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EFFECT OF SULFUR ON THE QUALITY OF WINTER RAPE SEEDS

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Abstract

The paper presents the results of three-year (2000-2003) experiments to determine the effect of the date of sulfur application (fall + spring or spring only) and the fertilizer rate (0, 30, 60, 90 kg·ha^{-1}) on the usability of winter rape seeds.

The pre-sowing and the spring rates of sulfur as well as the rate applied entirely in the spring did not lead to significant variations in crude fat concentrations, but a clear tendency towards an increase in the total protein content was observed in rape seeds. A one-way increase was reported to the level of 60 kg S·ha^{-1}.

An increase in the sulfur rate (regardless of the date of application) to 90 kg·ha^{-1} raised the concentrations of alkene glucosinolates, mainly gluconapin and progoitrin, and – to a lesser degree – of indole glucosinolates, mainly 4-hydroxyglucobrassicin, in rape seed cv. Lisek.

The splitting of the total sulfur rate into two rates (fall + spring) caused a higher increase in the concentrations of gluconapin, progoitrin and 4-hydroxyglucobrassicin than a single rate application in the spring.

Key words: winter rape, sulfur fertilization, crude fat, total protein, gluosinolates.

SIARKA A JAKOŚĆ NASION RZEPAKU OZIMEGO

Abstrakt

W pracy przedstawiono 3-letnie (2000-2003) wyniki badań nad wpływem terminu aplikacji siarki (jesień + wiosna lub tylko wiosna) i poziomu dawki (0, 30, 60, 90 kg·ha^{-1}) na wartość użytkową nasion rzepaku ozimego.

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Siarka aplikowana przedsiewnie i wiosną oraz wyłącznie wiosną nie różnicowała istotnie zawartości tłuszczu surowego, powodując jednak wyraźną tendencję do wzrostu zawartości białka ogółem w nasionach. Przyrost ten był jednokierunkowy do dawki 60 kg S·ha^{-1}.

Zastosowanie siarki (niezależnie od terminu zabiegu) aż do dawki 90 kg na 1 ha powodowało w nasionach odmiany Lisek przyrost zawartości głównych glukozynolanów alkenowych – glukonapiny i progoitryny, a w mniejszym stopniu indolowych, tj. 4-hydroksyglukobrassicyny.

Warto podkreślić, iż podział dawki siarki na cześć jesienną i wiosenną w większym stopniu wpływał na zwiększenie zawartości progoitryny, glukonapiny oraz 4-hydroksyglukobrassicyny niż jednokrotna wiosenna aplikacja tego składnika.

Słowa kluczowe: rzepak ozimy, nawożenie siarką, tłuszcz surowy, białko ogółem, glukozynolany.

INTRODUCTION

Sulfur fertilization increases the total fat content of rape seeds (Booth et al. 1991ab, Rotkiewicz et al. 1996, Jankowski 2007). Sulfur increases the concentration of essential unsaturated fatty acids in oil and enhances the usability of rapeseed oil (Krauze, Bowszys 2000).

Sulfur deficiency usually results in a lower quantity and quality of protein by reducing the levels of exogenous amino acids, which are an important diet component (Schnug, Haneklaus 1995, Zhao et al. 1997, Wielebski, Wójtowicz 2000, Jankowski 2007). Contrary results were reported in a study conducted by Rotkiewicz et al. (1996), where the application of 80 kg S·ha^{-1} lowered (by 0.2-0.8%) the total protein content in winter rape seeds. Sulfur fertilization may increase the level of glucosinolates in defatted seed residues (Withers et al. 1995, Bilsborrow et al. 1995, Budzyński, Ojczyk 1995, Rotkiewicz 1996, Wielebski, Muśnicki 1998ab, Fimes et al. 2000, Jankowski 2007), but it is less likely to induce such an increase in rapeseed oil (Niewiadomski 1984). Due to sulfur fertilization, the total concentrations of glucosinolates in low-erucic acid double-zero („00”) rape varieties may increase by 20-30% (Rotkiewicz et al. 1996, Wielebski, Wójtowicz 2003, Jankowski 2007) and up to 80% (Wielebski, Wójtowicz 2003). Sulfur fertilization stimulates the biosynthesis of alkene glucosinolates (Zhao et al. 1995, Rotkiewicz et al. 1996, Wielebski 1997), mainly progoitrin and gluconapin (Wielebski 1997) as well as glucobrassiconapin (Rotkiewicz et al. 1996). This is because sulfur stimulates mainly the synthesis of methionine, the precursor of alkene glucosinolates (Zhao et al. 1994). At low sulfur fertilization rates, the concentration levels of those metabolites may decrease due to a heightened activity of myrosinase or a drop in the levels of available methionine (Bones et al. 1994).

