9.10	12.0
Soil	elemental	20	13.5	14.9	9.56	12.7
		60	14.0	15.0	9.66	12.9
		mean	13.7	14.9	9.61	12.8
	ionic	20	12.5	13.2	9.08	11.6
		60	12.9	13.0	9.28	11.7
		mean	12.7	13.1	9.18	11.6
	mean for the form	20	13.0	14.0	9.32	12.1
		60	13.5	14.0	9.47	12.3
Mean for the soil fertilisation			13.2	14.0	9.39	12.2
Foliar	elemental	20	12.5	12.9	9.01	11.5
		60	11.6	11.9	8.84	10.8
		mean	12.0	12.4	8.92	11.1
	ionic	20	14.0	12.6	9.75	12.1
		60	15.4	12.0	10.9	12.7
		mean	14.7	12.3	10.3	12.4
	mean for the form	20	13.2	12.7	9.38	11.8
		60	13.5	11.9	9.85	11.8
Mean for foliar fertilisation			13.4	12.3	9.61	11.8
Mean for fertilised objects			13.3	13.2	9.50	12.0
Annual mean			13.7	12.9	9.30	12.0
$LSD_{p=0.05}$ for fertilised objects:						
application method (A)			ns	0.14	0.09	ns
fertilisation form (B)			0.18	0.14	0.09	ns
fertilisation dose (C)			0.27	0.21	0.13	ns
interaction:						
A x B			0.25	0.20	0.12	0.69
A x C			ns	0.25	0.15	ns
B x C			0.31	0.25	0.15	ns
$LSD_{p=0.05}$ for the contrast:						
control – fertilisation object			0.54	0.43	0.26	0.14

ns – non-significant differences

The factors studied affected the total content of alkenyl glucosinolates (Table 5); over successive experiment years the relationships were similar as for the total content of glucosinolates. Three-year mean results showed an increased content of alkenyl glucosinolates as compared with the control due to soil fertilisation with elemental sulphur and foliar fertilisation with ionic sulphur. However, an increase in the sum of alkenyl glucosinolates was observed neither in seeds of plants soil-fertilised with ionic sulphur nor with foliar-applied elemental sulphur. Out of all the researched alkenyl glucosinolates in seeds, progoitrin dominated; its content, as compared with the control, was significantly higher in seeds obtained from all the experiment variants and was significantly affected by the interaction between two factors: the application method and fertilisation form. Its highest content was noted in seeds collected from plants fertilised with elemental sulphur into soil. Sulphur fertilisation did not show a significant effect on the content of gluconapin, accounting for the second largest share of alkenyl glucosinolates in seeds. There was shown a significant effect of the interaction between the application method and fertilisation form on the content of glucobrassicanapin and napoleiferin in seeds. As compared with the control, in seeds obtained from all the experiment objects there was recorded a lower content of glucobrassicanapin. Yet a significant increase was recorded in the content of napoleiferin in seeds when soil was fertilised with elemental sulphur and for foliar fertilisation with ionic sulphur. However a significantly lower content of the glucosinolates researched, as compared with the control, was observed in seeds collected from plants foliar-fertilised with elemental sulphur and soil-fertilised with ionic sulphur.

Table 5. Effect of sulphur fertilisation on the content of alkenyl glucosinolates in 'Star' spring oilseed rape seeds (mean for 1997-1999)

Sulphur fertilisation			$\mu M \cdot g^{-1}$ of dry matter				
Application method (A)	Form (B)	Dose $kg \cdot ha^{-1}$ (C)	progoitrin	gluconapin	glucobrassicanapin	napoleiferin	Sum
Control			3.99	1.43	0.74	0.66	6.83
Fertilized object							
Soil	elemental	20	4.32	1.55	0.57	0.68	7.12
		60	4.50	1.58	0.67	0.72	7.48
	ionic	20	4.09	1.32	0.57	0.58	6.55
		60	4.29	1.38	0.64	0.61	6.92
Mean for soil fertilisation			4.29	1.45	0.61	0.64	7.01
Foliar	elemental	20	4.21	1.43	0.44	0.55	6.63
		60	4.26	1.44	0.48	0.49	6.66
	ionic	20	4.25	1.34	0.68	0.69	6.96
		60	4.53	1.44	0.68	0.70	7.34
Mean for foliar fertilisation			4.31	1.42	0.56	0.60	6.90
Mean for fertilised objects			4.30	1.43	0.58	0.62	6.95
Mean			4.14	1.43	0.66	0.64	6.89
$LSD_{p=0.05}$ for:							
application method (A)			ns	ns	ns	ns	ns
fertilisation form (B)			ns	ns	ns	0.02	ns
fertilisation dose (C)			ns	ns	ns	ns	ns
interaction:							
A x B			0.04	ns	0.04	0.05	ns
A x C			ns	ns	ns	ns	ns
B x C			ns	ns	ns	ns	ns
$LSD_{p=0.05}$ for the contrast:							
control – fertilization object			0.05	ns	0.06	0.03	0.10

