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MODELLING BIOMETRIC TRAITS AND STRAW YIELD OF WHITE MUSTARD (*Sinapis alba* L.) GROWN FOR SEEDS BY THE SOWING DATE AND METEOROLOGICAL FACTORS

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ABSTRACT

Background. White mustard is a plant with good yield stability, low variability in the length of the growing season and a considerable resistance to climatic factors. However, delaying the sowing date of this plant results in significant changes in the plant habit and yield.

Material and methods. A three-year field experiment with white mustard cultivated for seeds was carried out as a one-factor, in the randomized block design in four replications. White mustard was sown on 13 dates at intervals of seven days, from the beginning of April to the turn of June and July, and harvested after reaching seed maturity.

Results. Delaying the sowing date of the white mustard cultivar 'Nakielska' grown for seeds from an early spring date resulted in changes to the plant habit. There was a reduction of plant height and an increased tendency to form low-productivity higher-order lateral branches, a reduction in both the number of siliques on the main stem and the number of seeds in siliques from the main stem and lateral stems. The shorter was the day after the summer solstice when the white mustard came into the next development phase, the smaller the number of yield structural components the plants were characterized by. The crops of white mustard from successive dates differed in their canopy structure because the field emergence capacity of seeds was deteriorating, which resulted in a lower plant density after emergence, an increase in plant loss during the growing season and a decrease in the straw yield.

Conclusion. Delaying white mustard sowing resulted in limiting the height of plants and increasing the tendency to form higher-order lateral branches. It was shown that the straw yield, the number of siliques on the main stem and the number of seeds in siliques from both the main stem and lateral stems were reduced as a result of delayed sowing.

Key words: biometric traits of plants, sowing date, straw yield, white mustard

INTRODUCTION

The advantages of white mustard are good yield stability, low variability of the duration of the growing season and resistance to climatic factors (Muśnicki *et al.* 1997; Toboła and Muśnicki, 1999; Jankowski and Budzyński, 2003; Paszkiewicz-Jasińska, 2005). Despite its considerable tolerance to habitat factors, white mustard cultivation has the best results in early sowing conditions when the soil is well moisturized (Jankowski and Budzyński, 1999; Toboła and Muśnicki, 1999; Zielonka and Szczebiot, 2001). Sowing delay leads to a poorer formation of individual plant yield components. This applies in particular to the

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number of siliques per plant and the number of seeds per silique (Zekaite, 1999; Dinda *et al.*, 2015). A sowing delay of 2-3 weeks in relation to the earliest date is usually conducive to obtaining a higher plant density after emergence (Jankowski and Budzyński, 1999; Zekaite, 1999; Angadi *et al.*, 2004). However, there are no results regarding the effect of a longer sowing delay on this trait. According to Jankowski and Budzyński (2003), plant density and the number of siliques per plant have a dominant influence on the yield of this species. Zielonka and Szczebiot (2001) report that white mustard plants sown at later dates form fewer flower buds and have fewer siliques compared to plants sown earlier. Dinda *et al.* (2015) showed that a delay in sowing white mustard by 15 days results in a significant reduction in the number of siliques per plant and the number of seeds per silique. Delaying sowing by another 15 days caused further significant reduction in these parameters and led to shortening the stems of plants and reducing the number of lateral branches. Little is known about the formation of biometric traits of white mustard with longer sowing delays, which are sometimes encountered with late plant re-sowing.

The aim of this study was to determine the effect of early and late sowing dates of the white mustard cultivar 'Nakielska' and changing agrometeorological conditions on the biometric traits of plants and straw yield.

The research hypothesis assumed that one of the important factors affecting the biometric traits of white mustard is the sowing date. It was assumed that white mustard, as a long day plant with a strong photoperiod reaction, would react to delaying the sowing date with variability in the biometric traits, which would include a reduction in the number of yield structure components.