The objective of this study was to determine the effect of a fertilizer rate (0, 30, 60 and 90 kg·ha^{-1}) and the date of sulfur application on the content of total protein and crude fat, the concentration levels and the structure of glucosinolates in winter rape seeds.

METHODS

The study presents the results of three-year strict field and laboratory experiments conducted at the Research and Experimental Station of the University of Warmia and Mazury, located in Bałcyny (N = 53°35′49″ E = 19°51′20.3″). Field experiments were performed in a randomized split-plot design, with four replications:

factor I – sulfur rate (kg·ha^{-1}): (Ia) control without S fertilization; (Ib) 30; (Ic) 60; (Id) 90;

factor II – date of sulfur application:
(IIa) fall (BBCH – 00) and spring (BBCH – 30),
(IIb) spring only (BBCH – 30).

IIa	BBCH - 00	0	15	30	30
	BBCH - 30	0	15	30	60
IIb	BBCH - 30	0	30	60	90

The experiments were established on typical lessive silty soil developed from light loam, of quality class IIIa representing a very good rye complex (2000 and 2001) or a good wheat complex (2002) – Table 1. The content of available phosphorus was evaluated as average to very high, potassium – as average, magnesium and sulfate sulfur – as low. Topsoil was acidic

Table 1

Description of soil conditions

Specification	Growing season		
	2000/2001	2001/2002	2002/2003
Soil type	typical lessive soil		
Soil species	light loam		
Soil pH (1 M KCl)	5.3	5.9	5.9
Soil quality class	IIIa		
Soil suitability complex	very good rye complex		good wheat complex
Content of available nutrients (mg·kg^{-1} soil)			
– P	62.0	114.8	89.9
– K	107.9	103.8	207.5
– Mg	41	83	57
– S-SO_4	18.1	15.2	6.7

or slightly acidic (pH 5.3-5.9 in 1 M KCl). The rape forecrop were grain crops – spring barley (2000 and 2002) and winter wheat (2001). The experimental plot covered an area of 18 m^2.

A pre-sowing rate of 35 kg P·ha^{-1} in the form of triple superphosphate and 100 kg K·ha^{-1} in the form of highly concentrated potash salt were applied. The autumn pre-sowing N rate was 20 kg·ha^{-1}. The spring nitrogen rate (160 kg·ha^{-1}) was applied in two parts – 100 kg·ha^{-1} at stage BBCH 30 and 60 kg·ha^{-1} at stage BBCH 51. Nitrogen was applied in the form of ammonium nitrate (-S) or ammonium sulfate and ammonium nitrate (+S) as fertilizer balancing the nitrogen and sulfur rate.

Dressed winter rape seeds cv. Lisek were sown between the 10th and 20th of August (2001, 2002) and in the last week of August (2000) in the quantity of 120 germinating seeds per m^2 of plot area, at spacing of 20 cm.

Dicotyledonous weeds were controlled with a post-sowing application of 999 g·ha^{-1} metazachlorine and 249 g·ha^{-1} of quinmerac, and monocotyledonous weeds – with 52 g·ha^{-1} of haloxyphop-R. Insecticide was applied after the level of insect infestation had exceeded the standards given by the Institute of Plant Protection in Poznań. During the spring growing season in the first and second year of the experiment, a single treatment for the control of the rape blossom beetle was applied (300 g·ha^{-1} chloropiryphos + + 30 g·ha^{-1} cypermetrine). During the third experimental cycle in the spring growing season, three treatments for the control of rape pests were applied (1 x cabbage curculio, 2 x rape blossom beetle) with the use of 7.5 g·ha^{-1} deltametrine, 7.5 g·ha^{-1} cypermetrine and 10 g·ha^{-1} alpha-cypermetrine. Fungicides were not applied due to low disease incidence. Rape was harvested using a two-stage method at the beginning or end of the second week of July.