ns – non-significant value of the feature studied

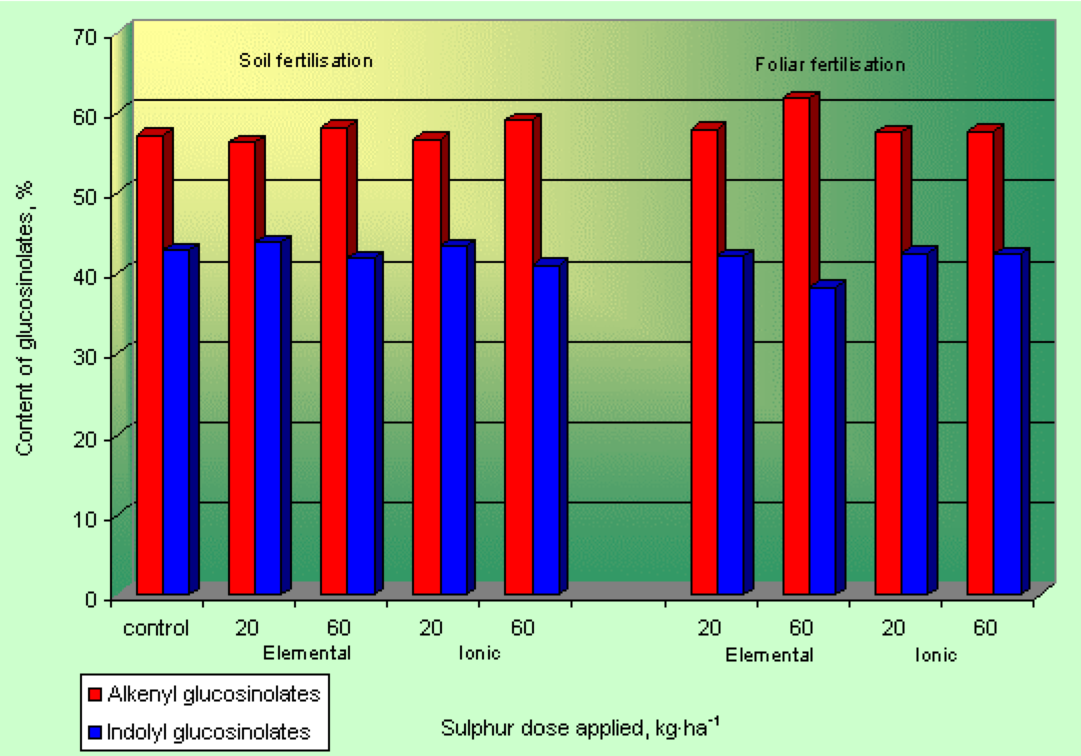
Table 6. Effect of sulphur fertilisation on the content of indolyl glucosinolates in 'Star' spring oilseed rape seeds (mean for 1997-1999)