MATERIAL AND METHODS

The experiment was established as a one-factor, in the randomized block design in four replications. The sowing date was the variable factor in the experiment. A seven-day interval was used between the thirteen successive sowing dates. The dates of sowing white mustard grown for seeds with assigned symbols of sowing dates are listed in Table 1. The area of each harvested plots was 13 m^2.

The field experiment was established at the Research Station in Mochełek (53°13' N; 17°52' E), on podzolic soil with a reaction similar to neutral (pH in 1 M KCl 6.0). The mean daily air temperature during the study period was 13.8°C, and the total rainfall 339,9 mm (Table 2). The mean monthly average air temperature from April to July increased and in the following months of the growing season systematically decreased. In April, at the beginning of the studied growing seasons, the 3-year average amount of precipitation was 43 mm, in June and July it was more than 50 mm, while May and August were months with above average rainfall for this region, that is more than 70 mm.

Table 1. Sowing dates of white mustard grown for seeds

Sowing date symbol	1	2	3	4	5	6	7	8	9	10	11	12	13
							2005						
Sowing date	06.04	13.04	20.04	27.04	04.05	11.05	18.05	25.05	01.06	08.06	15.06	22.06	29.06
							2006						
Sowing date	12.04	19.04	26.04	02.05	10.05	17.05	24.05	31.05	07.06	14.06	21.06	28.06	05.07
							2007						
Sowing date	04.04	11.04	18.04	25.04	02.05	09.05	16.05	23.05	30.05	06.06	13.06	20.06	27.06

Table 2. Meteorological conditions in the study area in 2005–2007 and in the long-term period 1949–2006

Years	Month							Mean temperature April-October
	April	May	June	July	August	September	October	
Mean daily air temperature, °C								
2005–2007	7.7	12.8	16.6	19.9	16.9	14.2	8.4	13.8
1949–2006	7.3	12.8	16.3	17.9	17.5	13.1	8.3	13.3
Average monthly precipitation, mm								Total precipitation April-October
2005–2007	43.1	71.5	52.6	54.2	71.5	32.0	15.0	339.9
1949–2006	27.8	41.6	54.5	71.7	50.7	41.7	32.2	320.2

The crop previous to white mustard was spring barley. After its harvest traditional ploughing tillage was carried out. Fertilization with phosphorus (50 kg·ha^{-1} P) and potassium (70 kg·ha^{-1} K) was applied pre-sowing, during spring soil cultivation. Fertilization with nitrogen (103.5 kg·ha^{-1} N) was applied in three equal parts: pre-sowing, at the beginning of stem elongation (BBCH 30–31) and at the flowering stage (BBCH 61–62). The sowing rate was adjusted to reach a density of 120 plants per m^2.

During the growing season of the plants, observations on the course of plant development were carried out and the white mustard plant density was calculated (number of plants per 1 m^2) after the completion of emergence. The field emergence capacity (%) was determined from the ratio of the number of seeds sown per 1 m^2 and the number of plants that emerged. In addition, on the basis of the plant density after emergence and before harvest, the loss of plants (%) during the growing season was calculated.

Directly before the harvest of the white mustard the following measurements were made: on a sample of 20 plants from each replication, their heights (cm) were determined and converted to an average height for 1 plant, the number of branches of the first and the higher orders, the number of siliques on the main stem and lateral stems (number per 1 plant), the mean number of seeds per 1 silique from the main stem and the lateral stems. After the harvest the straw weight was determined and the straw yield was calculated by weight of dry matter.

The results of the biometric measurements of plants were analysed by variance in accordance with the method of establishing the experiment in the field. The synthesis of variance analysis was carried out in a mixed model, taking the effects of years and blocks as random factors. The analysis of variance was carried out using the STATISTICA 10.0 software (StatSoft, Tulsa, Oklahoma, USA). The working hypotheses in the study of differences between treatment-related means were verified using the Tukey's multiple comparison test. In order to understand the relationships between particular traits the values of the Pearson simple correlation coefficients as well as selected traits relative to the sowing date and their mutual relationships were calculated.

