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ARTYKUŁ ORYGINALNY

Wpływ zachwaszczenia na produkcję biomasy odmian sorga [*Sorghum bicolor* (L.) Moench] w zachodnio-centralnej Polsce

Influence of weed infestation on biomass production of sorghum varieties [*Sorghum bicolor* (L.) Moench] in the western-central Poland

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Streszczenie

Chwasty są głównym czynnikiem ograniczającym produkcję biomasy sorga. W badaniach oceniono wskaźnik powierzchni liści (LAI), zawartość chlorofilu (SPAD), wysokość roślin, plon świeżej masy sorga oraz liczbę i masę chwastów. Oceniono odmiany sorgo: KWS Freya, KWS Sammos, KWS Sole, KWS Juno, Rona 1 i Sucrosorgo 506. W 2016 roku zawartość chlorofilu w roślinach sorgo różniła się w zależności od odmiany 8 tygodni po siewie, jednak przed zbiorami nie zaobserwowano żadnych różnic. W 2017 roku nie stwierdzono różnic między odmianami sorga. Podobne zależności zaobserwowano w przypadku wskaźnika powierzchni liści. Odmiana KWS Juno charakteryzowała się najwyższymi roślinami, a odmiana Rona 1 najniższymi, co znalazło również odzwierciedlenie w plonie sorga. Zbiorowiska chwastów były zbliżone gatunkowo między latami, a także między odmianami sorgo. Najbardziej rozpowszechnione były *Chenopodium album*, *Brassica napus*, *Viola arvensis* i *Fallopia convolvulus*. Wpływ chwastów na plon sorga i wysokość roślin różnił się w zależności od odmiany sorga i roku. W 2016 roku najwyższej plonowała odmiana KWS Juno (44,9 t/ha), a w roku 2017 roku odmiana Sucrosorgo 506 (36,8 t/ha), natomiast najniższej odmiana Rona 1 (31,7 t/ha) i odmiana KWS Sammos (23,6 t/ha). Konkurencyjność odmian uprawnych można wykorzystać do złagodzenia presji chwastów, co może wzmocnić zrównoważoną ochronę upraw, ale badane odmiany sorga nie wykazały żadnych zauważalnych różnic w reakcji na presję chwastów.

Słowa kluczowe: chlorofil, powierzchnia liści (LAI), konkurencja roślin, odmiany sorgo, chwasty

Abstract

Weeds are the primary constraint on the production of sorghum biomass. The leaf area index (LAI), chlorophyll content (SPAD), plant height, sorghum fresh weight yield, number and weight of weeds were assessed. Sorghum varieties: KWS Freya, KWS Sammos, KWS Sole, KWS Juno, Rona 1, and Sucrosorgo 506 were evaluated. In 2016, the chlorophyll content of sorghum plants varied among varieties 8 weeks after planting; however, no variation was observed before harvest. In 2017, there was no variation between sorghum varieties. Similar relationships were observed for leaf area index. Weed communities were comparable between the years, as well as between sorghum varieties. The KWS Juno variety consisted of the tallest plants, while Rona 1 was the shortest, as also evidenced by the sorghum yield. The most abundant species were *Chenopodium album*, *Brassica napus* volunteer, *Viola arvensis* and *Fallopia convolvulus.* The impact of weed infestation on sorghum yield and plant height differed between sorghum varieties and years. In 2016 the KWS Juno (44.9 t/ha), and in 2017 Sucrosorgo 506 (36.8 t/ha) yielded the highest, while Rona 1 (31.7 t/ha) and KWS Sammos (23.6 t/ha) the lowest. The competitiveness of crop varieties can be leveraged to mitigate weed pressure, which can bolster sustainable crop protection but tested sorghum varieties exhibited no discernible dissimilarities in their responses to weed pressure.

Keywords: chlorophyll, leaf area (LAI), plant competition, sorghum varieties, weeds

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Wstęp / Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most widely cultivated cereal in the world (Popescu et al. 2018; FAOSTAT 2025). The high nutritional and energy value of sorghum renders it more commonly utilized as fodder in Poland and as grain on a global scale. In developing countries, sorghum grain is an important source of nutrition (Adebo 2020). It can also be employed to manufacture alcohol, including beer (Dicko et al. 2006; Witkowski et al. 2017). Sorghum is a valuable feedstock that can be utilized for the production of bioethanol and biogas or to create biocarbon and pellets (Dar et al. 2018; Wirawan et al. 2024). Some varieties of sorghum can produce a comparable quantity of methane to corn (Mahmood et al. 2013).

