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Influence of sowing date and cultivar on grain and protein yield of grain sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract. Sorghum is a warm-climate crop that is tolerant of water shortages and drought. In terms of climate change in Europe, this cereal could be increasingly grown to replace maize where maize cannot be grown. Unfortunately, the agronomics and especially the optimum sowing date are currently not sufficiently researched, which means that many farmers potentially interested in growing sorghum do not know what sowing date to use. The diversity of cultivar also poses a problem in terms of their appropriate selection and sowing date for the weather conditions in Poland. The study used two different sowing dates for sorghum: in the first decade of May and the second decade of May. Three different grain sorghum cultivars were used: Albanus, Anggy and GK Emese. In the conducted experiment, such features as grain yield and its components as: plant density, number of panicles, tillering index, grain weight per panicle and thousand grain mass were studied. Protein content in grain was also studied and protein yield was calculated. The GK Emese variety proved to be the most stable in terms of grain and protein yield, but it was also the most sensitive to sowing date. The other two varieties Anggy and Albanus showed a varied response to sowing date in terms of grain and protein yield.

Keywords: grain sorghum, sowing date, grain yield, cultivar, protein yield

INTRODUCTION

Sorghum is mainly grown in regions with warm climate, as it is a crop that is demanding in terms of germination temperature, but at the same time resistant to rainfall deficiencies. The advantage of sorghum is that it can be used both for feed purposes (green matter for silage or grain for fodder), but also for human consumption. Poland is the largest producer of poultry in Europe and therefore requires a constant supply of feed grain. Sorghum grain is widely used in poultry feed production, but the previous production of other cereals (triticale and wheat) from domestic production has resulted in less interest of farmers in sorghum cultivation (Różewicz, 2020). The grain of this cereal can be used in the feeding of various poultry species as well as for pigs (Różewicz, 2022). Sorghum grain contains a significant amount of energy from starch and fat as well as protein, but also contains calcium and phosphorus, very important elements in the feeding of broiler chickens (Sibanda et al., 2023). It can replace maize in broiler feed (Hidayat et al., 2022). Sorghum contains protein with a reasonably good amino acid profile, but a limitation to the greater use of the grain for feed is the tannins present in the grain as antinutritional components (Feng et al., 2023). Sorghum grain is gluten-free, and additionally, it contains starch, protein and vitamins. A unique feature of sorghum grain compared to other cereals is its high content of antioxidants mainly phenols and flavonoids (Ziółkiewicz et al., 2023). Grain sorghum cultivar cultivated under Polish climate conditions are characterised by a similar content of bioactive (antioxidant) compounds in grain as imported grain from other African and Asian countries (Przybylska-Balcerek et al., 2024). Increasingly unfavourable growing conditions for spring cereals in Europe are related to the

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higher frequency of drought (Wójcik et al., 2019). Periods with higher temperatures and lower precipitation occur more frequently in Poland, especially in spring (Ziernicka-Wojtaszek, 2021). The greatest impact of temperature and precipitation on yields is in the months of April-June (Wójcik-Gront, Gozdowski, 2023). Increasingly warming climate favors earlier spring sowing of crops and causes a longer growing season (Menzel et al., 2020). The earliest possible sowing of spring forms of cereals allows the use of water reserves stored in the soil during winter. According to Wawer et al. (2021), despite higher annual precipitation totals, their distribution over time (maximum rainfall in winter and minimum in summer) create precipitation deficits during the growing season. As growing conditions and the impact of climate change on cereals vary around the world, country- or region-specific adaptation strategies need to be investigated. The results of a study by Olesen et al. (2011) show that farmers across Europe, due to climate change, are sowing crops much earlier, at the same time selecting cultivars and cereal species that are more drought tolerant. In Poland, one such strategy is the increasing prevalence of winter cereals in sowing than spring cereals. The warming of the climate and the lengthening of the growing season have favoured the introduction into the cropping structure of cereal species not previously grown in Poland. This was the case with maize, which was initially grown in the southern regions of Poland and is now widely cultivated throughout the country. Unfortunately, according to Król-Badziak et al. (2024), as a result of rainfall shortages, the cultivated area of Poland where maize crops is adequately supplying with water will decrease. According to the forecasts of the cited authors, it will decrease from 69 to 67% in the next 25 years, and in the longer term, by 2080, it may be as low as 44%. A crop with a similar use to maize, but with lower water requirements and higher resistance to high temperatures, is sorghum. The disadvantages of sorghum are its high temperature requirements for grain germination and its sensitivity to frost, so that a plantation established too early may frost. The low-temperature sensitivity can vary between sorghum cultivars. Long periods of too low temperatures slow down seed germination and seedling growth (Parra-Londono et al., 2018). The requirements of individual sorghum cultivar in terms of minimum seed germination temperature vary and have a fairly wide range from 4.5 to 16 °C (Emendack et al., 2021). One method to protect against losses due to lower temperatures during the emergence and initial growth of sorghum plants in Europe is to breed cultivar that are more resistant to cold stress (Vera Hernández et al., 2023; Bonnot et al., 2023). An agronomic method is also to choose the sowing date of sorghum appropriately, so as to minimise the risk of frosts that can destroy seedlings, but early enough to take advantage of soil moisture reserves. Few Polish studies indicate that later sowing in the third decade of May has a positive effect on sorghum plant density (Kruczek et al., 2014), while others indicate that in years with favourable thermal conditions an earlier sowing date for grain sorghum in the third decade of April is more beneficial for higher grain yield (Sowiński, Szydełko-Rabska, 2013; Gierasimiuk et al., 2023). Thus, an important problem for farmers is the selection of an appropriate sowing date and cultivar of grain sorghum. The aim of the conducted research was to verify the research hypothesis assuming that earlier sowing of grain sorghum promotes higher grain yield, but this depends on the cultivar.