RESULTS

In the case of white mustard sown from the beginning of April to mid-May (dates 1–6), the plant density after emergence was on average 110 per 1 m^2 and on average was higher by 15 plants per 1 m^2 than at later dates (7–13), and statistical confirmation of these differences was obtained (Table 3).

The field emergence capacity was significantly higher when white mustard was sown in April or early May (dates 1–5), with the highest capacity being after mid-April to the first days of May (dates 3–4), than it was when sowing occurred in June or later (Table 3). The difference between the extreme values amounted to 27.0 percentage points. The loss of white mustard plants in the field during the growing season was related to the sowing date. It was lowest for plants sown at the beginning of April (38.9%) at date 1, and significantly higher for the plants sown in the first half of June (77.0%) at date 10 (Table 3).

White mustard sown on the first days of June (date 9) had significantly more first-order branches than that from sowings after mid-April (date 3) or around mid-May (date 6) (Table 4). The number of higher-order branches of the plants was significantly diversified by the sowing date. For the first six dates (from the beginning of April to mid-May) the plants produced significantly fewer lateral branches than from those sown from the end of May to mid-June (dates 8–10). For the first seven sowing dates from the beginning of April to the beginning of the second half of May the plants formed fewer higher-order branches than first-order branches. At later sowing dates, white mustard showed a tendency to branch more abundantly (especially from the end of May to mid-June (dates 8–10) and the number of higher--order branches was higher than that of the first-order branches. The number of siliques on the main stem of white mustard was significantly differentiated by the sowing date (Table 4). The plants sown in April or at the beginning of May (dates 2–5) had the largest number of siliques (32–36) on the main stem, while the plants sown in the second half of May and in June had significantly fewer of them – 11–24 pieces (dates 7–12). Differentiation in the number of siliques on lateral stems was statistically proven (Table 4). The variability of this trait ranged from 43 pieces at date 12 to 95 pieces at date 8.

Table 3. Plant density of white mustard after emergence of plants and field emergence capacity and losses in density – mean of the years of the study

Sowing date symbol[1]	Density after emergence, plants·m^{-2}	Field emergence capacity	Losses in plant density, %
1	104.6	48.2 abc[2]	38.9 b
2	100.0	46.7 abc	57.3 ab
3	118.1	55.2 a	55.3 ab
4	114.6	53.6 a	66.3 ab
5	121.7	50.1 ab	67.8 ab
6	103.7	42.7 bcd	63.1 ab
7	97.9	40.3 bcd	54.5 ab
8	95.8	39.4 cd	64.7 ab
9	95.3	35.0 de	70.6 ab
10	106.1	39.0 cde	77.0 a
11	94.5	34.7 de	65.8 ab
12	87.9	32.3 de	58.5 ab
13	84.8	28.2 e	74.4 ab
Mean	101.9	42.0	62.6

[1] description in Table 1
[2] values of observations within the column marked with the same lowercase letter do not differ significantly at $P < 0.05$

Table 4. Number of first-order and higher-order branches of the seed shoot and the number of siliques on these branches (pieces per 1 white mustard plant) – mean of the years of the study

Sowing date symbol[1]	Number of 1st order branches	Number of higher-order branches	Number of siliques on the main stem	Number of siliques on lateral stems
1	5.00 abc[2]	2.71 c	31.7 abc	71.7 abcd
2	4.75 abc	2.61 c	36.1 a	72.5 abc
3	3.75 c	1.58 c	32.5 ab	54.6 cd
4	4.75 abc	2.24 c	35.8 a	57.3 bcd
5	5.25 ab	1.75 c	32.6 a	47.1 d
6	4.50 bc	3.25 c	25.3 bcd	43.4 d
7	5.50 ab	5.06 bc	17.8 de	45.6 d
8	5.25 ab	13.30 a	11.4 e	95.5 a
9	6.00 a	9.20 b	23.1 d	85.4 ab
10	5.50 ab	9.16 b	24.2 cd	78.0 abc
11	5.25 ab	5.94 bc	22.7 d	54.1 cd
12	5.00 abc	3.76 bc	23.9 cd	43.0 d
13	4.75 abc	4.95 bc	25.3 bcd	68.2 abcd
Mean	5.02	5.04	26.3	62.3