Sulphur fertilisation			μM·g^{-1} of dry matter		
Application method (A)	Form (B)	Dose kg·ha^{-1} (C)	4-hydroxy-glucobrassicin	glucobrassicin	Sum
Control			4.29	0.83	5.12
Fertilized object					
Soil	elemental	20	4.54	1.00	5.54
		60	4.29	1.11	5.40
	ionic	20	4.12	0.89	5.01
		60	3.83	0.97	4.80
Mean for soil fertilisation			4.19	0.99	5.18
Foliar	elemental	20	3.97	0.85	4.82
		60	3.22	0.89	4.11
	ionic	20	4.21	0.93	5.14
		60	4.36	1.03	5.39
Mean for foliar fertilisation			3.93	0.92	4.86
Mean for fertilised objects			4.06	0.95	5.02
Mean			4.17	0.89	5.07
$LSD_{p=0.05}$ for:					
application method (A)			ns	ns	ns
fertilisation form (B)			ns	ns	ns
fertilisation doses (C)			ns	ns	ns
interaction:					
A x B			0.333	ns	0.380
A x C			ns	ns	ns
B x C			ns	ns	ns
$LSD_{p=0,05}$ for the contrast:					
control – fertilized object			0.03	0.04	0.05

ns – non-significant value of the feature studied

Most of the factors studied also significantly affected the content of indolyl glucosinolates in seeds (Table 6). Over successive research years there were recorded similar relationships as for the sum of glucosinolates and the sum of alkenyl glucosinolates, especially for the application method and fertilisation form. On average over the three-year research period the content of indolyl glucosinolates was highest following soil fertilisation in elemental form. Studying the effect of sulphur fertilisation on the content of respective forms of indolyl glucosinolates, as compared to those of the control seeds, a higher content of 4-hydroksyglucobrassicin was recorded only in seeds of plants fertilised with elemental sulphur at the dose of 20 kg·ha^{-1} into soil and foliar-applied ionic sulphur at the dose of 60 kg·ha^{-1}. However the content of glucobrassicin in seeds obtained from all the fertilisation variants was significantly higher as compared with the control. Foliar fertilisation with elemental sulphur at the dose of 20 kg·ha^{-1} was the only one which showed the content of this glucosinolate similar to the control.

Fig. 1. Effect of sulphur fertilisation of 'Star' spring oilseed rape on the content of the sum of alkenyl and indolyl glucosinolates in seeds (mean for 1997-1999)



Alkenyl glucosinolates accounted for 57.1% of all the glucosinolates in seeds of plants not fertilised with sulphur, while indolyl glucosinolates – 42.9%. Depending on sulphur application variant, the share of alkenyl glucosinolates in the total pool of these metabolites ranged from 56.2 to 61.8%, while that of indolyl glucosinolates from 38.2 to 43.7% (Fig. 1).

DISCUSSION

Spring oilseed rape, similarly to the winter one, shows a high demand for sulphur from the beginning of shooting to silique setting by plants [18]. Its demand ranges from 15-20 kg·t^{-1} of the seeds produced [20]. Many authors [10,12,15,16,22,24] researching the effect of this macroelement on the growth and yielding of oilseed rape, show a necessity of fertilising plants with sulphur.

Sulphur fertilisation applied in the experiment increased the mean seed yield from 6.61 to 33.4% as compared with the control. The highest mean yield in the present experiment was obtained due to foliar fertilisation of oilseed rape with elemental sulphur at the dose of 60 kg·ha^{-1}. The sulphur form applied not only increased yield but also improved the phytosanitary status, inhibiting the development of fungal pathogens of *Alternaria* genus, especially *Alternaria brassicae* and *Alternaria brassicicola* species [17].

A positive effect of sulphur fertilisation on oilseed rape cultivated on soils deficient in this macroelement was shown as early as in 1968 by Appelqvist [1] who observed that increasing sulphur dose, whenever its deficit is recorded in the medium, to the amount which would satisfy plant nutrient requirements, increased the yield, as compared with the control, by 80-129%. The report by Bilsborrow et al. [2] showed a varied effect of sulphur fertilisation on oilseed rape yield depending on the sulphur content in soil and in the air**.** The highest yield was recorded for oilseed rape fertilised with 40 kg S·ha^{-1} cultivated on plots of a low sulphur content, and the yield obtained was 65% higher than that from control objects (poor in sulphur). A weak reaction of oilseed rape to fertilisation with sulphur which coincided with a good sulphur supply was observed by Evans et al. [6], Haneklaus et al. [9] and for oilseed rape cultivated in Poland by Wielebski and Muśnicki [21]. Scarce research into the effect of sulphur on spring oilseed rape showed that as for soil of low sulphur content (14.3 mg S-SO_4·kg^{-1} of soil) fertilisation with a dose of 12 kg S·ha^{-1} increased the seed yield from 8.14 to 14.7% as compared with the yield from non-fertilised plants [12]. The results, as well as the present results, state that spring oilseed rape shows a lower increase in seed yield due to sulphur fertilisation applied than traditional and double-low winter oilseed rape cultivars.