MATERIAL AND METHODS

Preliminary results in the two growing seasons of 2020 and 2021, a micro-plot experiment was conducted on experimental plots (51°41' N, 21°95' E) belonging to the Institute of Soil Science and Plant Cultivation in Puławy as a two-factor experiment to determine the effect of sowing date and cultivar on sorghum grain yield. The experiment was conducted in a randomised block design in four replications, each plot having an area of 1 m^2. In 2020, the forecrop was maize, while in 2021 the forecrop was winter wheat. Three cultivars of grain sorghum were used – two with typical grain use Albanus and Anggy, and one cultivar with a Double purpose of use GK Emese.

Detailed characteristics of the cultivar are available under the following links (accessed 20.03.2024):

Albanus: https://api-com.lidea-seeds.com/uploads/2022/02/fiche_sorgho_albanus_compressed.pdf

Anggy: https://ragt-semences.fr/fr-fr/nos-varietes/anggy-sorgho

GK Emese: https://www.gabonakutato.hu/en/our-seeds/sorghum/grain-sorghum/gk-emese.

The seed of the cultivar used in the experiment was obtained from the Sorgo Polska Janusz Sus company. Seed sowing was performed in the first or second decade of May. The first sowing date fell on 5 May in each year of the study, while the second in 2020 it was 15 May and in 2021 17 May. Weather conditions (average temperatures and precipitation) during the growing seasons are presented in Table 1. The experiment was established on brown soil classified as good wheat complex. Pre-sowing fertilization with 70 kg P_2O_5 ha^{-1} (triple superphosphate) and 100 kg K_2O ha^{-1} (potassium salt 40%) with nitrogen in the form of urea in the amount of 120 kg N ha^{-1}. The inter-row spacing was 0.5 m and the sowing norm used was 24 plants per m^2. Plant sowing was done manually. Weeding of the plots was done manually, carried out throughout the season on an ongoing basis when weeds were observed to appear. The panicles were harvested at full maturity in the third decade of October. After harvesting, yield structure analysis was carried out by calculating plant density, tillering coefficient, and number of panicles. Then, grain from panicles was threshed and dried in a drying chamber at 55 °C for 48 hours with forced air circulation. After

Table 1. Characteristics of weather conditions during the years of the study.

Month	Average air temperature [°C]			Precipitation [mm]		
	2020	2021	multi-year average 1981–2010	2020	2021	multi-year average 1981–2010
May	11.9	12.9	14.5	93.9	61.0	58.0
June	19.1	20.0	17.2	159.0	53.0	65.0
July	19.3	22.2	19.5	31.9	110.0	80.0
August	20.3	17.1	17.8	95.5	219.0	87.0
September	14.9	12.9	13.3	102.0	77.6	55.0
October	10.4	8.7	8.0	90.0	5.0	44.0
Sum	95.9	93.8	90.3	572.3	525.6	389.0

re-drying, the grain was weighed and the yield per hectare of area was calculated. In addition, the weight of one thousand grains was calculated (according to norm PN–68/R–74017), and representative grain samples from each plot of two (a total of eight for each experimental site) were analysed for total protein content, using the Kjeldahl method (protein conversion factor 6.25). The protein yield per hectare was calculated according to the formula grain yield ×grain protein content.

