PROGRESS IN PLANT PROTECTION
66 (2): 53–61, 2026
eISSN 2084-4883

DOI: 10.14199/ppp-2026-006
Published online: 15.05.2026

Received: 13.02.2026 / Accepted: 20.04.2026

ARTYKUŁ ORYGINALNY

Wpływ herbicydów na parametry fizjologiczne sześciu odmian sorga [*Sorghum bicolor* (L.) Moench] i wybranych gatunków chwastów

Impact of herbicides on physiological parameters of six sorghum varieties [*Sorghum bicolor* (L.) Moench] and selected weed species

Robert Idziak*, Hubert Waligóra, Piotr Szulc, Leszek Majchrzak, Sylwiana Nowicka

Streszczenie

W przypadku sorga stosowanie herbicydów jest najbardziej efektywnym sposobem zwalczania chwastów. Celem badania była ocena wpływu herbicydów na wskaźnik aktywności fotochemicznej (Fv/Fm) roślin. Zastosowano mieszanki dikamba + prosulfuron (DP), mezotrion + S-metolachlor (MS) oraz terbutylazyna + mezotrion + S-metolachlor (TMS). Współczynnik Fv/Fm określał wpływ herbicydu na potencjalną wydajność fotosystemu II (PSII) roślin sorga. Wydajność PSII odmian była zróżnicowana i wynosiła od 0,701 do 0,764. Największy stres po zastosowaniu mieszanki TMS zaobserwowano u odmiany Rona 1, a po zastosowaniu DP u odmiany Sucrosorgo 506. Nie stwierdzono żadnych uszkodzeń roślin sorgo po DP, natomiast po zastosowaniu MS uszkodzenia były poważne w przypadku odmian KWS Freya, KWS Juno, KWS Sammos, Rona 1 i Sucrosorgo 506. Odmiana KWS Sole była mniej dotknięta. Ponadto po zastosowaniu TMS zaobserwowano uszkodzenia liści, jednak znacznie słabsze niż po zabiegu MS. Uszkodzenia były jednak tylko tymczasowe i całkowicie ustąpiły 14 dni po zabiegu, a w przypadku odmian KWS Juno i Sucrosorgo 506 kilka dni później. Skuteczność herbicydów stosowanych do zwalczania *Echinochloa crus-galli* była minimalna. Najskuteczniejsza w zwalczaniu *Chenopodium album* była mieszanka terbutylazyny z mezotrionem i S-metolachlorem, a najmniej skuteczna – dikamba z prosulfuronem. Zastosowanie terbutylazyny z mezotrionem i S-metolachlorem doprowadziło do całkowitego zahamowania fotosyntezy u *C. album*.

Słowa kluczowe: aktywność fotochemiczna, chwasty, herbicydy, odmiany sorga, uszkodzenia roślin

Abstract

In sorghum, herbicides are the most effective in weed control. The study's aim was to assess the impact of herbicides on the photochemical activity index (Fv/Fm). The mixtures dicamba + prosulfuron (DP), mesotrione + S-metolachlor (MS), and terbuthylazine + mesotrione + S-metolachlor (TMS) were applied. Fv/Fm determined the impact of herbicide on the potential photosystem II (PSII) productivity of sorghum plants. The PSII efficiency of the varieties varied at this time, and values ranging from 0.701 to 0.764. Variety Rona 1 experienced the most severe stress following the application of TMS, as well as variety Sucrosorgo 506 in response to DP application. No damage to sorghum plants was observed following the DP, severe following MS, particularly in the KWS Freya, KWS Juno, KWS Sammos, Rona 1, and Sucrosorgo 506. The KWS Sole variety was less affected. Additionally, leaf damage was observed following TMS application; however, it was considerably less severe than the symptoms observed following MS herbicide spraying. However, the damages were only temporary and completely dissipated 14 days after the treatment, and in the case of the KWS Juno and Sucrosorgo 506 varieties, a few days later. The effectiveness of the herbicides applied to control *Echinochloa crus-galli* was minimal. The terbuthylazine + mesotrione + S-metolachlor mixture most effective control *Chenopodium album*, and dicamba + prosulfuron the least effective. The use of terbuthylazine + mesotrione + S-metolachlor lead to complete photosynthesis inhibition of *C. album*.

Keywords: photochemical activity, weeds, herbicides, sorghum variety, crop injuries

Uniwersytet Przyrodniczy w Poznaniu
ul. Dojazd 11, 60-632 Poznań
* corresponding author: robert.idziak@up.poznan.pl

Wstęp / Introduction

Weed growth is facilitated by the wide inter-rows and slow initial growth of sorghum plants. The competitive effect of weeds can reduce sorghum yield from 15 to as much as 97%, depending on climatic conditions (Peerzada et al. 2017). Consequently, it is crucial to regulate them shortly after sorghum emergence. There is minimal impact on yield when weed infestation occurs at a later stage (Kaczmarek et al. 2012).

