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QUANTITY AND QUALITY OF WHITE MUSTARD SEED YIELD DEPENDING ON SULPHUR FERTILIZATION

Magdalena Serafin-Andrzejewska✉, Marcin Kozak, Andrzej Kotecki

Institute of Agroecology and Plant Production, Wrocław University of Environmental and Life Sciences
24 A Grunwaldzki Square, 50-363 Wrocław, **Poland**

ABSTRACT

Background. In white mustard cultivation for seeds, in addition to basic NPK fertilization, fertilization with sulphur is of great importance. Sulphur affects the proper use of nitrogen in Brassicaceae and that stimulates their development and yield. The aim of the present research was to evaluate the effect of various sulphur doses on yield quantity and the chemical composition of seeds of three traditional white mustard cultivars.
Material and methods. A field experiment was carried out in the years 2007–2009 in the weather conditions of south-west Poland (Lower Silesian Voivodeship). The experiment was set up as a split-plot design. The primary factor was white mustard cultivars: Metex, Nakielska, and Radena. The secondary factor was diversified sulphur doses: 0, 10, 20, and 30 kg·ha^{-1}.
Results. The highest white mustard seed yield was obtained from the cultivar Nakielska when fertilized with 10 kg·ha^{-1} S or 20 kg·ha^{-1} S. The cultivar Nakielska was also characterized by the highest of all the studied cultivars crude fat productivity per 1 ha at the applied fertilization rates of 10 kg·ha^{-1} S and 20 kg·ha^{-1} S, and the highest total protein productivity after the application of 20 kg·ha^{-1} S. Total protein and crude fat contents in seeds were significantly modified by the weather conditions in the study years.
Conclusion. The study demonstrated that in white mustard cultivation for seeds the optimal sulphur dose amounts to circa 10-20 kg·ha^{-1}, and that it is necessary for high yield. Also, the high yield-forming potential of the seed cultivar Nakielska was confirmed.

Key words: chemical composition, fertilization, sulphur, yield, white mustard

INTRODUCTION

Due to the possibility of multidirectional use and cultivation of white mustard this plant at present appears to be one of the most suitable spring oilseed crops for the diversification of oil raw material production and the expansion of species diversity in crop rotation, as well as for reducing agricultural environmental degradation (Sawicka and Kotiuk, 2007). In Europe there is a new trend of using white mustard cultivars with lower erucic acid and glucosinolate contents as an alternative for rapeseed on lighter soils that are exposed to periodic drought (Piętka *et al.*, 2014). The species may be grown for seeds, which are used as a spice and natural preservative, as well as for medicament components used in phytotherapy and, due to its ability to improve soil structure and its fertilizing and phytosanitary effects, for green fertilizer (Toboła, 2010). Recent studies also indicate the possibility of using white mustard oil as a biodiesel production material (Ciubota-Rosie *et al.*, 2013; Sultana *et al.*, 2014; Ambrosewicz-Walacik *et al.*, 2015).

✉ magdalena.serafin-andrzejewska@upwr.edu.pl, marcin.kozak@upwr.edu.pl, andrzej.kotecki@upwr.edu.pl

In white mustard cultivation, as in the case of other species from the Brassicaceae family, in addition to basic elements such as nitrogen, phosphorus, and potassium, the proper supply of sulphur to plants is also of great significance for optimal development, especially for yield (Abdallah *et al*., 2010; Grant *et al*., 2012; Jankowski *et al*., 2015). The yield-forming effect of sulphur in Brassicaceae is related to the association of this element with nitrogen metabolism. Application of a sulphur fertilizer affects the efficiency of nitrogen use. Both of these elements determine seed yield and lead to changes in the chemical composition of seeds. Sulphur affects protein quality, being a component of sulphur amino acids. It activates enzymes and takes part in enzymatic reactions, thus affecting photosynthetic activity and increasing the contents of protein, carbohydrates and fat in plants (Scherer, 2001; Maathuis, 2009; Gaj and Klikocka, 2011). Sulphur also determines the fatty acids profile (Fismes *et al*., 2000). A study by Poisson *et al*. (2019) demonstrated that sulphur and nitrogen affect plant metabolism synergistically when they are applied in optimal doses, whereas the application of too high doses of one of the above elements affects antagonistically the use of the other.