The results obtained were statistically elaborated by means of analysis of variance, assessing the significance of differences with the t-Tukey test at $\alpha \leq 0.05$. Statistica v.13.1 was used for this purpose.

RESULTS AND DISCUSSION

In the case of sorghum, this is related to the germination temperature, which determines the germination process of plants and the death of seedlings if frost occurs. During the period of this study, no frost was recorded. Our own research has shown that sowing date affects plant density in the cultivars tested (Table 2). In the Anggy cultivar, differences were found between the study years. In 2020, significantly higher plant density was found at the first sowing date, while in 2021 the number of plants was higher at the second sowing date. The cultivar GK Emese showed an inverse relationship to the cultivar Albanus, as in both years for the cultivar GK Emese a significant increase in plant number was favoured by the second sowing date. The results obtained indicate that for a better sorghum plant density, the sowing date should be adapted to the requirements of the specific cultivar. On average, for all three grain sorghum cultivars tested in 2020, there was no significant effect of sowing date on plant density during harvest, while 2021 showed a significant difference in favour of delayed sowing (Table 3). This indicates that thermal conditions may have an impact on seed germination and subsequent plant density, but rainfall is equally important. In 2020 and 2021 similar average air temperatures were observed in May (1 °C higher was the average temperature in May 2021 compared to 2020), but nevertheless in 2021 the precipitation was lower and this could be a factor that determined the differential response of the cultivar to the sowing date. GK Emese and Anggy cultivars had significant higher number of panicles per m^2 in second sowing date in 2020 and 2021 respectively. Sowing date have no effect on this trait in case of Albanus cultivar in both years. Gierasimiuk et al. (2023) showed that earlier sowing of sorghum influences a higher number of panicles per unit area, which was confirmed in all years of the study.

Table 2. Effect of sowing date and cultivar on yield structure of grain sorghum.

Sowing date	Cultivar	Plant density [pcs m^{-2}]		Number of panicles per m^2		Tillering index	
		Year					
		2020	2021	2020	2021	2020	2021
I	Albanus	21.0 a	20.0 a	35.5 ab	43.3 a	1.7 a	2.2 a
	Anggy	20.5 a	15.8 c	32.5 ab	28.0 b	1.6 a	1.8 a
	GK Emese	16.8 b	16.8 bc	27.8 b	33.5 ab	1.7 a	2.0 a
II	Albanus	17.5 b	17.8 b	37.0 ab	36.3 ab	2.1 a	2.0 a
	Anggy	18.3 b	19.5 ab	34.5 ab	42.8 a	1.9 a	2.2 a
	GK Emese	21.8 a	21.5 a	42.5 a	40.8 ab	2.0 a	1.9 a

Values in columns signed with different letters (a, b) are significantly different ($\alpha \leq 0.05$).

Table 3. Effect of sowing date and cultivar on yield structure elements of sorghum.

Item	Plant density [pcs m^{-2}]		Number of panicles per m^2		Tillering index	
	Year					
	2020	2021	2020	2021	2020	2021
Sowing date						
I	19.4 a	17.5 b	31.9 b	34.9 b	1.7 a	2.0 a
II	19.2 a	19.6 a	34.9 a	39.9 a	1.8 a	2.0 a
Cultivar						
Albanus	19.3 a	18.9 a	36.2 a	39.8 a	1.9 a	2.1 a
Anggy	19.4 a	17.6 a	33.5 a	35.4 a	1.8 a	2.0 a
GK Emese	19.3 a	19.1 a	35.1 a	37.1 a	1.8 a	2.0 a

Values in columns signed with different letters (a,b) are significantly different ($\alpha \leq 0.05$).