The majority of sorghum is grown in Africa, but sorghum grain yields are very low (about 0.28 t/ha), especially compared to such countries as the USA (4.3 t/ha), Argentina (4.9 t/ha), and China (3.2 t/ha) (Agele et al. 2025). In Europe, sorghum is a minor crop that is cultivated on only approximately 0.1% of the land, resulting in less than 2% of the global sorghum production (Gurgu-Lazar et al. 2025). Sorghum is a cereal of minimal significance and use in Poland. Increasing droughts in Poland are not conducive to grain yields, which may prompt a search for alternative feed species. Sorghum is a potential candidate due to its widespread cultivation in countries with dry climates and its use in both human and animal nutrition (Sowiński and Szydełko-Rabska 2013). Sorghum is characterized by high heat requirements (Monteiro et al. 2012), low soil requirements and high tolerance to salinity (Popescu et al. 2018). On light soil and in years with insufficient or uneven rainfall, sorghum has a greater yield potential than corn (Sowiński and Liszka-Podkowa 2008).

Weed growth is facilitated by the wide inter-row and slow initial growth of sorghum plants (Staniak et al. 2016). Weeds can reduce sorghum yield even by over 90% (Peerzada et al. 2017; Bekele 2022). Consequently, it is crucial to regulate them shortly after sorghum emergence (Thompson et al. 2017). The most common weeds in sorghum in Poland are *Chenopodium album* L., *Echinochloa crus-galli* (L.) Beauv., *Fallopia convolvulus* (L.) Á. Löve, *Polygonum aviculare* L., *Viola arvensis* Murr., and *Thlaspi arvense* L. (Kaczmarek et al. 2009; Waligóra et al. 2023).

It is crucial to understand the competitive capabilities of individual sorghum varieties due to the varietal diversity of sorghum and its capacity to compete with weeds (such as allelopathic interactions) (Waligóra et al. 2023). The aim of the study was to assess the effect of weed infestation on leaf chlorophyll content, leaf area, height, and yield of six sorghum varieties.

Materiały i metody / Materials and methods

The study was carried out in 2016 and 2017 at the Research and Education Centre Złotniki (REC Złotniki; N 52°48.792; E 016°82.287), Poznań University of Life Sciences. The study was executed as a single factor experiment (1 factor – variety, 6 factor levels = 6 varieties) in a randomized block design, with four replicates, on lessive soil containing 1.4–1.5% organic matter and pH 6.7–6.9. The plots for all sorghum varieties were prepared in the same manner, and the same treatments, as stated below, were implemented. Sowing was conducted in 28 m^2 (10 × 2.8 m) plots, depth of 4 cm, using a Monosem NC Technic Planter precision seed drill to cover 4 rows at a spacing of 75 cm. The sorghum plant density was 26–30 plants/m^2. Winter rapeseed (2016) and spring barley (2017) were the previous crops for sorghum. Nitrogen (urea, N 46%) was applied at 200 kg/ha (92 kg N/ha) in April, P and K (Polifoska 5, NPK 5–15–30, Mg 2, S 7) at 400 kg/ha (20 kg N/ha, 60 kg P/ha, 120 kg K/ha, 8 kg Mg/ha, 28 kg S/ha). During study, the following sorghum varieties were used: KWS Freya, KWS Sammos, KWS Sole, KWS Juno, Rona 1, and Sucrosorgo 506. These varieties were sown on May 16 in both years and harvested on October 22 and 23, respectively.