Herbicides are the most effective method of controlling weeds in sorghum (Machado et al. 2016). A permanent use of a limited number of herbicides (several agents) can result in the selection of weed species that are resistant to a specific active substance (Ofosu et al. 2023). According to Kaczmarek et al. (2009) and Idziak et al. (2013), weed communities in sorghum are similar in composition to those found in maize, with the dominant species being primarily *Chenopodium album* L., *Viola arvensis* Murr., *Polygonum* ssp. L., *Echinochloa crus-galli* (L.) Beauv., *Brassica napus* var. *oleifera*, *Matricaria inodora* (L.), *Geranium pusillum* L., and *Thlaspi arvense* (L.). Grass weeds particularly those species from the genus *Echinochloa*, *Panicum*, *Digitaria* are considered to be the most common and troublesome weeds in grain sorghum (Peerzada et al. 2017). Traore et al. (2003) indicated that also *Amaranthus* spp. are among the ten most common and ten most troublesome weeds in sorghum (Traore et al. 2003). In Poland, only herbicides based on glyphosate, pendimethalin and dicamba are authorised for weed control in sorghum. Worldwide, the range of active substances is much wider and also includes bentazon, bromoxynil, mesotrione, dicamba, S-metolachlor, quinclorac, fluroxypyr, dimethenamid-P, halosulfuron-methyl, saflufenacil or 2.4-D (Ikley et al. 2025). The similarity between sorghum and corn plants suggests that agents that have been registered for corn can also be used in sorghum (Snarska et al. 2012). Nonetheless, not all selective agents for corn have the same impact on sorghum (Takano et al. 2016). In comparison to corn, sorghum plants have a much lower tolerance to formulations containing nicosulfuron (Bowman et al. 2020), and within three weeks of application, over 90% of most sorghum varieties may be injured (Takano et al. 2016). In addition, formulations that are selective against corn and contain a combination of floramsulfuron and methylsodium iodosulfuron contribute to the complete destruction of sorghum plants (Kaczmarek et al. 2009). It is crucial to investigate potential agents for chemical weed control in sorghum due to the species' limited availability of herbicides.

The phytotoxicity of herbicides to plants can be attributed to the sensitivity of sorghum varieties, the time of application, and the dose of the product (Waligóra and Majchrzak 2019). Research has shown that 2.4-D had phytotoxic effects on all hybrid varieties that were tested in the initial days following spraying (Besancon et al. 2016). However, the damage to the majority of hybrids dissipated over time, with the exception of those that experienced a substantial decline in yield (by 12–27%). According to Takano et al. (2016), the response of sorghum was also influenced by s-metolachlor and a combination of s-metolachlor and atrazine, which varied depending on the variety. Dicamba is an additional active substance that may exhibit varying selectivity based on the specific sorghum varieties (Besancon et al. 2016). This reaction among the varieties may be attributed to the slower metabolism of dicamba in sensitive varieties.

In both crops and weeds, the primary focus of herbicides is the regulation of processes such as photosynthesis, respiration, cell division, or amino acid synthesis (Sherwani et al. 2015). Consequently, herbicides, which are substances intended to eradicate weeds, have harmful effects on plants and block and inhibit a number of processes. A reduction in leaf area per unit area, a parameter that directly impacts plant productivity (Lambert et al. 2014), and a decrease in chlorophyll content in the leaves are potential symptoms of the herbicide's phytotoxic effects on a crop (Zheryakov and Zheryakova 2021).

The proposed research hypothesis suggested that herbicides do more than just manage weeds; they may also negatively affect sorghum plants. However, this effect may be temporary and not reflected in the crop's yield. Simultaneously, it is impossible to exclude the possibility of variegated responses from sorghum plants. The study's objective was to assess the impact of applied herbicides on the photochemical activity index, and potential photosystem II (PSII) productivity of sorghum plants and selected weed species.

Materiały i metody / Materials and methods

The greenhouse study was carried out at the Poznań University of Life Sciences in 2017. The research employed herbicides that are frequently employed in the cultivation of corn. Treatments included the mixtures included dicamba + prosulfuron (DP, Casper 55 WG, 0.3 kg/ha, Syngenta Poland, Warszawa), mesotrione + S-metolachlor (MS, Camix 560 SE, 2.0 l/ha, Syngenta Poland, Warszawa) and terbuthylazine + mesotrione + S-metolachlor (TMS, Lumax 537.5 SE, 3.5 l/ha, Syngenta Poland, Warszawa), and the untreated check (no herbicide were applied). Herbicides were applied at the 2–3 leaf stage of sorghum. Active substances with varying mechanisms of action were present in herbicide formulations, including auxin mimics (dicamba, group 4 according to HRAC), inhibitors of acetolactate synthase (prosulfuron, HRAC 2), inhibitors of hydroxyphenyl pyruvate dioxygenase (mesotrione, HRAC 27), inhibitors of very long-chain fatty acid synthesis (S-metolachlor, HRAC 15), and inhibitors of photosynthesis at photosystem II (terbuthylazine, HRAC 5).

