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THE EFFECT OF PLUVIO-THERMAL CONDITIONS AND CHANGING DAY LENGTH ON WHITE MUSTARD (*Sinapis alba* L.) DEVELOPMENT

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ABSTRACT

Background. White mustard is a plant whose economic importance is gradually increasing. This is a result of the growing demand for its seed material due to a more common use of its green biomass in the developing systems of integrated and organic crops. The aim of the study was to estimate the effect of the sowing date of white mustard cultivar `Nakielska` on plant development, the length of growing period and the ability to achieve full seed maturity.

Material and methods. The study presents the results of a three-year field experiment on white mustard (*Sinapis alba* L.). It was a one-factorial experiment in the randomized complete block design with four replications. The variable factor was the sowing date. White mustard was sown on 13 dates at seven-day intervals, from the beginning of April to the end of June or beginning of July depending on year, and harvested after reaching seed maturity.

Results. For successive sowing dates, starting in April, the total average daily temperature at maturity systematically increased until it reached a maximum for the plants sown at the beginning of May. Maturation of white mustard sown from the end of May happened at successively lower temperatures, and the lowest total of average daily temperatures was recorded at sowing date 13. The average day length for the period from sowing to emergence of white mustard lengthened at sowing dates from the beginning of April to the beginning of June and for the next sowing dates (10–13) it shortened, reaching eventually 16.6 hours. With delayed sowing of the white mustard cultivar 'Nakielska', with a time-frame for growth for seeds, the plant growth period was significantly shortened and this had the effect of accelerating emergence and shortening rosette formation and budding.

Conclusion. Vegetative development of white mustard grown for seeds sown from the beginning of April until mid-May proceeded at a systematically growing day length. Plants sown after mid-May until the first days of July came into the generative phase at ever shorter day length. The flowering of plants sown in mid-May proceeded at an average day length of 17 hours, whereas those sown at the beginning of July had an average day length of 14 hours.

Key words: growth stages, sowing date, white mustard

INTRODUCTION

In recent years there has been observed a growing interest in the cultivation of white mustard in Poland and other EU countries. This is a result of the growing demand for seed material due to the more common application of its green biomass in the developing systems of integrated and organic crops (Piętka *et al.*, 2004; Thiessen-Martens and Entz, 2011). Studies by Jankowski and Budzyński (1999) and Toboła and Muśnicki (1999) indicate that to achieve optimal white mustard growth and development, it should be

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sown at the time of sowing spring cereals. Those authors report that, taking into consideration the quantity and quality of seed yield, sowing dates after mid-May should be considered as delayed. According to Oplinger *et al*. (1991) and Du val (2015), due to its strong photoperiodic reaction, quite high resistance to spring frosts and susceptibility to drought, it is recommended to sow white mustard in early spring. However, Brandt (1992) and McKenzie *et al.* (2006) obtained good production results with sowing in the first half of May. The length of the growth period presented in the literature ranges from 80 to 120 days (Brandt, 1992; Oplinger *et al.*, 1991). Currently we observed the need to increase the range of commodity plants, so-called emergency plants, for late re-sowing of frozen winter cereals or oilseed rape. According to Davis *et al.* (2010), white mustard is more resistant to high temperatures and precipitation deficits in summer than spring oilseed rape. Taking into consideration the small number of new studies concerning an assessment of white mustard response to a delayed sowing date and the related changing day length and pluvio-thermal conditions, it was deemed justifiable to carry out extended research in this area. The research hypothesis assumed that white mustard, as a long-day plant, will respond to a delay in an early spring sowing date by shortening its vegetative development and that the increasing length of the day and changing pluvio-thermal conditions will have an effect on the length of the whole growing period. The aim of this study was to estimate the effect of the sowing date of white mustard cultivar `Nakielska` and the changing pluvio-thermal conditions on plant development, the length of growing period and the ability to achieve full seed maturity.

MATERIAL AND METHODS

The field study was conducted over the period 2005–2007 at the Research Station Mochełek (53°13’ N; 17°52’ E), Poland. The experiments were performed in *Luvisol* (IUSS Working Group WRB, 2007), with a reaction similar to neutral (pH in 1 M KCl 6.0) and an average abundance of macroelements. The experimental factor was the sowing date of white mustard. The interval between successive sowing dates was seven days (Table 1). Classic tillage was applied in the period from harvesting the previous crop (spring barley) to sowing white mustard, and fertilization with nitrogen 34.5 $kg \cdot ha^{-1}$ N, phosphorus 50 $kg \cdot ha^{-1}$ P and potassium 70 $kg \cdot ha^{-1}$ K was applied prior to sowing. Additionally, nitrogen in an amount of 34.5 $kg \cdot ha^{-1}$ was applied at the beginning of stem elongation and 34.5 $kg \cdot ha^{-1}$ at the flowering stage. The sowing rate was adapted to obtain a plant density of 120 plants per m^2.