Therefore, it is important to adjust sulphur doses so that this element interacts with nitrogen and stimulates high seed yield and quality, achieved in a sustainable way, especially in the context of decreasing the amount of fertilizers applied. The aim of this study was an evaluation of white mustard seed yield and quality at various doses of sulphur fertilization.

MATERIAL AND METHODS

The experiment was carried out in the years 2007–2009 on fields belonging to the University of Environmental and Life Sciences in Wrocław (51°10′ N; 17°06′ E). The experiment was set up in a split-plot design. The primary factor was white mustard cultivars: Metex, Nakielska, and Radena. The secondary factor was diversified sulphur doses: 10 kg·ha^{-1}, 20 kg·ha^{-1}, and 30 kg·ha^{-1}, and the control plot of 0 kg·ha^{-1} (no fertilization). Four repetitions were carried out in the experiment, and the area of a single plot was 15 m^2 (10 m × 1.5 m).

The field experiment was set up every year on Cutanic Stagnic Luvisol (IUSS Working Group WRB, 2014), in Poland classified as gleba płowa opadowo-glejowa (Kabała *et al*., 2019), developed from glacial sandy loam on loam that was evaluated as class IIIb (3rd class of 9) and of 2nd complex of agricultural usefulness (2nd complex of 14). Every year before the experiments were established soil samples were taken for chemical analyses in which nutrient contents and soil pH were established. Phosphorus and potassium assimilable for plants were established using the Egner-Riehm method, with the application of calcium lactate buffered to pH = 3.6 as extraction solution. Magnesium was extracted from the soil with a solution of 0.01 M $CaCl_2$ and established with the use of spectrophotometry. Total sulphur content was established after previous soil sintering with magnesium nitrate using the nephelometric method. Establishment of soil pH was carried out with the potentiometric method in 1M KCl (Table 1).

Table 1. Chemical properties of the soil in the years 2007–2009; available macroelements (mg·kg^{-1})

Year	S_{total}	P	K	Mg	pH 1 M KCl
2007	12.1	82.2	150.0	58.8	5.9
2008	10.8	97.4	158.9	111.1	5.7
2009	7.5	94.6	135.3	79.7	5.9

Every year before the establishment of the experiment, mineral fertilization was applied (kg·ha^{-1}): 10 S, 20 S, and 30 S (ammonium sulphate 24% S + 21% N), and the remaining N dose was supplemented to 100 kg (ammonium nitrate 34%), 26.5 P (triple superphosphate 46%) and 100 K (sylvinite 60%). The fertilizers were applied directly before sowing and mechanically mixed with the soil to a depth of circa 5 cm. In every study year the forecrop for white mustard was winter wheat. Mustard was sown on the following dates: April 6th, 2007, April 15th, 2008, and April 14th, 2009. Sowing dates were delayed in relation to the optimum due to too moist soils that existed earlier.

Per 1 m^2, 100 seeds of full cultivation value were sown. In all the study years, in order to limit infestation, 333 $g \cdot ha^{-1}$ metazachlor and 83 $g \cdot ha^{-1}$ chinomerac were applied after sowing. For white mustard protection the following were applied: neonicotinoid insecticide acetampiride at the dose of 24 $g \cdot ha^{-1}$ and two pyrethroids: 7.5 $g \cdot ha^{-1}$ lambda-cyhalothrin and 2.5 $g \cdot ha^{-1}$ cypermethrin. Every year before harvest, desiccation was carried out with the use of 340 $g \cdot ha^{-1}$ diquat. Plant harvest was carried out on the following dates: August 14th 2007, August 11th, 2008, and August 10th, 2009 at the full seed ripeness stage. Weather course in the study years is presented in Table 2. After harvest and seed cleaning the seed yield was established ($Mg \cdot ha^{-1}$) at a humidity of 13%.