The above authors also showed a higher plant density for earlier sowing and a higher tillering coefficient, while in their study there was a differentiated response of the cultivars tested, but the averages for the cultivars in both years of the study showed significant differences in favour of earlier sowing in terms of plant density and in 2020 a significantly lower tillering coefficient at the first sowing date. Similarly, Sowiński and Szydełko-Rabska (2013) in the grain sorghum cultivar 251 found that earlier sowing resulted in lower plant tillering, but increased plant density and panicle number. The different response of cultivar may therefore be due to a genetic factor. The discrepancy in the response of the cultivar to sowing date for the traits tested (plant density, number of panicles from 1 m^2 and tillering coefficient) may also be due to a genetic factor as each cultivar originated was produced by a different breeding company. The different response may also be due to the interaction between environmental factor and genotype, as pointed out by Schaffasz et al. (2019) in the aspect of sorghum adaptation to cultivation in Europe.

The study showed a slight effect of sowing date on grain weight per panicle (Table 4). In 2020, small differences were found that were not significant except for the cultivar GK Emese in which an earlier sowing date resulted in a significant increase in grain weight per panicle compared to the second sowing date. A similar trend was found in this cultivar in 2021, but the difference was not statistically significant. The cultivar Albanus also showed a statistically non-significant difference in grain weight per panicle with both years. In 2020, an earlier sowing date resulted in an increase in grain weight per panicle while in 2021 a slight difference was found in favour of a delayed sowing. The cultivar Anggy, on the other hand, tended to have higher grain weight per panicle with earlier sowing date in both years of the study, with the difference being greater in 2021 and very small in 2020.

Sowing date affected the grain yield of the cultivar, but this varied between the years of the study. Only the GK Emese cultivar showed significantly higher grain yield at the second sowing date in both years, and Anggy in 2021. In contrast Albanus had significantly higher yield in first sowing date in 2020.

The different response of the cultivar related to sowing date on thousand grain weight was also observed across the years of the study. In 2020, a significant difference in thousand grain weight occurred only in the Anggy cultivar. It was higher when a later sowing was used. In contrast, more significant differences were found in 2021. All cultivars tested had significantly higher thousand grain weight when the second sowing date was used. On average for the cultivar in both years of the study, the earlier sowing date proved to be more favourable in terms of the obtained grain

Table 4. Effect of sowing date and cultivar on yield components and grain yield.

Sowing date	Cultivar	Grain weight per panicle [g]		Grain yield [t ha^{-1}]		Weight of thousand grains [g]	
		Year					
		2020	2021	2020	2021	2020	2021
I	Albanus	29.15 b	29.82 a	10.35 a	12.3 a	23.23 b	22.15 c
	Anggy	24.04 b	30.85 a	7.83 c	8.63 b	20.73 b	20.52 c
	GK Emese	34.20 a	29.90 a	9.51 b	9.80 b	24.03 b	18.25 d
II	Albanus	25.70 b	30.94 a	9.51 b	11.07 a	21.03 b	25.98 b
	Anggy	23.18 b	27.82 a	8.00 c	11.89 a	30.70 a	32.60 a
	GK Emese	26.01 b	27.42 a	11.05 a	11.18 a	24.67 b	23.55 b

Values in columns signed with different letters (a–c) are significantly different ($\alpha \leq 0.05$).

Table 5. Effect of sowing date and cultivar on yield composition and average yields of sorghum.

Item	Grain weight per panicle [g]		Grain yield [t ha^{-1}]		Weight of thousand grains [g]	
	Year					
	2020	2021	2020	2021	2020	2021
Sowing date						
I	29.13 a	30.19 a	9.23 a	10.25 a	22.66 b	20.31 b
II	24.96 b	28.73 b	9.52 a	11.38 a	25.47 a	27.38 a
Cultivar						
Albanus	27.42 ab	30.38 a	9.93 a	11.69 a	22.13 b	24.04 b
Anggy	23.61 b	29.34 a	7.92 b	10.26 b	25.71 a	26.56 a
GK Emese	30.11 a	28.66 a	10.28 a	10.49 b	24.35 a	20.90 c

Values in columns signed with different letters (a–c) are significantly different ($\alpha \leq 0.05$).

weight per panicle, but resulted in a significant reduction in thousand grain weight and did not significantly affect the final grain yield (Table 5). Sowiński and Szydełko-Rabska (2013) in the same grain sorghum cultivar, found differences in yield depending on sowing date and years of study. Similar correlations were found in our study which indicates a strong influence of weather during the emergence and initial growth of sorghum plants. Szumiło and Rachoń (2014) showed that sowing sorghum of the Rona cultivar in the second decade of May is more favourable than an earlier sowing date, influencing higher grain yield through higher number and weight of grains per panicle. Gierasimiuk et al. (2023), on the other hand, showed that each of the 5 sorghum cultivars tested exhibited higher grain weight per panicle and yield with an earlier sowing date, while in the case of thousand grain weight, the response of cultivars varied with almost all cultivars (except one) having a higher thousand grain weight when seed sowing was done at the optimum date (12–15 May).