Evaluations of the weed infestation were conducted 6–7 weeks after sowing (weeds were not controlled during vegetation season). At random, a 0.5 m × 0.5 m frame was placed twice in each plot. Weeds were collected and subsequently separated into species, counted, and weighed. The weed community similarity analysis between sorghum varieties and study years was calculated using the following formula: Sorensen coefficient of similarity Ss = 2a / 2a + b + c, where, "a" is the number of species common to both samples, "b" is the number of species in the sample 1 only and "c" is the number of species in the sample 2 only (Dessie et al. 2025). The SPAD-502 chlorophyll meter was employed to measure the chlorophyll content of the leaves of sorghum with the SPAD optical method. The device's value corresponds to the amount of chlorophyll in the leaves (Olszewska et al. 2016). The device's head was applied to the center of the leaf, where it was measured. After two seconds, the measurement was repeated on 30 different plant leaves (the 2–3 leaf from plant top) for each test treatment. The average of 30 repetitions was the value that the camera displayed. The linear PAR radiation was measured and the LAI leaf area index was calculated using a portable AccuPAR LP-80 instrument to evaluate the leaf area index. The LAI ratio is a metric that quantifies the ratio of the substrate's area to the area of the canopy's assimilative organs, which are primarily leaves (Oleksy et al. 2009; Adeboye et al. 2018). The measurement was carried out in each plot at two randomly selected locations, each 84 cm long. The upper PAR was measured above the plants to ascertain the LAI. Subsequently, the device was positioned in the center of the canopy, approximately 20–30 cm above the ground surface, and the lower PAR reading was obtained. The post-treatment leaf area was determined by the AccuPAR LP-80 instrument using these two values. After the treatment, measurements of SPAD and LAI were taken at 7, 9, 11, 13 and 18 weeks after sowing.

Sorghum height was determined by measuring the plants in the two middle rows of each plot and reporting the results in centimetres. The sorghum was manually harvested (cut) from the same rows when the plant's dry matter content reached approximately 30%. The plant was subsequently weighed and converted to t/ha.

The average temperature during the growing season in each year of the study was higher than long-term average, with 2016 being the warmer. Total precipitation in both years was also higher than the long-term average. However, in 2016 periods of lower precipitation were observed in May, August, and September (tab. 1).

Statistical analysis of the data was preceded by checking the normality of the distribution of the dependent variables using the Shapiro-Wilk test, and the homogeneity of the variables using the Brown-Forsyth test. Further handling of the data obtained in the experiments consisted of statistical analyses using analysis of variance (ANOVA) for one-factor experiments. Field study was arranged as single-factor experiment randomized in blocks, 4 replications. Statistical procedures were conducted using Statistica 13 software (StatSoft Polska Sp. z o.o., Kraków, Poland). If the influence of a factor on a characteristic was proven, homogeneous groups were determined using the Tukey's test (HSD) at a significance level of $p = 0.05$. Correlation coefficients between number and weight of weeds, SPAD, LAI and plant height and yield of sorghum were evaluated using Pearson's correlation coefficient r. Only correlation coefficients with proven significance ($p < 0.05$) are presented.

Wyniki i dyskusja / Results and discussion

Weed species, including *C. album*, field pansy (*V. arvensis*), oilseed rape (*Brassica napus* L.), black-bindweed (*F. convolvulus*), common knotgrass (*P. aviculare*), barnyard grass (*E. crus-galli*), small-flowered crane's-bill (*Geranium pusillum* L.), common fumitory (*Fumaria officinalis* L.), red dead-nettle (*Lamium purpureum* L.), field pennycress (*T. arvense*), and redroot pigweed (*Amaranthus retroflexus* L). were found. The four most prevalent weed species during the two-year study were *F. convolvulus*, *B. napus*, *V. arvensis*, and *C. album*. The weight of all weed species between plants of various sorghum varieties varied from 2139 to 3115 and 512–596 g/m^2, number varied from 24 to 33 and 41–46 pcs/m^2. Although there was some variation, the weed communities did not differ between the varieties during the study years (tab. 2).