Table 1. Sowing and harvesting dates of white mustard grown for seeds

Symbol of sowing date	1	2	3	4	5	6	7	8	9	10	11	12	13
Year 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
Harvesting date	26.07	26.07	05.08	05.08	18.08	18.08	31.08	09.09	09.09	22.09	22.09	22.09	28.10
Year 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
Harvesting date	26.07	26.07	02.08	02.08	09.08	09.08	28.08	15.09	15.09	15.09	29.09	29.09	29.09
Year 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
Harvesting date	01.08	01.08	08.08	08.08	21.08	29.08	05.09	12.09	12.09	12.09	21.09	21.09	21.09

During plant growth observations were carried out of the beginning and end of developmental stages. This enabled registration of precipitation total, air temperature and day length for individual periods, and calculation of the total day hours for individual periods. White mustard growth conditions were calculated in the following periods: from sowing to the end of emergence; from the beginning of rosette formation to the end of budding; at flowering; from the beginning of seeds to harvesting.

Taking into consideration the number of sowing dates studied (13), the attribute of continuity was given to the experimental factor. In-depth analyses of the relationships between the formation of research characteristics and the passage of time were performed.

To analyse the relationship between plant sowing date and meteorological parameters at successive developmental stages, sowing dates were transcoded to the same linear scale, where value 1 denotes the date 01 April, after which sowings were performed for each of 3 years. This enabled an analysis of the correlation between the studied parameters, including the sowing date treated as a continuous variable. Analysis of individual meteorological parameters from the years of the study was complemented by determination of the standard deviation.

Average daily air temperature and total precipitation from April to October in the successive years of the study were respectively: in 2005 – 13.4°C and 257.8 mm, in 2006: 14.3°C and 362.6 mm, in 2007 – 13.7°C and 400.5 mm. Detailed analysis of the meteorological conditions are given in the chapter Results.

RESULTS

The first four sowing dates differed significantly in total precipitation during white mustard emergences, 7.5 mm – date 2, 30 mm – date 3, which was also characterized by quite high variability of rainfall in the years of the study (Fig. 1). During the study period the beginning of May (date 5) abounded in rainfall – on average 45 mm with low variability in each year. Emerging plants at subsequent sowing dates (6–13) had rainfall below the average total for all dates. The first six sowing dates of white mustard from April to 17 May, at a systematically falling number of growth period days, was characterized by a gradually falling total precipitation for the period from rosette formation to budding from 100 mm (date 1) to 38 mm (dates 5 and 6). From date 7 to 13, the amount of water from rainfall in those periods ranged from 50 mm to more than 80 mm. The flowering of the white mustard from the first five sowing dates proceeded at a precipitation level of 29–38 mm. In plants sown later, total precipitation during this stage varied between (39–75 mm), but was regularly higher than with the sowings performed up until 10 May. The maturation of plants sown in April proceeded at similar total precipitation level of 65–72 mm. Plants sown at the beginning of May (date 5) reached their maturation period with the highest total precipitation level of 94 mm. With further delay in the sowing date, a decrease in total precipitation was noted during plant maturation as well as throughout the white mustard growth period.

From plant sowing to the full emergence of white mustard, the sum of average daily temperatures at the first sowing date was the lowest (102°C), but it increased systematically and at date 13 it amounted to 175°C (Fig. 2). For sowing in the middle of April (date 2) and at the end of June and beginning of July, the sums of average temperatures for the stages of rosette formation and budding were similar at 600°C, whereas for the other sowing dates they fluctuated within the range 440–500°C. The sum of average daily temperatures during white mustard flowering in the present study (Fig. 2) ranged on average from 360°C at date 2 to 557°C at date 8.

For successive sowing dates from April, the total average daily temperature at maturing grew systematically and reached a maximum for the plants sown at the beginning of May (date 5). Maturation of white mustard sown from the end of May proceeded at successively lower temperatures, and the lowest total of average daily temperatures was recorded at sowing date 13.