Sorghum was sown in pots (12 cm in diameter), with 4 plants in each pot, in 3 replications. Universal soil with pH 5.5–6.5 from Wokas was used as a substrate. Herbicides were applied at the 2–3 leaf stage of sorghum, using a greenhouse sprayer equipped with one TeeJet AIXR 11004 flat jet nozzle (TeeJet Technologies GmbH, Germany) with a spray rate of 200 l/ha and an operating pressure of 0.35 MPa, and a speed of 4.5 km/h. The study was conducted on the following varieties of sorghum: KWS Freya, KWS Sammos, KWS Sole, KWS Juno, Rona 1, and Sucrosorgo 506.

Substrate moisture content was maintained at approximately 60–70% of its maximum water capacity. The air temperature during the experiments was 25°C ±2 during the day and 18–20°C ±1 at night, with natural sunlight supplemented by artificial lighting at 600 μE/m/s. Humidity was maintained between 50–80%. The photochemical activity index (Fv/Fm) of the photosynthetic apparatus determined the impact of herbicide application on the potential PSII productivity of sorghum plants. Sorghum plants were assessed 3 and 14 days after herbicides treatment (3 and 14 DAT). The potential PSII productivity of *C. album* and *E. crus-galli* plants were assessed 3, 5, 7 and 14 days after herbicides treatment (3, 5, 7 and 14 DAT). Fluorescence measurements were conducted using an OS5p fluorometer from OPTISCIENCES.INC. The fluorescence after dark adaptation with PAR (photosynthetically active radiation) clip – Fv/Fm test protocol was selected, where the following parameters were measured: Fm – maximum and Fv/Fm – maximum photochemical yield of PSII (Zai et al. 2012). For optimal plant growth, this parameter is approximately 0.85, while a value of 0.2–0.3 suggests irreversible structural modifications (Cetner et al. 2016). According to the manufacturer's guidelines, the instrument settings were determined (OS5p User's Guide, The standard in Plant Stress Measurement, Opti-Sciences, 040113). The detector signal amplification was set to 5, and the modulation light source was configured to emit red light at an intensity level of 10. The intensity of the saturation flash was configured to 30. A single plant was chosen randomly from each pot, and a clip was fastened to the middle section of its youngest, completely grown leaf. They were permitted to remain stationary for 30 minutes before being assessed using a fluorometer.

Phytotoxicity of the experimental treatments was evaluated at 3 and 14 days following herbicide treatment (3 and 14 DAT). On a scale of 0 to 100%, the phytotoxicity of the treatments to sorghum (the inhibition of sorghum plant growth) was evaluated, with 0% indicating no damage and 100% indicating the complete destruction of the plants. The experiment on weed control efficacy was designed as a single-factor experiment in three replications. The study subjects were plants of weed species commonly found in sorghum, namely *C. album* and *E. crus-galli*. The efficacy of the herbicides was visually assessed 3, 5, 7 and 14 days after treatment in each treated plot by comparison to the untreated control treatment. The results were expressed simply as a percentage according to an inverted scale to express percent weed control (0% = no weed control, 100% = full weed control).

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 two-factor experiments, and single-factor experiment for weed control study (herbicides). Study was arranged as two-factor experiment (varieties and herbicides) completely randomized, in 3 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 $p = 0.05$.

Wyniki i dyskusja / Results and discussion

The initial three days following the application of the herbicides were the sole time during which the photosynthetic activity index (Fv/Fm) of sorghum plants varied. The PSII efficiency of the varieties varied at this time, as evidenced by the results from the control facility, with values ranging from 0.701 to 0.764 (tab. 1). A reduction in the index value suggests that the PSII function has been compromised, which suggests that the plants were under stress. After the application of a specific active substance herbicide mixture, the differences between varieties are not readily apparent. However, statistical analysis suggests that there is typically no discernible interaction between varieties and herbicides. The sorghum plants of Rona 1 cultivar experienced the most severe stress following the application of TMS mixture (0.542), as well as Sucrosorgo 506 in response to DP application (0.645). Generally, the lower index values observed following the application of primarily MS and TMS mixtures in comparison to the control objects suggest that the plants of the tested varieties have responded to the applied herbicides. After the application of MS and TMS, the plant function is already disrupted, despite the fact that the mean values do not indicate any effect of DP on the photoperiodic (0.729 and 0.714). In contrast, the average values for the varieties indicate that KWS Freya, KWS Sammos, and KWS Sole exhibit a similar response, KWS Juno and Sucrosorgo 506 exhibit intermediate responses, and Rona 1 exhibits the strongest response. Compared to coefficient values from the control object, average values from objects that were pressured with herbicide show that

Tabela 1. Wpływ herbicydów na potencjalną wydajność PSII roślin sorga wyrażoną wskaźnikiem aktywności fotochemicznej aparatu fotosyntetycznego

Table 1. Effect of herbicide application on the potential PSII productivity of sorghum plants as expressed by the photosynthetic apparatus photochemical activity index