[1] description in Table 1
[2] values of observations within the column marked with the same lowercase letter do not differ significantly at $P < 0.05$

The number of seeds in the silique from the main stem and from the lateral stems was significantly dependent on the sowing date of white mustard (Table 5). The highest number of seeds were found, both in silique from the main stem and from the lateral stems, in plants sown from 09 to 17 May (date 6), but in terms of the extent of this trait a homogeneous group was formed by plants sown from the beginning of the growing season to the beginning of June (dates 1–9), while those sown at dates 11–13 produced significantly fewer seeds. The number of seeds per siliqua on the main stem was on average 8.2% higher than in siliques from lateral stems.

The tallest white mustard was that was sown in April, and plants sown from the 11th of May to the beginning of July were significantly shorter (Table 6). On average, for the entire study period, the largest straw yield was produced by plants sown in the first half of April, and it was significantly lower after sowing from around mid-May (dates 6–7).

With a delay in sowing, compared to the beginning of the growing season, there were changes in the biometric traits of plants (Tables 4–6). These relationships are explained by the established correlations between the sowing date of white mustard in cultivation for seeds (measured by the number of days from 1st April to the day of sowing) and the biometric traits of plants (Table 7). The tendency of the main stem to produce a variable number of first-order branches depending on the sowing date was not significant, while more higher-order branches were formed by plants sown at later dates. White mustard responded to delaying the sowing date by limiting the number of siliques on the main stem and the number of seeds in siliques coming from the main stem as well as from the lateral stems.

A significant and negative correlation was found between the sowing date and the plant density after full emergence and between the sowing date and the field emergence capacity, while there was a positive correlation between the sowing date and plant loss during growth (Table 8). Delaying the sowing date of white mustard grown for seeds caused a decrease in the field emergence capacity, which resulted in a smaller number of plants after emergence. Delaying the sowing date contributed to the increase of plant losses during the growing season and also to the decline in straw yield.

Table 5. Number of seeds per silique on the main stem and lateral stems (pieces per 1 silique) of white mustard grown for seeds – mean of the years of the study

Sowing date symbol[1]	Number of seeds per silique on the main stem	Number of seeds per silique on lateral stems
1	4.89 ab[2)]	4.73 ab
2	4.86 ab	4.80 ab
3	4.95 ab	4.56 ab
4	5.29 a	4.80 ab
5	5.21 ab	4.75 ab
6	5.48 a	5.07 a
7	5.20 ab	4.50 ab
8	4.65 abc	4.48 abc
9	4.89 ab	4.46 abc
10	4.27 bcd	3.97 bc
11	3.83 cde	3.48 cd
12	3.53 de	3.33 d
13	3.23 e	3.17 d
Mean	4.64	4.32

[1] description in Table 1
[2] values of observations within the column marked with the same lowercase letter do not differ significantly at $P < 0.05$

Table 6. The height of white mustard plants before harvesting seeds and straw dry matter yield

Sowing date symbol[1]	Plant height, cm	Straw dry matter yield, $Mg \cdot ha^{-1}$
1	137.8 a[2]	7.73 a
2	137.4 a	7.52 ab
3	126.5 ab	6.37 abc
4	126.7 a	6.32 abc
5	113.2 bc	6.06 abc
6	102.5 cd	4.73 c
7	95.0 d	4.69 c
8	90.0 d	5.39 abc
9	92.6 d	5.06 bc
10	87.1 d	5.33 abc
11	69.7 e	4.18 c
12	77.3 e	3.89 c
13	96.5 d	5.80 abc
Mean	104.0	5.62

[1] sowing dates suitable for the symbol in Table 1
[2] values of observations within the column marked with the same lowercase letter do not differ significantly at $P < 0.05$