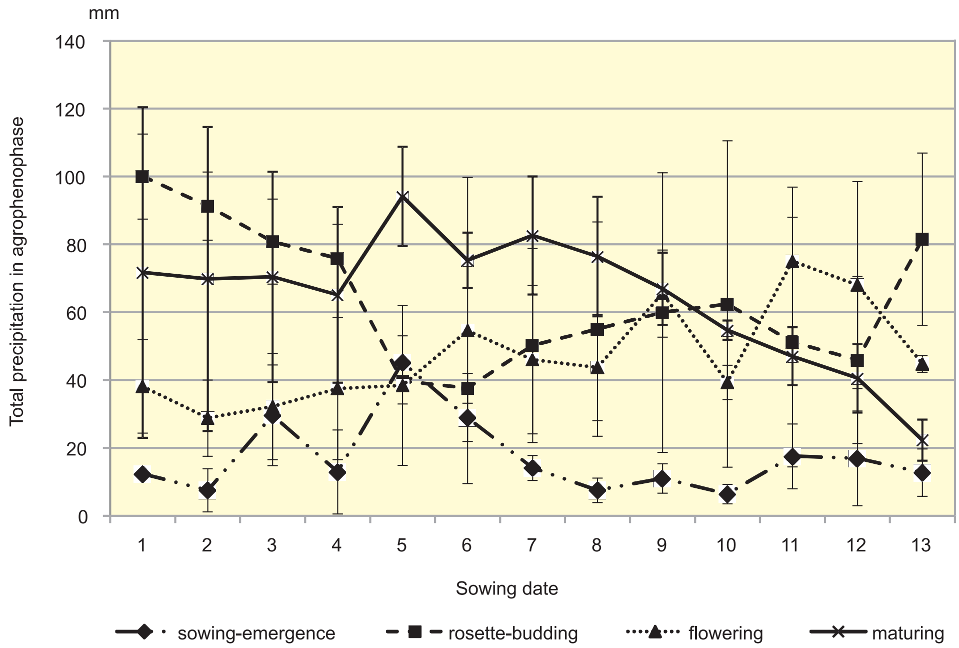

Fig. 1. Total precipitation in mm in individual agrophenophases of white mustard grown for seeds – average from the study years (bars show standard errors)

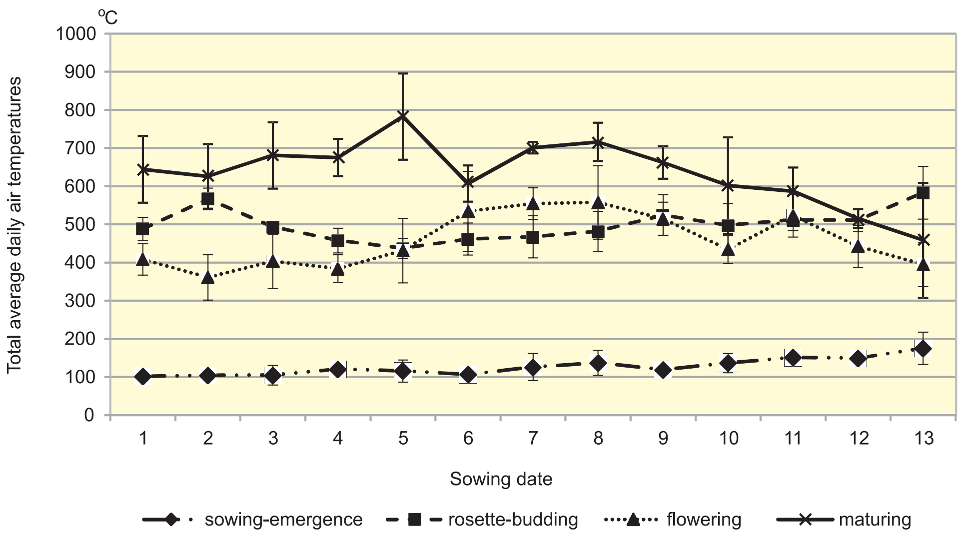

Fig. 2. Total average daily air temperatures in °C in individual agrophenophases of white mustard grown for seeds – average of years of study (bars show standard errors)

The average day length for the period from sowing to emergence of white mustard lengthened at dates from the beginning of April to the beginning of June (from date 1 to 9) and from then (10–13) it shortened, reaching eventually 16.6 hours (Fig. 3). The period of white mustard rosette formation and budding also occurred at different day length dependent on the sowing date, although with low variability between the years of the study. At the first sowing date the period of rosette formation and budding of white mustard occurred at a day length of 15.5 hours, at subsequent dates until the middle of June (date 11) the day length increased systematically to 16.7 hours. At later dates (12 and 13) the day was getting shorter. Flowering of white mustard sown at the first six dates proceeded on average at a day length of 16.8 hours. From sowing from around 25 May (date 8) this stage fell on a gradually shortening day. For the last sowing date the average day length amounted to 14.8 hours.