Growth stages were determined with the use of the BBCH scale – Biologische Bundesanstalt, Bundessortenamt und Chemical Industry (MUŚNICKI, MRÓWCZYŃSKI 2006).

Seed samples (treatment average) were subjected to a chemical analysis to determine the levels of crude fat (by electromagnetic resonance) and nitrogen (by Kjeldahl method, expressed as crude protein, according to the Polish Standard PN-75/A-04018/Az3:2002). The concentrations of glucosinolates were estimated by high-performance liquid chromatography (HPLC), as described by HEANEY et al. (1986).

Chemical analyses of soil and seeds were performed at the laboratories of the Chemical and Agricultural Station in Olsztyn, Institute of Animal Nutrition and Fodder Science, Department of Plant Raw Materials Processing and Chemistry, University of Warmia and Mazury in Olsztyn and the Center for Excellence of the Institute of Animal Reproduction and Food Research at the Polish Academy of Sciences in Olsztyn. The results of chemical analyses were verified by an analysis of variance in accordance with the established experimental method. The mean values of the investigated parameters in all treatments were compared with the use of Duncan's test. LSD values were stated for 5% error. Analyses of variance were performed with the use of STATISTICA® applications, and the remaining calculations were carried out in EXCEL® spreadsheet.

RESULTS

Agrometeorological conditions

Total atmospheric precipitation from August to October 2000, 2001 and 2002 exceeded the multi-year precipitation average by 2 to 54%. The above is emphasized due to possible changes in sulfur translocation in soil. In the fall of 2000, intense precipitation was reported only in the pre-sowing period and at the beginning of germination (in August). In 2001, precipitation in excess of the average monthly levels was noted in August and September, and in 2002 – in all months of the fall growing season (Table 2).

Table 2

Moisture conditions during the autumn growing season (August – October)

Growing season	Precipitation (mm)				Percentage of long-term precipitation total			
	VIII	IX	X	Σ	VIII	IX	X	Σ
2000/2001	141	47	5	47	181	82	9	102
2001/2002	82	99	35	99	105	174	65	114
2002/2003	87	61	144	61	112	107	267	154

The winter dormancy period lasted from 153 to 172 days in subsequent years of field experiments (2000-2003). Although according to multi-year statistics, January is the coldest month in Ostróda Lakeland, the coldest month during the study was December (2001/2002, 2002/2003) and January in only one of the experimental years (2000/2001). The drop in mean daily air temperature (below 5°C) in the winter was always accompanied by snow cover (with a depth of 5-10 cm), which minimized the effect of low temperature on plant wintering.

The spring and summer growing seasons in 2001-2003 were marked by moderate precipitation, which covered the water demand of winter oilseed rape. The highest precipitation was reported in the spring and summer season of 2000/2001 and 2002/2003. The monthly distribution of precipitation was highly diversified in the studied years. Insufficient precipitation to cover the water requirements of plants was reported annually only in April (Table 3).

Table 3

Moisture conditions during the spring growing season (April – August)

Growing season	Precipitation (mm)					Percentage of long-term precipitation total				
	IV	V	VI	VII (first 20. days)	Σ	IV	V	VI	VII	Σ
Water demand (acc. to Klatt)										
–	45	70	75	30	220	129	124	110	37	91
Actual atmospheric precipitation (mm)										
2000/2001	44	31	49	110	234	126	54	72	167	107
2001/2002	10	90	73	37	210	29	158	107	53	98
2002/2003	24	79	61	83	247	69	139	90	146	117

CONTENT AND BIOLOGICAL YIELD OF CRUDE FAT

Sulfur fertilization had a non-significant effect on the crude fat content of rape seeds. In the first and third experimental cycle, sulfur fertilization had an adverse effect on crude fat concentration. Those years were characterized by relatively high precipitation in the period of rape ripening. The date of sulfur application (fall + spring, spring only) did not lead to significant variations in crude fat concentration levels in rape (Table 4).