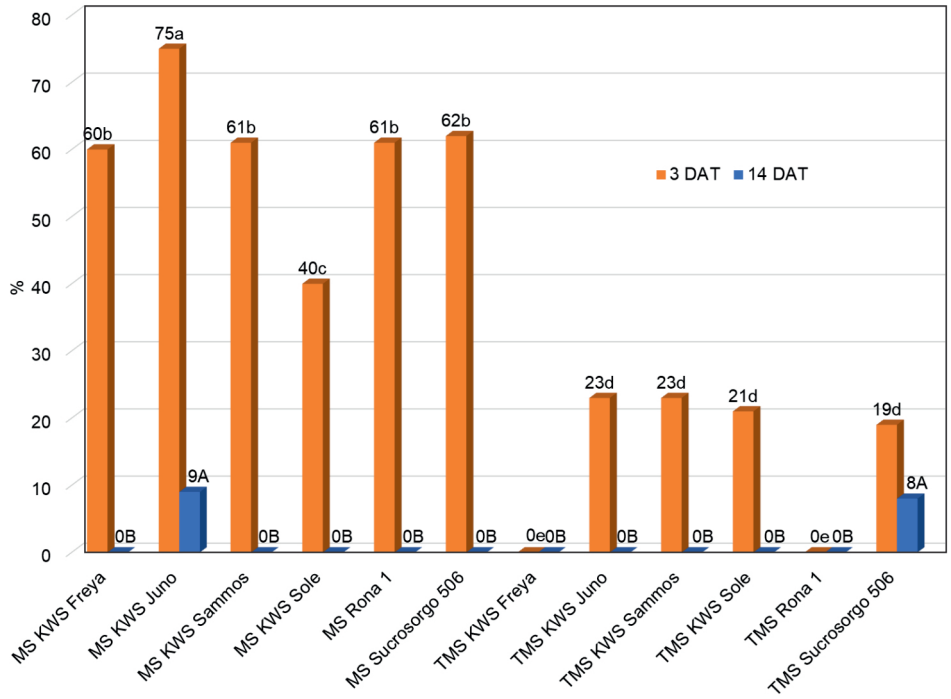
Odmiana Variety	Herbicyd – Herbicide				Średnia Mean
	3 DAT[1]				
	kontrola – control	DP	MS	TMS	
KWS Freya	0.764 a	0.741 ab	0.695 a-d	0.693 a-d	0.723 A (0.710)[2]
KWS Sammos	0.734 ab	0.736 ab	0.733 ab	0.690 a-d	0.723 A (0.720)
KWS Sole	0.742 ab	0.729 ab	0.682 bcd	0.683 bcd	0.709 A (0.698)
KWS Juno	0.727 abc	0.736 ab	0.677 bcd	0.676 bcd	0.704 AB (0.696)
Rona 1	0.701 a-d	0.698 a-d	0.649 cd	0.542 e	0.647 C (0.630)
Sucrosorgo 506	0.705 a-d	0.645 d	0.672 bcd	0.673 bcd	0.674 BC (0.663)
Średnia – Mean HE	0.729 A	0.714 A	0.685 B	0.659 C	–
	14 DAT				
KWS Freya	0.714 a	0.718 a	0.698 a	0.675 a	0.701 AB (0.697)
KWS Sammos	0.688 a	0.723 a	0.695 a	0.702 a	0.702 AB (0.707)
KWS Sole	0.705 a	0.724 a	0.708 a	0.699 a	0.709 A (0.710)
KWS Juno	0.693 a	0.687 a	0.690 a	0.691 a	0.690 AB (0.689)
Rona 1	0.687 a	0.679 a	0.682 a	0.670 a	0.679 B (0.677)
Sucrosorgo 506	0.701 a	0.701 a	0.673 a	0.702 a	0.694 AB (0.692)
Średnia – Mean HE	0.698 A	0.705 A	0.691 A	0.690 A	–

[1] DAT – dni po zabiegu – days after treatment
[2] wartości obiektów kontrolnych są wyłączone ze średnich – control object values are excluded from the averages
DP – dikamba + prosulfuron – dicamba + prosulfuron
MS – mezotrion + S-metolachlor – mesotrione + S-metolachlor
TMS – terbutylazyna + mezotrion + S-metolachlor – terbuthylazine + mesotrione + S-metolachlor
Jednorodne grupy w obrębie kolumn i wierszy oznaczone są małymi literami, natomiast średnie dla danego czynnika oznaczone są wielkimi literami
Uniform groups within columns and rows are denoted by lowercase letters, while the averages for a specific factor are denoted by uppercase letters

plants were stressed. The data collected on day 14 suggests that the reaction was short-lived, disappearing after only a dozen days, despite the reaction of the varieties on the third day after herbicide application. The statistical analysis results suggest that the parameter under investigation did not vary between varieties and herbicides. However, the average values suggest that Rona 1 was subjected to the most severe stress.