The Sorensen coefficient (Ss) of similarity confirms the high similarity of weed communities that occur in the canopy of each sorghum variety in a given year of the study, as indicated by the number of species and their weights (tab. 2, 4). The Ss values (greater than 50%) also suggest that the communities are highly similar between the years of the study (tab. 2). The height of the plants (PH) and the yield of sorghum (SY) varied not only between years but also between varieties. The taller plants in 2016 measured between 337 and 369 cm in height (KWS Freya, KWS Sammos, KWS Sole, KWS Juno), while the lower plants measured between 247 and 283 cm (Rona 1, Sucrosorgo 506). In the second year, the plants of KWS Juno were the tallest at 337 cm, while Rona 1 had the lowest at 274 cm. In 2016, all varieties of sorghum produced higher yields,

Tabela 1. Warunki pogodowe w sezonie wegetacyjnym w Zakładzie Doświadczalno-Dydaktycznym Złotniki
Table 1. Weather condition during growing seasons at Złotniki Research and Education Centre

Lata Years	Temperatura – Temperature [°C]						
	maj May	czerwiec June	lipiec July	sierpień August	wrzesień September	październik October	maj–październik May–October
2016	16.3	19.9	20.3	19.0	16.5	8.0	16.7
2017	13.7	17.4	18.0	18.9	13.3	10.6	15.3
Średnia – Mean 1951–2015	13.6	16.8	18.7	18.0	13.7	8.9	15.0
	Opady – Precipitation [mm]						
2016	47.2	123.8	132.8	50.3	5.6	105.0	77.5
2017	56.8	68.2	168.0	82.0	45.6	91.8	85.4
Średnia – Mean 1951–2015	51.4	59.0	76.0	57.8	43.8	37.3	54.2

Tabela 2. Charakterystyka zbiorowisk chwastów i ich podobieństwo między odmianami sorga
Table 2. A description of the weed communities and their similarity in relation to the sorghum varieties

Odmiana Variety	2016		2017		Ss 2016/2017
	WN [no./m^2]	FWW [g/m^2]	WN [no./m^2]	FWW [g/m^2]	
KWS Freya	28 a	2710 a	46 a	579 a	0.55*
KWS Sammos	24 a	2959 a	43 a	525 a	0.67
KWS Sole	29 a	2153 a	43 a	596 a	0.67
KWS Juno	28 a	2456 a	49 a	576 a	0.50
Rona 1	32 a	2139 a	41 a	549 a	0.67
Sucrosorgo 506	33 a	3115 a	44 a	512 a	0.71

WN – liczba chwastów – weed number, FWW – waga chwastów – weed weight, Ss – współczynnik Sorensena – Sorensen coefficient
* – im wartość jest bliższa 1, tym większe jest podobieństwo między zbiorowiskami – the closer to 1 the more similar the communities are to each other
0 – brak podobieństwa – no similarity
Średnie w kolumnach oznaczone tą samą literą nie różnią się istotnie według testu Tukeya ($p \leq 0,05$)
Means within a columns followed by the same letter are not significant different according to Tukey's test ($p \leq 0.05$)

Tabela 3. Wysokość i plon roślin w zależności od odmiany sorga
Table 3. Sorghum plants height and yield in relation to sorghum varieties

Odmiana Variety	2016		2017	
	sorgo – sorghum			
	SH [cm]	SY [t/ha]	SH [cm]	SY [t/ha]
KWS Freya	337 a	39.8 ab	312 ab	26.1 b
KWS Sammos	337 a	36.1 ab	324 ab	23.6 b
KWS Sole	369 a	33.9 ab	318 ab	31.7 ab
KWS Juno	369 a	44.9 a	337 a	30.7 ab
Rona 1	247 b	31.7 b	274 b	28.0 ab
Sucrosorgo 506	283 b	41.5 ab	297 ab	36.8 a

SH – wysokość rośliny – plant height, SY – plon – yield
Średnie w kolumnach oznaczone tą samą literą nie różnią się istotnie według testu Tukeya ($p \leq 0,05$)
Means within a columns followed by the same letter are not significant different according to Tukey's test ($p \leq 0.05$)

Tabela 4. Porównanie składu zbiorowisk chwastów w różnych odmianach sorgo, określone za pomocą współczynnika podobieństwa Sorensena. Im wartość jest bliższa 1, tym większe jest podobieństwo między zbiorowiskami, 0 – brak podobieństwa
Table 4. Comparison of the composition of weed communities among sorghum cultivars, as measured by the Sorensen coefficient of similarity. The closer to 1 the more similar the communities are to each other, 0 – no similarity

with KWS Juno being the highest and Rona 1 the lowest. In 2017, Sucrosorgo 506 was the highest yielding variety and KWS Sammos was the lowest (tab. 3).