The sowing date affected the length of all phenological phases of white mustard (Fig. 4). On average over the years, emergence occurred within the time-frame from 7 to 12 days, while a slightly longer time of emergences was typical of plants sown up to the end of May (sowing dates 1–6), and at successive dates emergence occurred several days faster. The period from leaf rosette formation to budding lasted from 26 to 43 days. The longest time for this stage occurred in plants sown at the first four dates (1–4), but with a clear tendency of shortening this time in the successive weeks of sowing. At the other dates white mustard developed the rosette and formed flower buds in about 30 days. Flowering lasted from 21 to 29 days. Plants from the first five weeks of sowing (4–12 April to 2–10 May) were at this stage for 21–24 days, whereas in plants from subsequent sowing dates it lasted from 25 to 29 days. Maturation of white mustard seeds occurred within the time-frame from 32 to 43 days.

According to the methodology, successive dates for plant sowing were always longer than the previous by 7 days. Total rainfall and temperature for that time was positively correlated with the sowing date (Table 2). With a delay in white mustard sowing, within the dates intended for its growth for seeds, emergence was accelerated and rosette formation and budding stages were shortened, but the delay had no significant effect on the length of flowering and maturation periods. Plant emergence from later sowing dates lasted for a significantly shorter time and at higher temperatures. No correlation was shown between delaying the sowing date and the weather conditions of the flowering period.

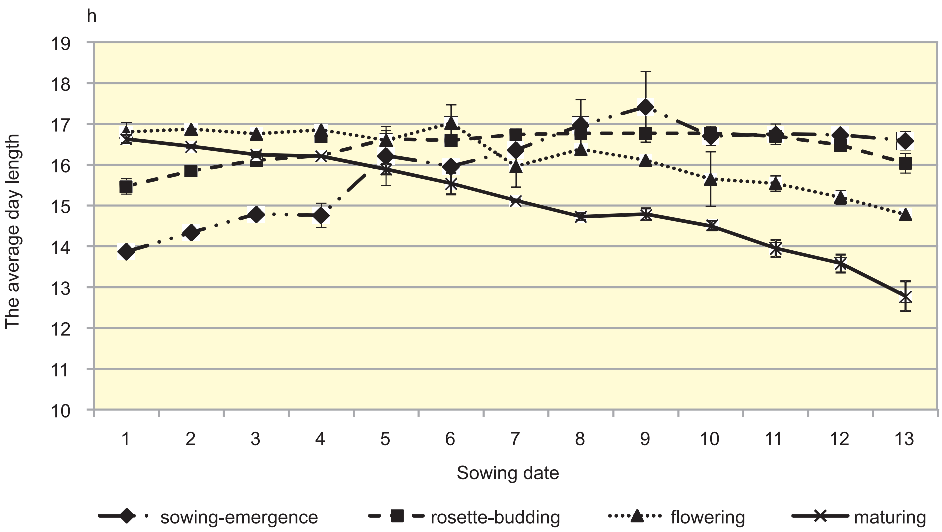

Fig. 3. Average length of growth day in individual agrophenophases of white mustard (bars show standard errors)