Fertilisation of oilseed rape with sulphur, besides an increase in seed yield, can deteriorate the seed quality by increasing the content of glucosinolates [2,8,24]. The present experiment shown differences in the level of these metabolites depending on the application method and sulphur form. There was observed a significant increase in the sum of glucosinolates in plant seeds fertilised with elemental sulphur into soil and a lower content of the sum of glucosinolates and the sum of alkenyl and indolyl glucosinolates in seeds of plants foliar-fertilised with this sulphur form, yet no significant effect of the sulphur dose. The reaction of oilseed rape cultivars to foliar fertilisation with elemental sulphur was researched by Booth et al. [4], showing that fertilising the 'double-low' cultivars with a dose of 16 kg $S\cdot ha^{-1}$ increased only the sum of indolyl glucosinolates in seeds. Higher elemental sulphur doses applied as foliar fertilisation (to 64 $kg\cdot ha^{-1}$) inconsiderably increased the sum of alkenyl glucosinolates and decreased the content of indolyl glucosinolates. All that can point to no relationship between the content of glucosinolates in seeds and foliar fertilisation with elemental sulphur dose as in that form only 2% of sulphur is uptaken directly by leaves. The remaining amount together with precipitation reaches soil where it is transformed by microorganisms and gradually included in the plant metabolism [4].

The foliar fertilisation of oilseed rape with ionic sulphur and soil fertilisation with elemental sulphur in the present research increased the content of glucosinolates in seeds proportionally to the dose applied. The highest total content of glucosinolates (12.8 $\mu M\cdot g^{-1}$ of dry matter), including the sum of alkenyl glucosinolates (7.48 $\mu M\cdot g^{-1}$ of dry matter), was recorded in seeds of plants when soil was fertilised with elemental sulphur at the dose of 60 $kg\cdot ha^{-1}$. A varied level of glucosinolates in seeds affects the pathogen-plant relationship. As shown by Trzciński [17] and Drozdowska et al. [5], the seeds collected from objects where soil was fertilised with elemental sulphur at 60 $kg\cdot ha^{-1}$ were least infected by pathogenic fungi.

Sulphur fertilisation significantly increased the total content of alkenyl glucosinolates in seeds, however, its effect on the indolyl glucosinolates was not clear. An increased content of alkenyl glucosinolates in seeds of oilseed rape fertilised with sulphur was mostly due to an increase in the content of progoitrin. Mean results of the three-year experiment show that sulphur enhanced the accumulation of only this form of alkenyl glucosinolate. Similarly Zhao et al. [26] showed that fertilisation with sulphur mainly increased the content of alkenyl glucosinolates. Apparently, an increased dose of sulphur applied stimulates the synthesis of the sulphur-containing aminoacid methionine which is a precursor of all alkenyl glucosinolates present in oilseed rape [25]. With a low supply with sulphur, a decrease in the level of these metabolites can be due to their limited biosynthesis or a decreased content of available methionine [3].

The present research showed that 'Star' spring oilseed rape cultivated on soil of a low content of sulphur reacted with the highest increase in yield to foliar fertilisation with elemental sulphur at the dose of 60 $kg\cdot ha^{-1}$. The content of glucosinolates in seeds collected from that object (10.8 $\mu M\cdot g^{-1}$ of dry matter) was comparable with the control (11.9 $\mu M\cdot g^{-1}$ of dry matter) and with the results reported by COBORU (10.0 $\mu M\cdot g^{-1}$ of dry matter) [18].