The relationships that were identified in the analysis of potential PSII productivity of sorghum are further validated by a visual assessment of herbicide phytotoxicity (fig. 1). No damage to sorghum plants was observed following the application of DP; therefore, it is not depicted in the graph. Severe damage (light spots along the entire length and ends of the leaves and partially curled leaves) was observed in sorghum plants following MS application, particularly in the KWS Freya, KWS Juno, KWS Sammos, Rona 1, and Sucrosorgo 506 varieties (60–75% of the area affected). The KWS Sole variety (40%) was less affected. Additionally, leaf damage was observed following TMS application; however, it was considerably less severe than the symptoms observed following MS herbicide spraying (19–20%). However, the damages were only temporary and completely dissipated 14 days after the treatment, and in the case of the KWS Juno and Sucrosorgo 506 varieties, a few days later.

The efficacy of the herbicides used against *E. crus-galli* was negligible, with a range of 10–40% (fig. 2). The TMS mixture was the most effective in *C. album* control, followed by the MS mixture (moderately effective), and the DP mixture, which was the least effective (100%, 80%, and 30%, respectively). In both weed species from the control and DP treatment, changes in the Fv/Fm ratio over time were comparable (fig. 3). When *E. crus-galli* plants were first treated, they showed a strong reaction to MS and TMS mixtures. However, this was only a short-term inhibition of photosynthesis, and after a few days, the plants were nearly as healthy as the control plants. The responses of *C. album* plants to TMS and MS varied. The plant's condition significantly improved after 14 days, following a strong inhibition of photosynthesis, which was followed by a moderate response to MS. On the other hand, the utilization of TMS was linked to a significant disruption of photosynthesis, which included its complete inhibition. The Fv/Fm index changes are entirely consistent with the results of the herbicidal efficacy analysis of the mixtures employed (fig. 2).



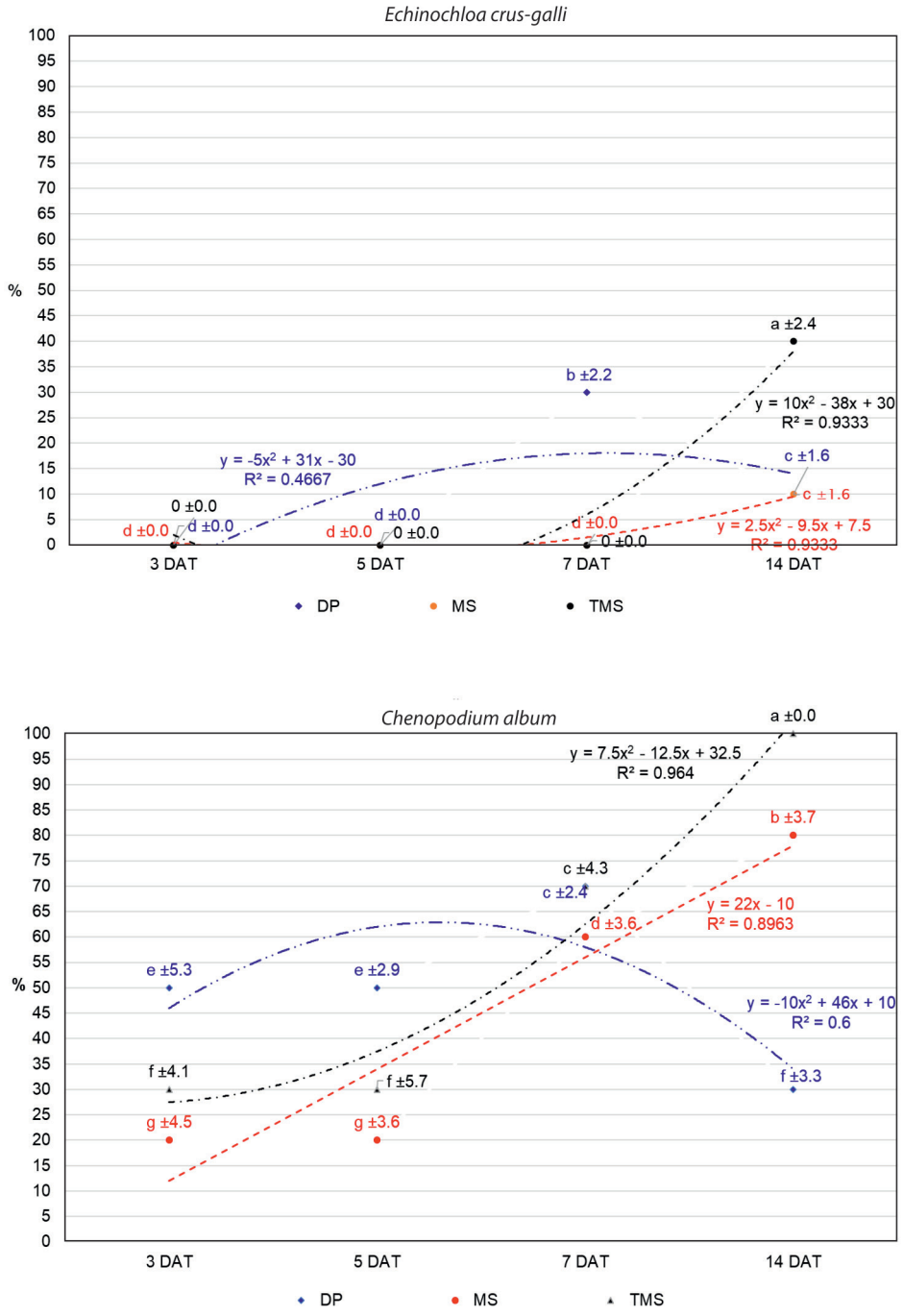
DAT – dni po zabiegu – days after treatment
MS – mezotrion + S-metolachlor – mesotrione + S-metolachlor
TMS – terbutylazyna + mezotrion + S-metolachlor – terbuthylazine + mesotrione + S-metolachlor