Table 7. Simple correlation coefficients between the sowing date of white mustard grown for seeds (measured by the number of days from 01.04. to the time of sowing) and biometric traits of plants

Biometric traits	r
Number of first-order branches of the main stem	0.294
Number of higher-order branches	0.395*
Number of siliques on the main stem	-0.488*
Number of siliques on lateral stems	0.057
Number of seeds per silique on the main stem	-0.524*
Number of seeds per silique on lateral stems	-0.546*

* values of correlation coefficients statistically significant at $P < 0.05$

A significant correlation was confirmed between the straw yield of white mustard and the height of plants while there was a lack of a linear relationship between the straw yield and the number of branches (Table 9).

Table 8. Simple correlation coefficients (r) between the sowing date of white mustard grown for seeds (measured by the number of days from 1st April to the sowing date) and the traits characterizing plant density in the growing season and the straw yield

Trait	Sowing date
Plant density after full emergence	-0.400*
Field emergence capacity	-0.687*
Plant losses during growth	0.442*
Straw yield	-0.460*

* values of correlation coefficients statistically significant at $P < 0.05$

Table 9. Simple correlation coefficients between the straw yield of white mustard and the height of plants and the number of first-order and higher-order branches

Trait	r
Plant height	0.647*
Number of the first-order branches of the main stem	0.002
Number of higher-order branches	-0.172

* values of correlation coefficients statistically significant at $P < 0.05$

DISCUSSION

White mustard should be sown at the time typical for spring cereals for optimal development (Jankowski and Budzyński, 1999; Toboła and Muśnicki, 1999; McKenzie, *et al.*, 2006). In the present study a wide range of sowing dates were evaluated and found to have a significant impact on most biometric traits (Tables 4–6). With different sowing dates plants developed in different weather conditions and at different day lengths (Harasimowicz-Hermann *et al.*, 2017). Later sowing significantly and negatively affected field emergence capacity and increased the loss of plants in the field during the growing season. Reducing the number of plants along with delaying the sowing of white mustard contributed to the significant modelling of many biometric traits of plants by this factor. The field emergence capacity of white mustard was on average 41.6%, and for sowing after mid-May it was usually significantly lower. The mean loss of white mustard plants in the field during the growing season was high and amounted to 63%. In a study by Zielonka and Szczebiot (2001) the delay of sowing from the last ten days of April to the second ten days of May caused an increase in losses in the field by only 7% while there was a decrease in the number of siliques set by 50%. The significant negative effect of delayed sowing on the field emergence capacity shown in the present study can be explained by the stage of emergence being shifting to a period with worse humidity conditions, which are a result not only of germinating seeds increasingly lower access to post-winter water, but also to the on average lower total precipitation that occurs during plant emergence from sowing that took place in the second half of May and in June (Harasimowicz-Hermann *et al.*, 2017). In a study by Zekaite (1999), a slight delay in the sowing date by 15 days had a positive effect on the number of plants, both after emergence and before harvesting, but negatively influenced the number of siliques on the plants and the seed yield. In a study by Brandt (1992) a delay in sowing from early May to the first half of June also had a positive effect on the number of plants. The different results in terms of the effect of the sowing date on the number and loss of plants could be related to conducting research in various soil conditions, as the study by Brandt (1992) was carried out on a very fertile chernozem that was richer in humus and with better water retention than the podzolic soil on which the present study was carried out. White mustard in the present study produced plants that formed on average 5.6 branches of the first order and a similar number of branches of the higher order (5.0). In our study the tendency of white mustard to branch was also associated with the plant density in the field. More numerous branches and more siliques were formed by plants in plots in which there had been high losses in plant density during the growing season, i.e. in a low density field. White mustard sown after mid-May was characterized by low density due to the occurrence of high losses, which promoted stronger branching and formation of a larger number of siliques on the plant, but with a smaller number of seeds per silique. However, further delay in sowing, despite the progressive reduction in the number of plants, did not result in compensation for these losses in the form of better branching of the plants. On the contrary, the plants sown in June formed fewer first-order and higher-order branches than the plants sown in May. Plants sown in April produced the fewest branches. In the scientific literature no results were found for the biometric traits of white mustard sown at such late dates as they were in this study. In a study by Paszkiewicz-Jasińska (2005), in which the effects of delaying white mustard sowing until the end of April were evaluated, plants of this species sown until the third decade of April formed more siliques (a total of 143 per plant) than in the present study, but with a similar number of seeds per silique (5).