CONCLUSIONS

1. Oilseed rape seed yield and its quality were significantly modified by the sulphur application method and dose as well as the interaction of all the factors studied in the present experiment.
2. The highest mean seed yield was obtained from plants when elemental sulphur was applied in foliar fertilisation at the dose of 60 kg $S\cdot ha^{-1}$. The seeds collected from these objects showed the level of glucosinolates comparable to that of the sulphur non-fertilised object.
3. The soil fertilisation with elemental sulphur at the dose of 60 $kg\cdot ha^{-1}$ applied increased the content of the total content of glucosinolates, mainly due to the increase in alkenyl glucosinolates, out of which the content of progoitrin increased most considerably, deteriorating the technological and nutritional seed value.

REFERENCES

1. Appelqvist L.Å, 1968. Lipids in *Cruciferae.* Fatty acid composition of *Brassica napus* L. seed as affected by nitrogen, phosphorus, potassium and sulphur nutrition of the plants. Physiol. Plant. 21, 455-465.
2. Bilsborrow P.E., Evans E.J., Milford G.F.J., Fieldsend J.K., 1995. The effects of S and N on the yield and quality of oilseed rape in the U.K. 9^{th} Inter. Rapeseed Congress, Cambridge, 280-283.
3. Bones A.M., Visvalingam S., Thangstad O.P., 1994. Sulphate can induce differential expression of thioglucoside glucohydrolases (myrosinases). Planta 193, 558-566.
4. Booth E.J., Batchelor S.E., Walker K.C., 1995. The effect of foliar applied sulphur on individual glucosinolates in oilseed rape seed. Z. Pflanzenernähr. Bodenk. 158, 87-88.
5. Drozdowska L., Szulc P., Łukanowski A., Sadowski C., 2002. Glucosinolate content and pathogenic fungi occurrence in seeds of spring oilseed rape fertilised with sulphur. Plant Breeding and Seed Sci. (in press).