A differential response of sorghum varieties was apparent in 2016, with differences between varieties disappearing rapidly in the case of LAI at 11 weeks after planting. The chlorophyll content (SPAD) stabilized within 9 weeks after sowing, and the differences between the varieties were apparent on the 11 weeks following sowing. However, these differences dissipated after an additional week (tab. 5). The results of the analysis indicate that there were no differences in the chlorophyll content and LAI values during the most recent measurement, with the exception of LAI in 2016, which was lower for Sucrosorgo 506 than for KWS Freya and KWS Sammos (tab. 5).

The correlations between the number and weight of weeds and the plant yield of individual sorghum species are illustrated in figure 1. Statistically significant relationships are the only ones for which correlation coefficients are provided. The correlations that were established in one year were not confirmed in the subsequent year, as evidenced by the data presented (fig. 1). In the case of the KWS Freya and Rona 1 varieties, a positive effect of WN was observed, whilst in the KWS Sole and KWS Juno varieties a positive effect FWW on sorghum yield was observed. An increase in weed numbers was associated with higher sorghum yields in the KWS Sammos and Sucrosorgo 506 varieties; however, the increase in their biomass resulted in reduced yields for these varieties.

Similar to corn, the presence of weeds in sorghum is one of the most significant factors that restricts crop yields (Dille et al. 2020). Typically, weed pressure changes with the year. In addition, the presence of weeds can be influenced by the competitive capacity of crop species and even between varieties of a species (Peters et al. 2014; Sardana et al. 2017). The height of crops and, in the end, their yield is typically influenced by the presence of weeds (Mhlanga et al. 2016).

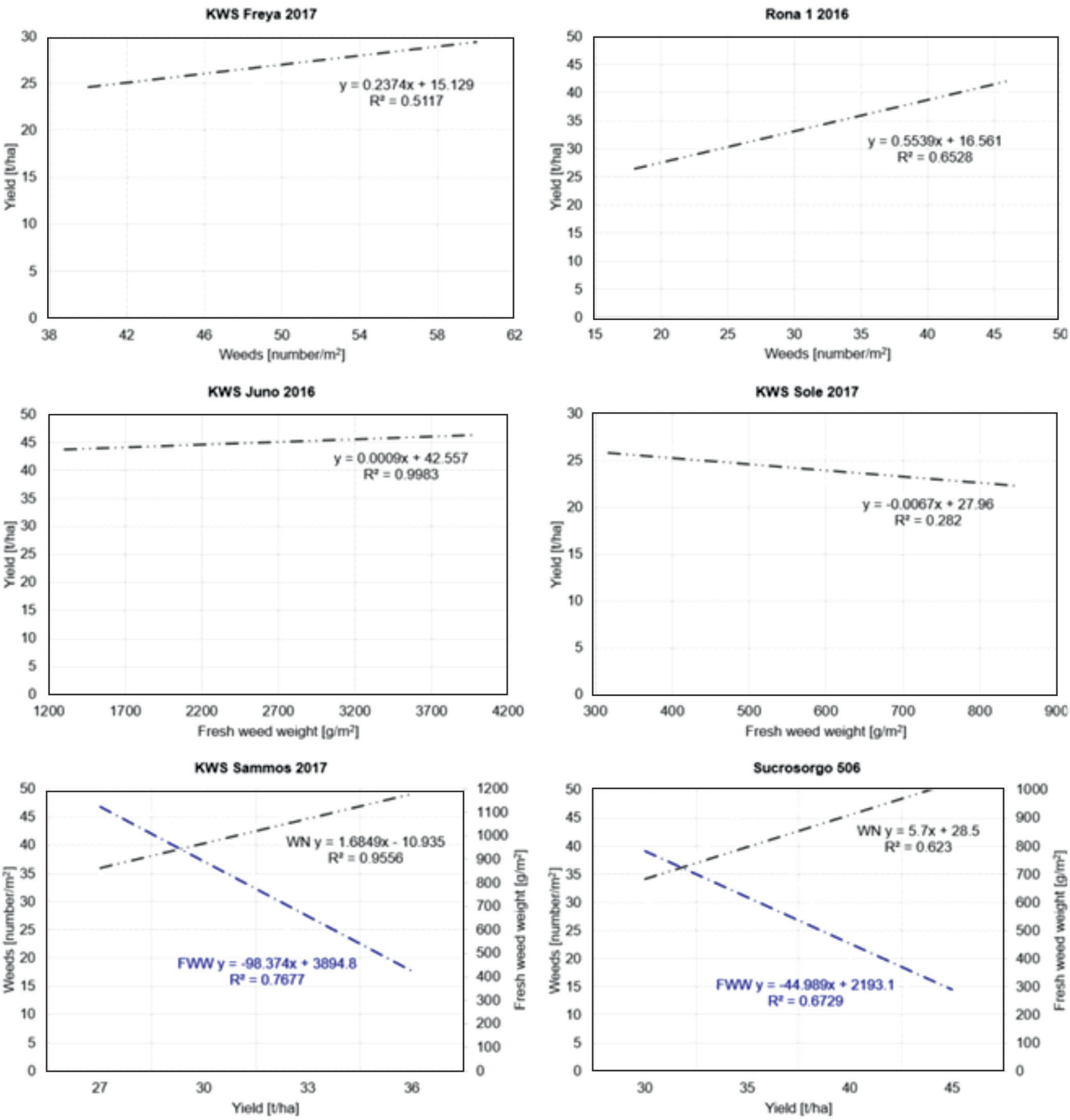
The analysis of the variation in weed species composition in our own research suggests that the communities are evenly distributed among the various sorghum varieties of any given year. The weed community analysis results, which include the species similarity (Sorensen coefficient), suggest that the weed communities are at least similar in terms of both years and varieties. The data presented suggest that the communities are highly similar, both qualitatively and quantitatively. Consequently, it was feasible to evaluate the reaction of the varieties to weed infestation. The chlorophyll content of sorghum leaves does not necessarily alter as a consequence of competition with weeds, suggesting that there are varietal responses to weeds (Giancotti et al. 2018). However, the presence of weeds can result in a slowdown in crop development, which is a negative plant response. The sorghum is in a fierce competition with the weeds for water,