The average height of white mustard in the present study was 104 cm, but as the sowing date was delayed until after mid-May the resulting plants were getting shorter, which together with the reduced density resulted in a decrease in the straw yield per hectare. The results in this respect obtained in the present study are consistent with the data found in the literature on this issue (Zekaite, 1999).

CONCLUSIONS

Delaying sowing of the white mustard cultivar 'Nakielska', beyond the dates recommended for cultivating it for seeds resulted in a change in the plants habit. The shorter was the day after the summer solstice when the white mustard came into the next development phase, the more the biometric traits of the plants changed. First of all, the proportion of elementary components determining the seed yield decreased. There was a reduction of plant growth in height and an increased tendency to form higher-order lateral branches as well as a reduction in the number of siliques on the main stem and a reduction of seeds in siliques from both the main stem and lateral stems. The highest straw yield was produced by plants sown in the first half of April. The further delay in sowing from early May to early July had no significant affect straw yield.

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MODELOWANIE CECH BIOMETRYCZNYCH ORAZ PLONU SŁOMY GORCZYCY BIAŁEJ (*Sinapis alba* L.) W UPRAWIE NA NASIONA PRZEZ TERMIN SIEWU I CZYNNIKI METEOROLOGICZNE

Streszczenie

Gorczyca biała jest rośliną o dobrej wierności plonowania, niewielkiej zmienności długości okresu wegetacji oraz znacznej odporność na czynniki klimatyczne. Jednak opóźnienie terminu siewu tej rośliny skutkuje istotnymi zmianami w pokroju i wydajności roślin. Trzyletnie doświadczenie polowe z gorczycą białą uprawianą na nasiona przeprowadzono jako jednoczynnikowe, w układzie losowanych bloków, w czterech powtórzeniach. Gorczycę białą wysiewano w 13 terminach w odstępach co siedem dni, od początku kwietnia do przełomu czerwca i lipca, a zbierano po osiągnięciu dojrzałości nasion. Opóźnianie terminu siewu gorczycy białej odmiany ‘Nakielska’, uprawianej na nasiona, w stosunku do terminu wczesnowiosennego powodowało zmianę pokroju roślin. Następowało ograniczenie wzrostu roślin na wysokość i zwiększenie skłonności do tworzenia nisko produktywnych rozgałęzień bocznych dalszego rzędu, zmniejszenie liczby łuszczyn na pędzie głównym oraz nasion w łuszczynach z pędu głównego i bocznych. W im krótszym dniu po dniu przesilenia letniego następowało wchodzenie gorczycy białej w kolejną fazę rozwojową, tym rośliny charakteryzowały się mniejszą liczebnością elementów strukturalnych odpowiadających za plonowanie. Zasiewy gorczycy białej z kolejnych terminów różniły się architekturą łanu, bowiem postępowało pogarszanie polowej zdolności wschodów nasion, co wpływało na mniejszą obsadę roślin po wschodach, wzrastał ubytek roślin w trakcie wegetacji i obniżał się plon słomy. Opóźnianie siewu gorczycy białej skutkowało ograniczeniem wzrostu roślin na wysokość i zwiększeniem skłonności do tworzenia rozgałęzień bocznych dalszego rzędu. Wykazano zmniejszenie plonu słomy, liczby łuszczyn na pędzie głównym oraz liczby nasion w łuszczynach zarówno z pędu głównego, jak i bocznych.

Słowa kluczowe: cechy biometryczne roślin, gorczyca biała, plon słomy, termin siewu