Table 4

Crude fat content (% seed d.m.)

Growing season	Time of S application	S rate ($kg \cdot ha^{-1}$)				Mean
		0	30	60	90	
2000/2001	BBCH 00 and BBCH 30	43.1	43.0	41.5	43.0	42.7
	BBCH 30	43.1	41.9	41.7	42.6	42.3
2001/2002	BBCH 00 and BBCH 30	47.1	45.5	48.3	47.2	47.0
	BBCH 30	47.1	47.3	48.2	47.3	47.5
2002/2003	BBCH 00 and BBCH 30	46.0	46.0	44.9	45.9	45.7
	BBCH 30	46.0	45.5	46.6	44.8	45.7
2000/2001	–	43.1	42.5	41.6	42.8	42.5
2001/2002	–	47.1	46.4	48.3	47.3	47.3
2002/2003	–	46.0	45.8	45.9	45.4	45.8
–	BBCH 00 and BBCH 30	45.4	44.8	44.9	45.4	45.1
–	BBCH 30	45.4	44.9	45.7	44.9	45.2
Mean		45.4	44.9	45.3	45.2	–
LSD n.s.						

The biological yield of crude fat was determined by seed weight and the fat content of seeds. As a result of sulfur fertilization, biological yield increased by nearly 11% in the first year and by 4% in the two subsequent years of the experiment. The date of sulfur application had no influence on crude fat yield per hectare (Table 5).

Table 5

Biological yield of crude fat (Mg·ha^{-1})

Growing season	Time of S application	S rate (kg·ha^{-1})				Mean
		0	30	60	90	
2000/2001	BBCH 00 and BBCH 30	2.13	2.30	2.35	2.48	2.32
	BBCH 30	2.13	2.37	2.34	2.28	2.28
2001/2002	BBCH 00 and BBCH 30	2.02	2.08	2.12	2.09	2.08
	BBCH 30	2.02	2.09	2.13	2.08	2.08
2002/2003	BBCH 00 and BBCH 30	2.06	2.14	2.08	2.21	2.12
	BBCH 30	2.06	2.13	2.25	2.09	2.13
2000/2001	–	2.13	2.34	2.35	2.38	2.30
2001/2002	–	2.02	2.09	2.13	2.09	2.08
2002/2003	–	2.06	2.14	2.17	2.15	2.13
–	BBCH 00 and BBCH 30	2.07	2.17	2.18	2.26	2.17
–	BBCH 30	2.07	2.20	2.24	2.15	2.17
Mean		2.07	2.19	2.21	2.21	–
LSD: S rate – 0.070						

The data in Figure 1 indicate that crude fat yield per hectare increased up to the fertilization rate of 60 kg S·ha^{-1} on average in the studied years (Figure 1). Nevertheless, a statistically significant increment, in comparison with the control treatment, was reported only to the level of 30 kg S·ha^{-1} (Table 4).

CONTENT AND BIOLOGICAL YIELD OF PROTEIN

In comparison with the control, sulfur fertilization increased the total protein content of rape seeds in the first and third experimental cycle (Table 6). This increase varied over years and was observed only to the level of 60 kg S·ha^{-1}. The date of sulfur application had only a minor effect (within statistical error limits) on total protein content (Table 6).

Regardless of the rate and date of application, sulfur fertilization increased the biological yield of protein by 190 kg·ha^{-1} in the first year and only by 10-60 kg·ha^{-1} in the remaining two years of the experiment (Table 7).