6. Evans E.J., Bilsborrow P.E., Zhao F.J., Syers J.K., 1991. The sulphur nutrition of winter oilseed rape in Northern Britain. 8th Inter. Rapeseed Congress, Saskatoon, 542-546.
7. Fenwick G.R., Heaney R.K., Mullin W.J., 1983. Glucosinolates and their breakdown products in food and food plants, CRC Crit. Rev. Food Sci. Nutr. 18 (2), 123-201.
8. Fismes J., Vong P.C., Guckert A., Frossard E., 2000. Influence of sulphur on apparent N-use efficiency, yield and quality of oilseed rape (*Brassica napus* L.) grown on a calcareous soil. Europ. J. Agron. 12, 127-141.
9. Haneklaus S., Paulsen H.M., Gupta A.K., Bloem E., Schnug E., 1999. Influence of sulphur fertilization on yield and quality of oilseed rape and mustard. 10th Inter. Rapeseed Congress, Canberra, Australia, CD ROM.
10. Horodyski A., Krzywińska F., 1979. Wpływ nawożenia siarką na plon i jakość nasion rzepaku ozimego [Effect of sulphur fertilization on the winter oilseed rape seed yield and its quality]. Zesz. Probl. Post. Nauk Roln. 229, 101-109 [in Polish].
11. Kotecki A., Malarz W., Kozak M., Aniołowski K., 2001. Wpływ nawożenia azotem na skład chemiczny nasion pięciu odmian rzepaku jarego [Effect of nitrogen fertilization on the seed chemical composition of five spring oilseed rape cultivars]. Rośliny Oleiste XXII, 81-89 [in Polish].
12. Krauze A., Bowszys T., 2001. Wpływ terminu nawożenia siarką rzepaku jarego 'Star' na plon nasion oraz zawartość siarki i tłuszczu [Effect of the 'Star' spring oilseed rape sulphur fertilization date on the seed yield and contents of sulphur and fat]. Rośliny Oleiste XXII, 285-290 [in Polish].
13. Krzymański J., 1995. Biosynteza i fizjologiczne funkcje glukozynolanów w roślinie [Biosynthesis and physiological functions of glucosinolates in plant]. Rośliny Oleiste XVI, 113-126 [in Polish].
14. Muśnicki C., Toboła P., 1998. Reakcja rzepaku jarego podwójnie ulepszonego na termin siewu [Reaction of double-improved spring oilseed rape to the sowing date]. Rośliny Oleiste XIX, 135-140 [in Polish].
15. Schnug E., Haneklaus S., 1995. Sulphur deficiency in oilseed rape flowers – symptomatology, biochemistry and ecological impact. 9th Inter. Rapeseed Congress, Cambridge, 296-298.
16. Szulc P., Piotrowski R., Drozdowska L., Skinder Z., 2000. Wpływ nawożenia siarką na plon i akumulację związków siarki w nasionach rzepaku jarego odmiany Star [Effect of sulphur fertilization on the yield and accumulation of sulphur compounds in 'Star' spring oilseed rape seeds]. Folia Univ. Agric. Stetin., Agricultura 81, 157-162 [in Polish].
17. Trzciński J., 2001. Wpływ wybranych zabiegów agrotechnicznych na zdrowotność rzepaku jarego [Effect of selected agronomic practices on the health status of spring oilseed rape]. Praca doktorska, ATR Bydgoszcz, maszynopis [in Polish].
18. Wałkowski T., 2000. Rzepak jary [Spring oilseed rape]. Wyd. IHAR Poznań [in Polish].
19. Wałkowski T., Krzymański J., Bartkowiak-Broda I., 2002. Rzepak ozimy [Winter oilseed rape]. Poznań 2000-2001. Wyd. IHAR Radzików [in Polish].
20. Wielebski F., 1997. Wpływ wzrastających dawek siarki na skład glukozynolanów zawartych w nasionach dwóch odmian rzepaku ozimego [Effect of increasing doses of sulphur on the composition of glucosinolates in seeds of two winter oilseed rape cultivars]. Rośliny Oleiste XVIII, 179-186 [in Polish].
21. Wielebski F., Muśnicki C., 1998. Wpływ wzrastających dawek siarki i sposobu jej aplikacji na plon i zawartość glukozynolanów w nasionach dwóch odmian rzepaku ozimego w warunkach doświadczeń polowych [Effect of increasing doses of sulphur and its application method on the yield and content of glucosinolates in seeds of two winter oilseed rape cultivars in field experiments]. Rocz. AR Poznań CCCIII, 149-167 [in Polish].
22. Wielebski F., Wójtowicz M., 1993. Wpływ wzrastających dawek siarki na plon nasion i zawartość glukozynolanów w nasionach dwóch odmian rzepaku podwójnie ulepszonego [Effect of increasing doses of sulphur on the seed yield and the content of glucosinolates in seeds of two double-improved oilseed rape cultivars]. Post. Nauk Roln. 6, 63-67 [in Polish].
23. Wielebski F., Wójtowicz M., 2000. Problemy nawożenia rzepaku siarką w Polsce i na świecie [Problems of fertilizing oilseed rape with sulphur in Poland and in the world]. Rośliny Oleiste XXI, 449-463 [in Polish].
24. Withers P.J.A., Evans E.J., Bilsborrow P.E., Milford G.F.J., McGrath S.P., Zhao F., Walker K.C., 1995. Improving the prediction of sulphur deficiency in winter oilseed rape in the UK. 9th Inter. Rapeseed Congress, Cambridge, 277-279.
25. Zhao F., Evans E.J., Bilsborrow P.E., Syers J.K., 1994. Influence of nitrogen and sulphur on the glucosinolate profile of rapeseed (*Brassica napus* L.). J. Sci. Food Agric. 64, 295-304.
26. Zhao F., Evans E.J., Bilsborrow P.E., 1995. Varietal differences in sulphur uptake and utilization in relation to glucosinolate accumulation in oilseed rape. 9th Inter. Rapeseed Congress, Cambridge, 271-273.

Piotr Mirosław Szulc, Lucyna Drozdowska
Department of Plant Physiology
University of Technology and Agriculture
Bernardyńska 6, 85-029 Bydgoszcz, Poland
Piotr Kachlicki
Institute of Plant Genetics
Polish Academy of Sciences
Strzeszyńska 34, 60-479 Poznań, Poland
e-mail:
szulc@atr.bydgoszcz.pl (Piotr Szulc)
drozd@atr.bydgoszcz.pl (Lucyna Drozdowska)
pkac@igr.poznan.pl (Piotr Kachlicki)

Responses to this article, comments are invited and should be submitted within three months of the publication of the article. If accepted for publication, they will be published in the chapter headed 'Discussions' in each series and hyperlinked to the article.