Rys. 1. Zahamowanie wzrostu roślin sorga po zastosowaniu herbicydów mezotrion + S-metolachlor i terbutylazyny + mezotrion + S-metolachlor
Fig. 1. The inhibition of sorghum plant growth by mesotrione + S-metolachlor and terbuthylazine + mesotrione + S-metolachlor herbicides

Dille et al. (2020) claim that in sorghum, as in corn, the main factor limiting yield is the presence of weeds. Weeds typically affect the height of crops and, as a result, their yield (Mhlanga et al. 2016). The ability of crop species to compete, as well as between varieties of a crop species, can affect the presence of weeds (Sardana et al. 2017). Weeds are particularly vulnerable to plants that are cultivated in wide rows and low density, such as corn and sorghum (Horvath et al. 2023). Weed control, which is primarily based on the use of herbicides, is imperative for their cultivation (Peerzada et al. 2017; Idziak et al. 2022). The objective of chemicals is to control weed infestations while remaining inert to crops. However, it is possible that the use of these substances, even in the recommended dosages, can have a negative impact on crops, such as growth inhibition, chlorosis, or necrosis (Magalhães et al. 2000). The majority of these modifications are temporary and do not have a lasting impact on yields, although they can also result in a decrease (Evaraarts 1993). Chlorophyll fluorescence measurement is employed to ascertain the photosynthetic activity and plant response to adverse environmental conditions (Cetner et al. 2016). The most accurate way to determine if a plant has experienced stress is to look at its PSII photosystem. The value of the Fm decreases in comparison to the control when unfavorable developmental conditions for the plant occur (Hazrati et al. 2016), as not all of the PSII electron acceptors have been completely down-regulated (Kalaji and Łoboda 2010). Plant stress also causes a drop in the Fv/Fm value (Cetner et al. 2016). According to Sharma et al. (2015), this parameter represents the maximum quantum yield of photosynthesis II.

Variable values of this parameter were also observed in the control, suggesting that there may be variations in this process among different varieties. All varieties responded more strongly to the application of mixtures containing MS and TMS, as indicated by lower index values during the first evaluation (3 DAT). The Rona 1 variety exhibited the most robust response to TMS and a particularly pronounced response to MS. In contrast, it was found that the Sucrosorgo 506 variety was more exposed to DP. Visual evaluation of the condition of sorghum plants verified that the application of MS and TMS mixtures resulted in leaf discolouration that covered over half of their leaf area in all sorghum varieties, except the KWS Sole variety. The discolouration was eradicated within a few days in the majority of plant varieties; however, the KWS Juno and Sucrosorgo 506 varieties necessitated an additional several days to regenerate.