Qualitative evaluation of white mustard seeds was based on the results of chemical analyses, which was carried out in agreement with the methodology of food product analysis. Dry matter was established with the gravimetric method at a temperature of 105±2°C for 5 h, total protein was established with a modified Kjeldahl method (total nitrogen was established in the seeds and then converted into total protein using the coefficient of 6.25). Crude fat content was established with the defatted residue method in a Soxhlet apparatus. Crude fibre content was established with the Henneberg-Stohmann method, and crude ash content through plant material burning in an electric stove at a temperature of 600°C. Contents of P and Mg were determined with the colorimetric method, and Ca, K, and Na contents with the flame photometry method (Krełowska-Kułas, 1993). Nitrogen-free extracts were calculated by subtracting from 1000 the total contents of basic components (total protein, crude fat, crude ash, and crude fibre). On the basis of the results of chemical analyses and the obtained seed yield, total protein and crude fat productivity was calculated in seed dry matter from an area of 1 ha. The results from the three years were statistically analysed using the program Statistica 10 PL with the Student's t-test at the lowest significant difference of $P < 0.05$.

Table 2. Weather conditions in the study years

Month	2007	2008	2009	1976-2005
	Temperature, °C			
March	6.5	4.6	4.6	3.7
April	10.9	8.9	12.0	8.3
May	16.2	14.3	14.2	14.1
June	19.2	18.8	15.8	16.9
July	19.3	19.8	19.6	18.7
August	18.9	18.9	19.4	17.9
Average March–August	15.2	14.2	14.3	13.3
	Precipitation, mm			
March	48.8	33.0	48.3	31.7
April	2.7	87.1	30.9	30.5
May	50.3	37.3	67.6	51.3
June	69.2	36.5	141.7	59.5
July	92.4	65.6	134.2	78.9
August	52.8	94.0	53.5	61.7
Sum March–August	316.2	353.5	476.2	313.6

RESULTS AND DISCUSSION

Total protein content in the white mustard seeds varied from 316 g·kg^{-1} d.m. to 331 g·kg^{-1} d.m., crude fat between 251 g·kg^{-1} d.m. and 264 g·kg^{-1} d.m., crude fibre between 85 g·kg^{-1} d.m. and 100 g·kg^{-1} d.m., crude ash between 51 g·kg^{-1} d.m. and 54 g·kg^{-1} d.m., and nitrogen-free extracts between 265 g·kg^{-1} d.m. and 285 g·kg^{-1} d.m. No interaction between the studied factors was found in relation to the chemical composition of white mustard seeds (Table 3).

Table 3. Chemical composition of white mustard seeds, g·kg^{-1} d.m.

Cultivar	S dose kg·ha^{-1}	Total protein	Crude fat	Crude fibre	Crude ash	NFE
Metex	0	325	253	95	54	273
	10	331	255	96	53	265
	20	322	251	100	51	276
	30	331	256	96	52	265
Nakielska	0	319	264	95	54	268
	10	316	263	93	52	276
	20	319	259	85	52	285
	30	321	257	87	51	284
Radena	0	323	255	88	53	281
	10	316	257	91	52	284
	20	324	263	91	54	268
	30	322	258	92	52	276
LSD ($P < 0.05$)		ns	ns	ns	ns	ns
Average for the study factors						
Metex		327	254	97	52	270
Nakielska		319	261	90	52	278
Radena		321	258	90	53	278
LSD ($P < 0.05$)		ns	4	ns	ns	ns
0		322	257	92	54	275
10		321	258	93	52	276
20		322	258	92	52	276
30		325	257	92	52	274
LSD ($P < 0.05$)		ns	ns	ns	1	ns
2007		355	222	92	57	274
2008		313	275	94	48	270
2009		300	275	92	53	280
LSD ($P < 0.05$)		10	4	ns	1	ns