A study on the effect of sowing date on grain protein content showed that sowing date in both years of the study had no significant effect on this trait in the Albanus cultivar (Table 6). In contrast, the cultivar Anggy showed a positive response in both years of the study to earlier sowing showing a significant increase in protein content. The cultivar GK Emese only showed a higher grain protein content in 2020 for II sowing date, while in 2021 the protein content was similar for both sowing dates. Averaged across cultivars, there was no significant effect of sowing date on grain protein content in either year of the study (Table 7). Sowing date did not affect protein yield significantly, but the response of the cultivar was dependent on the years of the study. The cultivar Albanus showed the highest protein yield in 2021 with no significant effect of sowing date, while it had a lower protein yield in 2020, but earlier sowing showed a positive effect on this trait (Table 6). The cultivar Anggy showed no significant response in protein yield with varying sowing date in 2020, while in 2021 delayed sowing resulted in higher protein yield. A significant increase in protein yield was shown by the GK Emese cultivar in second sowing date, the difference was 28.9% for 2020 and 11.6% for 2021. The averaged value of protein yield for the sowing dates in both years of the study showed no significant difference. Protein yield as an effect of grain protein content and grain yield is largely dependent on the genetic factor and nitrogen fertilisation. Despite the application of the same nitrogen dose, protein yield and grain protein content varied. This may have been

Table 6. Grain protein content and protein yield in relation to sowing date and cultivar.

Sowing date	Cultivar	Protein content [%]		Protein yield [kg ha^{-1}]	
		Year			
		2020	2021	2020	2021
I	Albanus	10.5 a	10.0 a	1086.3 a	1230.5 a
	Anggy	9.9 a	10.2 a	775.2 cd	880.3 b
	GK Emese	9.2 b	9.6 ab	874.9 b	941.8 b
II	Albanus	10.0 a	10.1 a	951.9 b	1118.1 a
	Anggy	9.0 b	9.4 b	719.2 d	1117.7 a
	GK Emese	10.2 a	9.4 b	1127.8 a	1050.9 a

Values in columns signed with different letters (a–d) are significantly different ($\alpha \leq 0.05$).

Table 7. Average protein content and protein yield as a function of sowing date and cultivar.

Item	Protein content [%]		Protein yield [kg ha^{-1}]	
	Year			
	2020	2021	2020	2021
Sowing date				
I	9.9 a	9.9 a	912.1 a	1017.5 a
II	9.7 a	9.6 a	933.0 a	1095.6 a
Cultivar				
Albanus	10.3 a	10.1 a	1019.1 a	1174.3 a
Anggy	9.5 b	9.8 ab	747.2 b	999.0 b
GK Emese	9.7 ab	9.5 b	1001.4 a	996.4 b

Values in columns signed with different letters (a, b) are significantly different ($\alpha \leq 0.05$).

influenced by conditions during the growing season. In particular, higher-than-average rainfall in July and August and a relatively rain-free October in 2021 could have significantly affected the protein yield of the cultivar tested. Furthermore, as indicated by Badigannavar et al. (2016), protein content in grain is a varietal trait. This is related to the use of plant-available nitrogen in sorghum, which is important, especially during flowering and grain filling, for grain yield and grain protein content (Worland et al., 2017). Research by Kostadinova et al. (2019) confirmed that in years with more favourable high rainfall, nitrogen utilisation by sorghum increases resulting in higher grain protein content and protein yield.

CONCLUSIONS

1. The cultivar tested differed in their response to sowing date, so the sowing date should be selected individually to the cultivar.
2. The Anggy and GK Emese cultivars are more sensitive to sowing date than Albanus cultivar, as their response to sowing date varied more in both years.
3. In 2020, the first sowing date was more favourable for the Anggy cultivar because it had a higher plant density, but it did not increase grain yield.
4. The GK Emese cultivar was the most sensitive to an earlier sowing date, so based on the significantly higher grain and protein yield in both years, a later sowing is recommended.

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