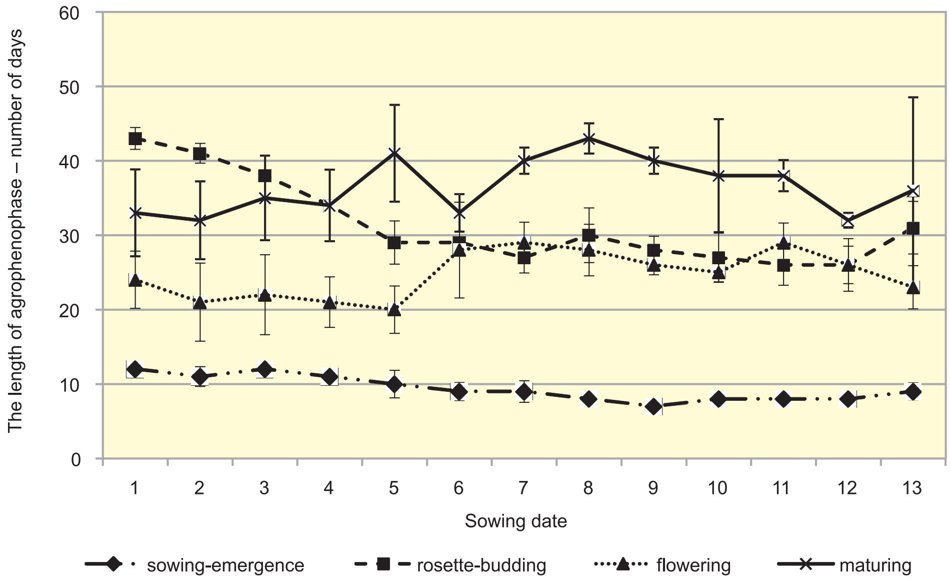

Figure 4. Length of growth period of individual agrophenophases of white mustard cultivated for seeds – average from the study years (bars show standard errors)

Table 2. Simple correlation coefficients (r) between sowing date of white mustard grown for seeds (measured by the number of days from 01 April to the sowing day) and meteorological parameters in period preceding sowing and in successive agrophenophases of white mustard

Period	Meteorological parameter			
	total rainfall	total temperature	number of days	total day hours
Prior to sowing	0.939*	0.943*	0.917*	–
From sowing to full emergences	-0.133	0.490*	-0.642*	-0.443*
From rosette formation to the end of budding	-0.254	0.208	-0.703*	-0.682*
Flowering	0.246	0.188	0.206	0.044
From the beginning of maturation to harvesting	-0.366*	-0.376*	0.085	-0.230
Growing – from sowing to harvesting	-0.287	0.026	-0.420*	-0.637*

* values of correlation coefficients statistically significant at $p = 0.05$

In the period from the beginning of maturation to harvesting the sowing date showed a low and negative correlation with the total precipitation and temperature. Analysing the whole plant growth period, the significant effect of a delay in the sowing date on reducing the number of growth days and in the total hours of the daylight required in white mustard cultivation has been shown.

DISCUSSION

In the present study, plants had varied humidity conditions depending on the sowing date. Total precipitation at individual stages and throughout the growth period was the most variable characteristic, both for the years of study and for sowing dates. No relationships were observed between the sowing date and plant water supply during germination. Delaying sowing from April to the second half of May or to June, when the air temperature is increasing, resulted in the shortening of the germination stage from 11–12 to 7–9 days. In the study by Paszkiewicz-Jasińska (2005) this stage lasted as long as 13–16 days, which the author justified by high humidity levels in conditions of heavy rainfall. Similarly, Murawa *et al.* (2003) recorded full emergence after 12–20 days, whereas for Toboła and Muśnicki (1999), and DuVal (2015) it was after 5–10 days. In the present study, a delay in sowing had a negative effect on plant supply with water in the periods of rosette formation to budding (dates 1–6) and maturation (dates 5–13). According to the long-term data, the period of rosette formation to budding, lasting on average about 30 days, should be very wet, but in the years of the study there was a high variability in the amount of rainfall. In the third year of the study, monthly precipitation in June and July was very heavy and exceeded 100 mm. However, the variability of rainfall in years is typical of Central and Eastern Europe (Brant *et al.*, 2009; Niedzwiedź *et al.*, 2009; Palmer and Räisänen, 2002). The sum of average daily temperature from plant sowing to their harvesting amounted to 1717°C, whereas both early and late sowing dates cause that the values of this parameter were slightly lower. According to Zekaite (1999) and Dorsainvil *et al.* (2005), precipitation deficits combined with high temperatures in the first weeks of growth adversely affects further plant vegetative development. The present study confirms the variability of flowering duration in different years, that is already known about from the literature (Zekaite, 1999). This was particularly large in regard of the first six sowing dates.