Tabela 5. Zawartość chlorofilu (SPAD) i wskaźnik powierzchni liści (LAI) odmian sorgo w Zakładzie Doświadczalno-Dydaktycznym Złotniki

Table 5. Chlorophyll content (SPAD) and leaf area index (LAI) of sorghum varieties at Research and Education Centre Złotniki

Odmiana Variety	2016					2017				
	tygodnie po siewie – weeks after planting									
	7	9	11	13	18	7	9	11	13	18
	SPAD									
KWS Freya	562 a	558 a	698 a	706 a	746 a	487 a	663 a	646 a	639 a	583 a
KWS Sammos	496 b	528 a	608 b	644 a	700 a	468 a	614 a	600 a	601 a	557 a
KWS Sole	518 ab	560 a	647 ab	667 a	670 a	478 a	613 a	639 a	614 a	556 a
KWS Juno	513 ab	557 a	644 ab	686 a	724 a	430 a	624 a	656 a	603 a	579 a
Rona 1	462 b	507 a	624 ab	635 a	728 a	487 a	622 a	700 a	664 a	627 a
Sucrosorgo 506	505 ab	519 a	614 b	628 a	714 a	508 a	638 a	651 a	650 a	638 a
	LAI									
KWS Freya	4.02 a	3.16 a	4.91 a	3.62 a	5.12 a	5.55 a	3.75 a	3.40 a	4.84 a	2.46 a
KWS Sammos	3.43 ab	3.23 a	4.32 a	3.64 a	5.27 a	5.50 a	3.58 a	3.41 a	4.07 a	2.62 a
KWS Sole	2.91 ab	3.24 a	5.33 a	3.60 a	4.96 ab	5.98 a	3.59 a	3.62 a	4.27 a	3.13 a
KWS Juno	3.75 a	2.94 a	4.05 a	3.67 a	4.75 ab	6.21 a	4.65 a	3.73 a	4.98 a	2.66 a
Rona 1	1.88 b	1.93 b	3.55 a	3.17 a	4.48 ab	5.03 a	3.80 a	3.32 a	3.84 a	2.79 a
Sucrosorgo 506	1.96 b	2.47 ab	4.72 a	3.01 a	3.45 b	5.83 a	4.81 a	3.70 a	4.82 a	3.00 a