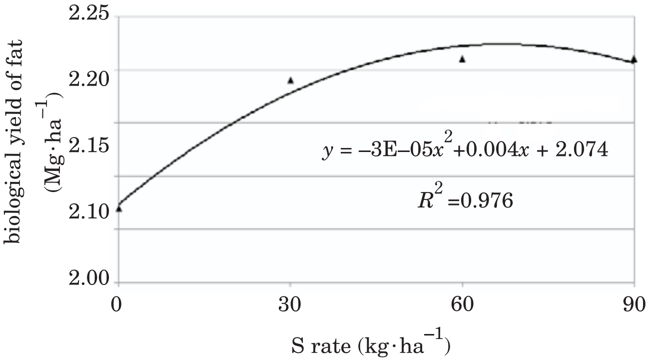

Fig. 1. Correlation between sulfur rate and the biological yield of crude fat, 2000-2003

Table 6

Total protein content (% seed d.m.)

Growing season	Time of S application	S rate (kg·ha^{-1})				Mean
		0	30	60	90	
2000/2001	BBCH 00 and BBCH 30	21.0	21.4	22.4	22.3	21.8
	BBCH 30	21.0	22.0	22.7	21.9	21.9
2001/2002	BBCH 00 and BBCH 30	21.1	20.4	21.1	21.2	21.0
	BBCH 30	21.1	21.0	21.1	21.1	21.1
2002/2003	BBCH 00 and BBCH 30	19.4	19.7	20.0	19.8	19.7
	BBCH 30	19.4	19.8	19.6	19.7	19.6
2000/2001	–	21.0	21.7	22.6	22.1	21.9
2001/2002	–	21.1	20.7	21.1	21.2	21.0
2002/2003	–	19.4	19.8	19.8	19.8	19.7
–	BBCH 00 and BBCH 30	20.5	20.5	21.2	21.1	20.8
–	BBCH 30	20.5	20.9	21.1	20.9	20.9
Mean		20.5	20.7	21.2	21.0	–
LSD n.s.						

Sulfur fertilization at the rate of 30 kg·ha^{-1} led to a significant increase in protein yield per hectare (by around 9% in comparison with control) in the experimental period. A successive increase in the sulfur rate (to 60 kg·ha^{-1}) resulted in an additional 3% growth in protein yield which remained within statistical error limits (Table 7). The data in Figure 2 show that the continued increase in sulfur rate (to 90 kg·ha^{-1}) did not affect the levels of this qualitative trait.

Table 7

Biological yield of total protein (Mg·ha)

Growing season	Time of S application	S rate (kg·ha^{-1})				Mean
		0	30	60	90	
2000/2001	BBCH 00 and BBCH 30	1.04	1.14	1.27	1.29	1.19
	BBCH 30	1.04	1.24	1.27	1.17	1.18
2001/2002	BBCH 00 and BBCH 30	0.90	0.93	0.92	0.94	0.92
	BBCH 30	0.90	0.93	0.93	0.93	0.92
2002/2003	BBCH 00 and BBCH 30	0.87	0.92	0.93	0.95	0.92
	BBCH 30	0.87	0.93	0.94	0.92	0.92
2000/2001	–	1.04	1.19	1.27	1.23	1.18
2001/2002	–	0.90	0.93	0.93	0.94	0.93
2002/2003	–	0.87	0.93	0.94	0.94	0.92
–	BBCH 00 and BBCH 30	0.94	1.00	1.04	1.06	1.01
–	BBCH 30	0.94	1.03	1.05	1.01	1.01
Mean		0.94	1.02	1.05	1.04	–
LSD: S rate – 0.065						

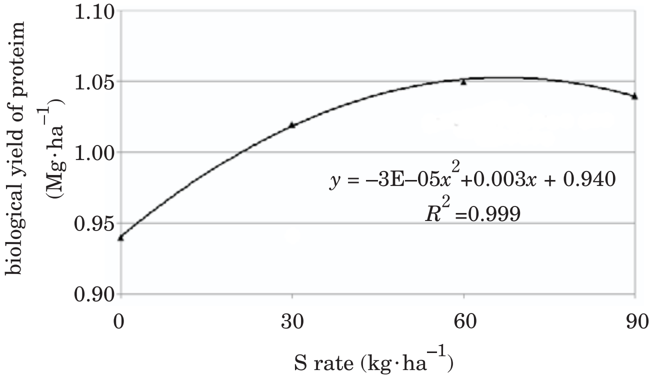

Fig. 2. Correlation between sulphur rate and the biological yield of total protein, 2000-2003

CONTENT AND COMPOSITION OF GLUCOSINOLATES

The total content of glucosinolates in rape seeds cv. Lisek was low. Sulfur fertilization at the rate of 30 – 60 – 90 kg·ha^{-1} gradually increased the accumulation of glucosinolates in defatted residues of winter rape seeds (Figure 3).