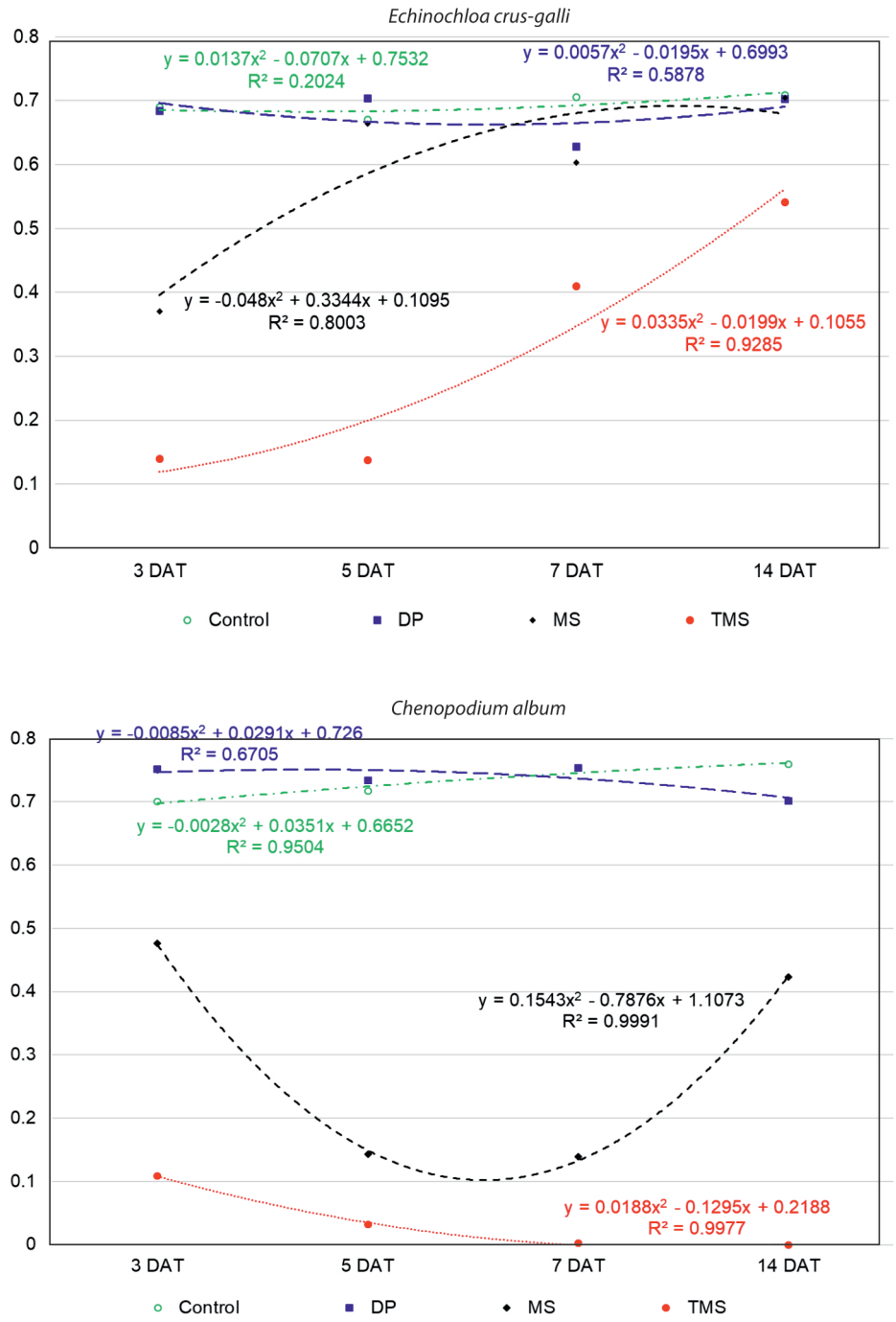
The efficacy of herbicides was in accordance with the condition of *E. crus-galli* and *C. album* plants, as indicated



DAT – dni po zabiegu – days after treatment
DP – dicamba + prosulfuron – dikamba + prosulfuron
MS – mezotrion + S-metolachlor – mesotrione + S-metolachlor
TMS – terbutylazyna + mezotrion + S-metolachlor – terbuthylazine + mesotrione + S-metolachlor

Rys. 2. Skuteczność zwalczania *Echinochloa crus-galli* i *Chenopodium album* za pomocą testowanych herbicydów
Fig. 2. Efficacy of *Echinochloa crus-galli* and *Chenopodium album* control with the tested herbicide mixtures

by the Fv/Fm index. The effectiveness of the MS and TMS mixtures is due to the presence of mesotrione, to which *C. album* is sensitive, especially in the early stages of development (Bajwa et al. 2019; Vranjes et al. 2019). The herbicides, the least effective control *E. crus-galli*. The TMS herbicide caused the most significant stress in this weed species, as indicated by the chlorophyll fluorescence index measurements. This stress was reflected in the herbicide's exceedingly low efficacy in controlling the weed. The presence of s-metolachlor in the mixture should lead to the effective control of *E. crus-galli* (Davos et al. 2008). However, our research results have not yet verified this.



DAT – dni po zabiegu – days after treatment
DP – dicamba + prosulfuron – dikamba + prosulfuron
MS – mezotrion + S-metolachlor – mesotrione + S-metolachlor
TMS – terbutylazyna + mezotrion + S-metolachlor – terbuthylazine + mesotrione + S-metolachlor

Rys. 3. Wpływ herbicydów na potencjalną wydajność PSII roślin *Echinochloa crus-galli* i *Chenopodium album* wyrażoną wskaźnikiem aktywności fotochemicznej aparatu fotosyntetycznego
Fig. 3. Effect of herbicide application on the potential PSII productivity of *Echinochloa crus-galli* and *Chenopodium album* plants as expressed by the photosynthetic apparatus photochemical activity index

Sorghum plants are particularly susceptible to intense competition from weeds during the initial weeks of their growth. Herbicides are the primary method of weed control in this species, which is a critical aspect of plant cultivation, similar to corn. To be effective in the elimination of weeds, herbicides must also be safe for sorghum. Sorghum plants responses to protective measures are contingent upon the active substances employed and the variety. However, research has indicated that the adverse effects of certain substances were minimal and, more importantly, transient.