NFE – nitrogen-free extracts; ns – non-significant difference

On average, for the studied experimental factors, white mustard genotype significantly affected only the crude fat content in seeds, which was the highest for the cultivar Nakielska and reached 261 g·kg^{-1} d.m. (Table 3). Chemical composition of white mustard seeds did not vary significantly under the effect of the applied sulphur fertilization; only a decrease in crude ash content was noted after the application of fertilization in relation to the control plot. Different results were obtained by Malhi *et al*. (2007), who demonstrated that plants from the Brassicaceae family responded with an increase in fat content and a significant, though small, increase in protein content in seeds under the effect of the applied sulphur fertilization (S doses that they studied amounted to: 0, 10, 20 30, and 40 kg·ha^{-1}). In the present study an effect of the weather course on the chemical composition of white mustard seeds was found in relation to the contents of total protein, crude fat, and crude ash (Table 3). Years 2009 and 2008 were particularly humid during silique and seed formation, which was conducive to higher crude fat concentration in seeds, whereas the more dry 2007 resulted in an increase in total protein content. Weather course in the study years conditioned crude ash concentration in the white mustard seeds in an ambiguous way. The results presented here are consistent with the research by Paszkiewicz-Jasińska (2005), in which a strong effect of humidity and thermal conditions on the formation of the chemical composition of white mustard seeds was found.

Contents of the particular elements in white mustard seeds were not significantly diversified under the effect of the interaction of the examined factors or of the cultivar factor (Table 4). Diversified sulphur doses significantly affected P, K, and Na contents in white mustard seeds, while at the same time they did not modify Ca and Mg concentration (Table 4). Increasing sulphur doses from 0 kg to 30 kg caused a decrease in P and K contents, as well as an increase in Na content in the seeds. In the seeds from the 2007 and 2009 harvests, significantly higher contents were found of: P (6.5 g·kg^{-1} d.m.), Mg (4.4 g·kg^{-1} d.m. and 4.2 g·kg^{-1} d.m.), and Na (0.4 g·kg^{-1} d.m.) in comparison with the seeds from the 2008 harvest (in g·kg^{-1} d.m.: P 5.6, Mg 3.4, Na 0.2). In the seeds collected in the years 2007 and 2008 a significantly higher Ca content was found (3.6 g·kg^{-1} d.m. and 4.0 g·kg^{-1} d.m., respectively) than in the seeds from the 2009 harvest (3.4 g·kg^{-1} d.m.). No effect of the variable course of the weather conditions on K concentration in white mustard seeds was found in the study years.

Table 4. Contents of elements in white mustard seeds, g·kg^{-1} d.m.

Cultivar	S dose kg·ha^{-1}	P	K	Ca	Mg	Na
Metex	0	6.5	6.2	4.2	3.7	0.3
	10	5.9	5.9	3.6	3.7	0.3
	20	6.1	5.9	3.8	3.9	0.3
	30	6.2	5.9	3.6	4.0	0.4
Nakielska	0	6.5	6.1	4.0	4.4	0.3
	10	6.6	6.2	3.9	3.8	0.4
	20	6.2	5.6	3.1	4.0	0.4
	30	6.0	5.5	2.1	4.3	0.4

Table 4. continued

Radena	0	6.5	5.9	3.6	4.0	0.3
	10	6.4	5.7	3.0	3.9	0.3
	20	6.0	5.7	2.4	4.1	0.4
	30	5.9	5.8	2.7	4.2	0.4
LSD ($P < 0.05$)		ns	ns	ns	ns	ns
Average for the study factors						
Metex		6.2	6.0	3.8	3.8	0.3
Nakielska		6.3	5.9	3.3	4.1	0.4
Radena		6.2	5.8	2.9	4.0	0.3
LSD ($P < 0.05$)		ns	ns	ns	ns	ns
0		6.5	6.0	3.9	4.0	0.2
10		6.3	5.9	3.5	3.8	0.3
20		6.1	5.8	3.1	4.0	0.4
30		6.0	5.7	2.8	4.2	0.4
LSD ($P < 0.05$)		0.3	0.2	ns	ns	0.1
2007		6.5	5.9	3.6	4.4	0.4
2008		5.6	5.9	4.0	3.4	0.2
2009		6.5	5.8	2.4	4.2	0.4
LSD ($P < 0.05$)		0.3	ns	0.8	0.4	0.1