The studies by Paszkiewicz-Jasińska (2005) showed that drought and high temperatures during plant maturation cause an acceleration in the ending of this stage and a shortening of the growth period. Results obtained in the present study confirm the relationship between the maturation period and the water supply. We observed a remarkable decrease in total precipitation during the maturation period of white mustard that had experienced delayed sowing, which resulted in a shortening of the duration of this stage even in the conditions of a decreasing sum of temperature. Plants sown later had a shorter period of vegetative development and this developmental stage proceeded with a significantly shorter day in comparison with those sown earlier. A relationship between delay in sowing and a shortening of the growth period has also been documented by Brandt (1992), Toboła and Muśnicki (1999) and Zekaite (1999). Variable weather conditions are also a reason for a high variability in the dynamics of other plants' development in this region (Bieniek *et al.*, 2016; Jędrszczyk *et al.*, 2016). Toboła and Muśnicki (1999) demonstrated that the duration of budding in white mustard is characterized by the lowest variability and the length of maturation by the highest. The same authors, as well as Murawa *et al.* (2003), reported that the length of the whole growth period is strongly determined by weather conditions, which mostly affect the variability of duration of the plant generative stage. In the present study involving a delay in sowing from the beginning of April to the beginning of July, the effect of this delay on the duration of generative development was unstable and lower than the effect that it had on the duration of vegetative development.

One of the results of a considerable delay in sowing was the displacement of particular agrophenophases into conditions with a different circadian rhythm. In the present study, the vegetative development of white mustard grown for seeds sown at dates from the beginning of April (date 1) to mid-May (date 6) proceeded at systematically increasing day length, whereas with a further delay in sowing the generative development occurred with a shortening day, particularly at dates from 6 to 13. The average length of the day during flowering of white mustard sown for seeds at the beginning of July amounted to slightly more than 14 hours. With increasing delay in the sowing date the seed maturation period of white mustard happened on increasingly shorter days. Over the years of the study variability in length of the maturation stage was relatively high and irregular and it resulted in a great variation in the time of seed maturation for harvest. On average, in the 3 years of the study, the duration of mustard growth ranged from 92 to 112 days. Plants sown at the beginning of April were characterized by the longest growth period. At subsequent sowing dates white mustard growth time was shortened, mainly as a result of a shortening of the vegetative development period, particularly the period of rosette formation. The plants sown for seeds after 20 June were characterized by the shortest growth period. According to Brandt (1992) and Zekaite (1999), the length of the whole growth period of plants sown at the optimal sowing date range from 95–102 days and delay in the sowing date leads to a shortening of the growth period. This shortening growth period was also found in the present study.

CONCLUSIONS

1. Delaying the sowing of the white mustard cultivar 'Nakielska' beyond dates intended for its cultivation for seeds resulted in a shortening of the plant growth period. This was accomplished by accelerated emergence and a shortened period from rosette formation to the end of budding. This acceleration did not systematically affect the length of flowering and maturation, even although they proceeded at lowering temperatures and decreasing precipitation.
2. Vegetative growth of white mustard cultivated for seeds sown at dates from the beginning of April to the middle of May occurred at systematically increasing day length. The flowering stage of plants sown in mid-May proceeded at an average day length of 17 hours.
3. Plants sown from the middle of May to the first days of July came into the generative stage and flowered in a gradually shorter day, which for the plants sown at the beginning of July was slightly more than 14 hours but which still allowed the plants to reach full seed maturity.

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WPŁYW WARUNKÓW PLUWIOTERMICZNYCH I ZMIENNEJ DŁUGOŚCI DNIA NA ROZWÓJ GORCZYCY BIAŁEJ (*Sinapis alba* L.)

Streszczenie

W pracy przedstawiono trzyletnie wyniki badań polowych nad gorczycą białą. Były to doświadczenia jednoczynnikowe, w układzie losowanych bloków, w czterech powtórzeniach. Czynnikiem zmiennym był termin siewu. 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. W miarę opóźniania siewu gorczycy białej odmiany ‘Nakielska’, w terminach przewidzianych na uprawę jej na nasiona, następowało istotne skrócenie okresu wegetacji roślin, na co wpłynęło przyspieszanie wschodów i skracanie fazy formowania rozety oraz pąkowania. Rozwój wegetatywny gorczycy białej uprawianej na nasiona, sianej w terminach od początku kwietnia do połowy maja, następował przy systematycznie wzrastającej długości dnia. Rośliny siane po połowie maja do pierwszych dni lipca przechodziły w fazę generatywną przy coraz krótszym dniu. Faza kwitnienia roślin sianych w połowie maja przebiegała przy średniej długości dnia – wynoszącej 17 godzin, natomiast sianej na początku lipca – przy długości dnia 14 godzin.

Słowa kluczowe: fazy rozwojowe, gorczyca biała, termin siewu