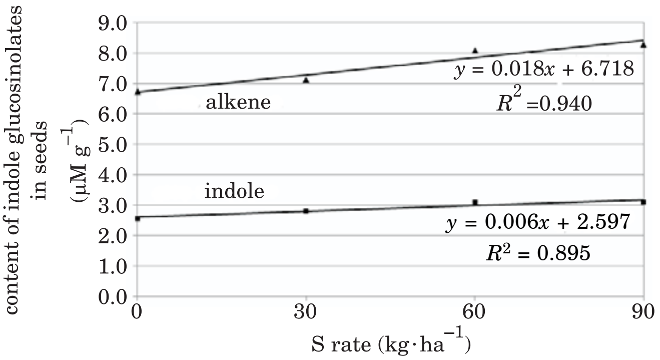

Fig. 3. Effect of sulfur rate on glucosinolates structure in winter rape seeds, 2000-2003

Sulfur stimulated the biosynthesis of alkene and indole glucosinolates to a similar extent (producing a similar ratio). The splitting of the total sulfur rate into two rates (fall + spring) had a more stimulatory effect on the accumulation of alkene and indole glucosinolates in defatted seed residues than a single rate application in the spring (Table 8).

Table 8

Effect of the rate and application time of sulfur on the total glucosinolate content of winter rape seeds (μM g^{-1} seeds), 2000-2003

Glucosinolates	S rate (kg·ha^{-1})						
	control	30		60		90	
		a+s	s	a+s	s	a+s	s
Alkene	6.74	7.43	6.82	8.30	7.90	8.45	8.15
Indole	2.55	2.88	2.73	3.12	3.07	3.10	3.09
$\frac{\text{Alkene}}{\text{Indole}}$	2.65	2.58	2.50	2.66	2.57	2.73	2.64

a+s – autumn + spring (BBCH 00 and BBCH 30)
s – spring (BBCH 30)

An increase in the content of alkene glucosinolates in winter rape seeds fertilized with sulfur was reported mostly in respect of gluconapin and progoitrin. In the group of compounds where tryptophan is the precursor, a particularly high increase was observed in 4-hydroxuglucobrassicin. The concentration of glucobrassicin increased to a lower degree, whereas the level of neoglucobrassicin remained unchanged (Table 9).

The date of sulfur application at particular rates did not affect the content of alkene and indole glucosinolates. A detailed analysis of the results

Table 9

Effect of the rate and application time of sulfur on the content of particular glucosinolates in winter rape seeds (µM g^{-1} seeds), 2000-2003

Glucosinolates		S rate (kg·ha^{-1})						
		control	30		60		90	
			a+s	s	a+s	s	a+s	s
Alkene	progoitrin	3.97	4.29	3.88	4.76	4.56	4.82	4.69
	sinigrin	0.06	0.06	0.06	0.07	0.07	0.07	0.07
	gluconapoliferin	0.13	0.15	0.15	0.19	0.18	0.19	0.18
	glucoalisin	0.20	0.21	0.24	0.27	0.22	0.29	0.25
	gluconapin	1.58	1.78	1.63	1.96	1.91	2.02	1.97
	glucobrassicanapin	0.80	0.94	0.86	1.05	0.96	1.06	0.99
Indole	4-hydroxyglucobrassicin	2.41	2.72	2.58	2.96	2.91	2.97	2.94
	glucobrassicin	0.09	0.11	0.10	0.11	0.11	0.08	0.10
	neoglucobrassicin	0.05	0.05	0.05	0.05	0.05	0.05	0.05

a+s – fall + spring (BBCH 00 and BBCH 30)
s – spring (BBCH 30)

obtained indicates that sulfur application in the spring resulted in lower concentrations of progoitrin, gluconapin and 4-hydorxyglucobrassicin in comparison with split dressing (fall + spring) (Table 9).