White mustard seed yield was significantly determined by the interaction of the cultivar factor, the sulphur dose applied before sowing and the weather course in all the study years (Table 5). The highest seed yield (1.27 $Mg \cdot ha^{-1}$ and 1.28 $Mg \cdot ha^{-1}$) was characteristic for the cultivar Nakielska fertilized with 10 $kg \cdot ha^{-1}$ S and 20 $kg \cdot ha^{-1}$ S, respectively. Total protein and crude fat productivity obtained from the seeds from 1 ha usually depends on the yield of the studied cultivar and the concentration of each given component in the seeds. Therefore, the highest total protein productivity (352 $kg \cdot ha^{-1}$) was found in the growth of the cultivar Nakielska fertilized with 20 kg of sulphur per 1 ha. Similarly, this cultivar was characterized by the highest crude fat productivity per 1 ha at the applied fertilization doses of 10 kg $S \cdot ha^{-1}$ and 20 kg $S \cdot ha^{-1}$. The present study confirms previous findings that state that for plants from the Brassicaceae family optimal sulphur dose should be about 10-30 $kg \cdot ha^{-1}$. Similar results have been presented by Wielebski and Muśnicki (1998), Grzebisz and Gaj (2000), Orlovius (2000), Grzebisz *et al*. (2005), Malhi *et al*. (2007), and Jankowski *et al*. (2020). A different conclusion is in the study by Barczak *et al*. (2011) who found that in the weather condition of Northern Poland the application of 40 $kg \cdot ha^{-1}$ S affects most favourably the yield structure elements, and so eventually also white mustard seed yield. In the present research the white mustard was cultivated in all the study years on plots very poor in sulphur. Therefore, its yield-forming response to the applied fertilization with this element was the same as the response of winter rapeseed. All the studied experimental factors significantly affected the yield and productivity of total protein and crude fat from white mustard seeds (Table 5).

Table 5. Seed yield and the productivity of total protein and crude fat from white mustard seeds

Cultivar	S dose kg·ha^{-1}	Seed yield Mg·ha^{-1}	Total protein productivity kg·ha^{-1}	Crude fat productivity kg·ha^{-1}
Metex	0	1.00	280	220
	10	1.08	309	241
	20	1.18	328	258
	30	1.12	322	251
Nakielska	0	1.11	307	259
	10	1.27	343	296
	20	1.28	352	293
	30	1.20	332	272
Radena	0	0.99	277	220
	10	1.12	304	253
	20	1.14	320	263
	30	1.18	327	265
LSD ($P < 0.05$)		0.03	9	8
Average for the study factors				
Metex		1.09	310	242
Nakielska		1.22	333	280
Radena		1.11	307	250
LSD ($P < 0.05$)		0.02	5	4
0		1.03	288	233
10		1.15	319	263
20		1.20	334	271
30		1.16	327	263
LSD ($P < 0.05$)		0.02	5	5
2007		0.99	306	192
2008		1.12	303	267
2009		1.31	340	313
LSD ($P < 0.05$)		0.02	5	4

The cultivar Nakielska was found to be the most favourable for obtaining high seed yield. In comparison to the other evaluated genotypes this cultivar was characterized by the highest total protein and crude fat productivity from the seeds from 1 ha. The presently obtained results confirm the usefulness of the cultivar Nakielska for cultivation for seeds in Polish conditions. The cultivar Nakielska is characterized by high yield-forming potential and its seeds are distinguished by a high fat concentration. The optimal level of sulphur fertilization in order to obtain the highest, average from all cultivars, white mustard seed yield (1.20 Mg·ha^{-1}), total protein productivity (334 kg·ha^{-1}), and crude fat productivity