Średnie w kolumnach oznaczone tą samą literą nie różnią się istotnie według testu Tukeya ($p \leq 0,05$)
Means within a columns followed by the same letter are not significant different according to Tukey's test ($p \leq 0.05$)



Rys. 1. Analiza zależności między liczbą i świeżą masą chwastów a plonem sorgo (istotne przy $p \leq 0,05$)

Fig. 1. An analysis of the relationship between weed density, fresh weight of weeds and sorghum yield (significant at $p \leq 0.05$)

ingredients, and space. Leaf area of crop plants serves as a visual representation of these challenges (Evaraarts 1993). Sorghum can cope with weeds to some extent due to the secretion of allelopathic substances, also varying by variety (Tibugari et al. 2018), limiting the development of companion plants, although this is not always confirmed in research results (Idziak et al. 2022).

According to the results of the own experiment, sorghum leaves' chlorophyll content rose over the course of the days following the treatments, demonstrating the plants' ongoing growth despite weed pressure. However, in practice, there was no distinction between the varieties of this regard. Furthermore, the leaf area index of sorghum plants was not significantly influenced by the presence of weeds, or at least no variation was observed between the varieties that were examined. The analysis of the yield of sorghum varieties of relation to weed number and weight does not clearly indicate consistent relationships. In reality, correlations between factors that were significant in the first year of the study were primarily not confirmed in the subsequent growing season, irrespective of the variety. Weeds reduces crop yield and they are a major constraint in crop production (Horvath et al. 2023; Yadav and Kumar 2025). Zingsheim and Döring (2024) do not confirm a positive relationship of crop productivity and weed evenness, but suggest that also less diverse weed communities may be maintained without suffering yield losses. In view of the above, it can be concluded that the results obtained in our study suggest similar patterns, indicating that certain sorghum varieties may even respond positively to the presence of a moderate number of small weeds. Sorghum plants are particularly susceptible to intense competition from weeds during the initial weeks of their growth. However, this response is subject to variation due to varieties, variation, which may be attributed to the secretion of substances with allelopathic effects that can restrict the growth of vegetation surrounding sorghum plants (Głąb et al. 2017).

Wnioski / Conclusions

1. The most prevalent weed species during the two-year study were lamb's quarters (*C. album*), field pansy (*V. arvensis*), oilseed rape (*B. napus*), and black-bindweed (*F. convolvulus*). The weight of all weed species between plants of various sorghum varieties varied in the years from 2139 to 3115 and 512–596 g/m^2, number from 24 to 33 and 41–46 pcs/m^2. The weed communities did not differ between the varieties during the study years.
2. Varieties KWS Freya, KWS Sammos, KWS Sole, and KWS Juno were higher in 2016, whereas Rona 1 and Sucrosorgo 506 in 2017. The tallest in both years were KWS Juno plants, while the lowest Rona 1. All sorghum varieties yielded higher in 2016 than 2017 but during the initial year the KWS Juno, and in the second year Sucrosorgo 506 yielded the highest, while Rona 1 and KWS Sammos the lowest.
3. The chlorophyll content (SPAD) for all varieties stabilised within 9 to 13 weeks after treatment. Were no differences in the chlorophyll content and LAI values during the most recent measurement, with the exception of LAI in 2016, which was lower for Sucrosorgo 506.
4. The relationships between weed number and weight and yield within individual sorghum varieties did not show consistency across years, which may be due to the prevailing weather conditions during the years the research was conducted. However, in the case of the KWS Freya and Rona 1 varieties, a positive effect of WN was observed, whilst in the case of the KWS Sole and KWS Juno varieties, a positive effect of FWW on sorghum yield was observed. An increase in weed numbers was associated with higher sorghum yields in the KWS Sammos and Sucrosorgo 506 varieties; however, an increase in weed biomass resulted in lower yields for these varieties.
5. It is possible that the yield of sorghum is not significantly affected by a moderate weed infestation. According to the results, some sorghum varieties may even respond favourably to the presence of a relatively small number of minor weeds. The response to the presence of weeds is likely due to the release of allelopathic substances that may inhibit the growth of vegetation surrounding the sorghum plants, which varies depending on the variety.

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