DISCUSSION

Deficiency of plant-available sulfur reduces the rate of protein biosynthesis (Zhao et al. 1997). A positive effect of sulfur on protein concentrations in winter rape seeds of open-pollinated (traditional and double-zero varieties) and hybrid varieties was reported by Wielebski and Muśnicki (1998a,b) and Jankowski (2007). The results of the present experiments also indicate that sulfur fertilization at a rate of up to 60 kg ha^{-1} had a beneficial effect (which varied between the studied years) on the total protein content of winter rape seeds.

The effect of sulfur on the oil content of winter rape seeds is ambiguous. Krauze and Bowszys (2000) reported that sulfur fertilization, regardless of the application method, decreased the crude fat content of rape seeds. In the experiments performed by Budzyński and Ojczyk (1995), Rotkiewicz et al. (1996), Zukalová et al. (2001), Wielebski and Wójtowicz (2004), sulfur fertilization had no significant effect on the accumulation of crude fat in winter rape seeds. In a study conducted by Jankowski (2007), the increase in sulfur rate (up to 90 kg·ha^{-1}) decreased the fat content of seeds by 0.6% d.m. In the current study, sulfur fertilization was not shown to have a significant effect on the fat content of rape seeds. It should be noted, however, that in years marked by high precipitation, sulfur fertilization decreased the crude fat content in seeds in the period of rape ripening (first and third experimental cycle).

Sulfur fertilization primarily deteriorates the quality of rape seeds due to elevated levels of glucosinolates (Withers et al. 1995, Bilsborrow et al. 1995, Budzyński, Ojczyk 1995, Rotkiewicz et al. 1996, Wielebski, Muśnicki 1998ab, Fismes et al. 2000, Zukalová et al. 2001, Wielebski, Wójtowicz 2003, 2004, Jankowski 2007). Sulfur fertilization may increase the total concentrations of glucosinolates in double-zero („00”) rape varieties by as much as 30% (Rotkiewicz et al. 1996). The adverse effects of sulfur fertilization on the usability of rape seeds were also noted in this study. Regardless of the application time, an increase in the sulfur rate to the level of 90 kg·ha^{-1} raised the concentrations of alkene and indole glucosinolates in rape seeds.

Sulfur fertilization stimulates primarily the biosynthesis of alkene glucosinolates (Zhao et al. 1995, Booth et al. 1995, Rotkiewicz et al. 1996, Wielebski 1997, Wielebski, Wójtowicz 2003, 2004), mainly progoitrin, gluconapin (Wielebski 1997) and glucobrassicanapin (Rotkiewicz et al. 1996). In the present study, sulfur fertilization had a stimulatory effect mainly on gluconapin and progoitrin (alkene glucosinolates), 4-hydroxyglucobrassicin and glucobrassicin (indole glucosinolates). Sulfur application in the spring resulted in lower concentrations of progoitrin, gluconapin and 4-hydroxyglucobrassicin in comparison with the application in the fall and spring.

CONCLUSIONS

1. The pre-sowing and the spring rates of sulfur as well as the rate applied entirely in the spring did not lead to significant variations in crude fat concentrations, but a clear tendency towards an increase in the total protein content was observed in rape seeds. This increase was reported to the level of 60 kg S·ha^{-1}.

2. An increase in the sulfur rate (regardless of the date of application) to 90 kg·ha^{-1} raised the concentrations of alkene glucosinolates, mainly gluconapin and progoitrin, and – to a lesser degree – of indole glucosinolates, mainly 4-hydroxyglucobrassicin, in rape seed cv. Lisek.

3. The splitting of the total sulfur rate into two rates (fall + spring) caused a higher increase in the concentrations of gluconapin, progoitrin and 4-hydroxyglucobrassicin than a single rate application in the spring.

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