(271 kg·ha^{-1}) was found to be 20 kg·ha^{-1}. The subsequent dose increase to 30 kg per 1 ha caused a significant decrease in both seed yield and total protein and crude fat productivity from the seeds (Table 5). Similar results in this respect were obtained by Wielebski (2006) in relation to the effect of sulphur fertilization on the seed yield of different winter rapeseed cultivar types. A somewhat different response of winter rapeseed to increasing sulphur doses within the range of 0 kg·ha^{-1} to 90 kg·ha^{-1} was noted by Malarz *et al*. (2010), whose study showed that with increases in sulphur doses the seed yield and total protein and crude fat productivity from 1 ha gradually increased. In the present study the weather course during the field experiment significantly modified the obtained seed yield and nutrient productivity. In the years of study the highest white mustard seed yield (1.31 Mg·ha^{-1}), total protein productivity (340 kg·ha^{-1}), and crude fat productivity (313 kg·ha^{-1}) were obtained from the seeds from the 2009 harvest, which was characterized by very high precipitation sums in June and July with temperatures in July exceeding the many-years' average (1975–2005). Budzyński and Jankowski (2001) strictly related the effectiveness of white mustard fertilization with sulphur to the weather conditions in the study years. However, they also found that including sulphur in typical mineral fertilization of plants from the Brassicaceae family is necessary for their proper development and effective yielding process.

CONCLUSIONS

1. From all the studied cultivars Nakielska was characterized by the highest seed yields when fertilized with 10 kg·ha^{-1} S or 20 kg·ha^{-1} S. The cultivar Nakielska was also characterized by the highest crude fat productivity from 1 ha with the application of both the 10 kg·ha^{-1} S and 20 kg·ha^{-1} S dose of fertilization and the highest total protein productivity after the application of 20 kg·ha^{-1} S.
2. An effect of the weather conditions on the chemical composition of white mustard seeds was found. Modifications applied to the contents of total protein, crude fat, and crude ash.
3. Chemical composition of white mustard seeds did not vary significantly under the effect of the applied sulphur fertilization. Also, there was no interaction of the studied factors in relation to the changes in the chemical composition of white mustard seeds.
4. Increasing sulphur doses caused a decrease in P and K contents and at the same time an increase in Na content in the seeds. Contents of the particular elements in white mustard seeds were not significantly modified by the interaction of the studied factors or by the cultivar factor.
5. For white mustard cultivated for seeds, as in the case of other spring plants from the Brassicaceae family, the optimal sulphur dose was found to be 20 kg·ha^{-1}.

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WIELKOŚĆ I JAKOŚĆ PLONU NASION GORCZYCY BIAŁEJ W ZALEŻNOŚCI OD NAWOŻENIA SIARKĄ

Streszczenie

W uprawie gorczycy białej na nasiona obok podstawowego nawożenia NPK istotne jest nawożenie siarką. Siarka wpływa na prawidłowe wykorzystanie azotu w roślinach krzyżowych, stymuluje rozwój i plonowanie. Zbadano wpływ różnych dawek siarki na wielkość plonu i skład chemiczny nasion trzech tradycyjnych odmian gorczycy białej. Doświadczenie polowe przeprowadzono w latach 2007–2009 w warunkach agroklimatycznych Polski południowo-zachodniej (woj. dolnośląskie). Doświadczenie założono metodą split-plot. Czynnikiem pierwszego rzędu były odmiany gorczycy białej: Metex, Nakielska i Radena, czynnikiem drugiego rzędu były różne dawki siarki: 0, 10, 20, 30 $kg \cdot ha^{-1}$. Najwyższy plon nasion uzyskano z odmiany Nakielska nawożonej odpowiednio 10 lub 20 $kg \cdot ha^{-1}$ S. Spośród wszystkich badanych odmian charakteryzowała się ona także najwyższą wydajnością tłuszczu surowego z 1 ha przy zastosowaniu nawożenia dawką 10 oraz 20 $kg \cdot ha^{-1}$ S oraz najwyższą wydajnością białka ogółem po zastosowaniu 20 $kg \cdot ha^{-1}$ S. Stwierdzono, że zawartość białka ogółem i tłuszczu surowego w nasionach była istotnie modyfikowana przez przebieg pogody w latach badań. Wykazano, że w uprawie gorczycy białej na nasiona optymalna dawka siarki wynosi około 20 $kg \cdot ha^{-1}$ i jest niezbędna dla wysokiego plonowania. Potwierdzono także duży potencjał plonotwórczy nasiennej odmiany Nakielska.

Słowa kluczowe: gorczyca biała, nawożenie, plon, siarka, skład chemiczny