Wnioski / Conclusions

1. A reduction in the index value suggests that the PSII function has been compromised, which suggests that the plants were under stress. The sorghum plants of Rona 1 variety experienced the most severe stress following the application of terbuthylazine + mesotrione and S-metolachlor mixture, as well as Sucrosorgo 506 in response to dicamba + prosulfuron application.
2. In general, the plant functions were already disrupted following the application of mesotrione with S-metolachlor and terbuthylazine + mesotrione + S-metolachlor mixture; however, the mean values do not suggest any effect of dicamba + prosulfuron mixture on the photoperiodic.
3. No damages to sorghum plants were observed following the application of dicamba + prosulfuron. Severe was observed following mesotrione + S-metolachlor application, particularly in the KWS Freya, KWS Juno, KWS Sammos, Rona 1, and Sucrosorgo 506 varieties. The KWS Sole variety was less affected. The damages were only temporary and completely dissipated over a dozen days after the treatment.
4. The effectiveness of the herbicides applied to control *E. crus-galli* was minimal. *Echinochloa crus-galli* plants showed a strong but temporary reaction to mesotrione + S-metolachlor and terbuthylazine + mesotrione + S-metolachlor mixtures.
5. The terbuthylazine + mesotrione + S-metolachlor mixture was the most effective in *C. album* control, the mesotrione + S-metolachlor mixture moderately effective, and the dicamba + prosulfuron mixture, the least effective.
6. The use of terbuthylazine + mesotrione + S-metolachlor lead to complete photosynthesis inhibition of *C. album*. The Fv/Fm index changes were entirely consistent with the results of the herbicidal efficacy analysis of the mixtures employed.

Literatura / References

Bajwa A.A., Zulfiqar U., Sadia S., Bhowmik P., Chauhan B.S. 2019. A global perspective on the biology, impact and management of *Chenopodium album* and *Chenopodium murale*: two troublesome agricultural and environmental weeds. Environmental Science and Pollution Research 26: 5357–5371. DOI: 10.1007/s11356-018-04104-y

Besancon T.E., Riar R., Heiniger R.W., Weisz R., Everman W.J. 2016. Rate and timing effects of growth regulating herbicides applications on grain sorghum (*Sorghum bicolor*) growth and yield. Advances in Agriculture 2016 (2): 302507. DOI: 10.1155/2016/9302507

Bowman H.D., Barber T., Norsworthy J.K., Roberts T.L., Kelley J., Gbur E.E. 2020. Resistance of InzenTM grain sorghum to multiple pre- and post-applied acetolactate synthase-inhibiting herbicides. Weed Technology 35 (1): 57–64. DOI: 10.1017/wet.2020.69

Cetner M.D., Dąbrowski P., Samborska I.A., Łukasik I., Sworyna T., Pietkiewicz S., Bąba W., Kalaji H.M. 2016. Zastosowanie pomiarów fluorescencji chlorofilu w badaniach środowiskowych. Kosmos 65 (2): 197–205.

Davos Y., Cougnon M., Vergucht S., Bulcke R., Haesaert G., Steurbaut W., Reheul D. 2008. Environmental impact of herbicide regimes used with genetically modified herbicide-resistant maize. Transgenic Research 17 (6): 1059–1077. DOI: 10.1007/s11248-008-9181-8

Dille J.A., Stahlman P.W., Thompson C.R., Bean B.W. 2020. Potential yield loss in grain sorghum with weed interference in the USA. Weed Technology 34 (4): 1–17. DOI: 10.1017/wet.2020.12

Evaraarts A.P. 1993. Effects of competition with weed on the growth, development and yield of sorghum. The Journal of Agricultural Science 120 (2): 187–196. DOI: 10.1017/S0021859600074220

Hazrati S., Tahmasebi-Sarvestani Z., Modarres-Sanavy S.A.M., Mokhtassi-Bidgoli A., Nicola S. 2016. Effects of water stress and light intensity on chlorophyll fluorescence parameters and pigments of *Aloe vera* L. Plant Physiology and Biochemistry Journal 106: 141–148. DOI: 10.1016/j.plaphy.2016.04.046

Horvath D.P., Clay S.A., Swanton C.J., Anderson J.V., Chao W.S. 2023. Weed-induced crop yield loss: a new paradigm and new challenges. Trends in Plant Science 28 (5): 567–582. DOI: 10.1016/j.tplants.2022.12.014

Idziak R., Skrzypczak W., Waligora H., Woznica Z. 2013. The effect of mesotrione applied with adjuvants on weed control efficacy and forage sorghum tolerance. Turkish Journal of Agriculture and Forestry 37 (3): 265–270. DOI: 10.3906/tar-1203-29

Idziak R., Waligóra H., Szuba V. 2022. The influence of agronomical and chemical weed control on weed of corn. Journal of Plant Protection Research 62 (2): 215–222. DOI: 10.24425/jppr.2022.141362

Ikley J., Christoffers M., Dalley C., Gramig G., Howatt K., Humphries T., Jenks B., Lim C., Ostlie M., Peters M., Robinson A., Stachler J., Thostenson A., Valenti H.H. 2025. North Dakota Weed Control Guide. North Dakota State University, Fargo, North Dakota, 136 ss.

Kaczmarek S., Matysiak K., Kierzek R. 2012. Ocena wrażliwości *Sorghum vulgare* L. na wybrane substancje aktywne herbicydów. Nauka Przyroda Technologia 6 (2): #27.

Kaczmarek S., Matysiak K., Krawczyk R. 2009. Badania nad chemicznym odchwaszczaniem sorga zwyczajnego (*Sorghum vulgare* Perz.). Acta Scientiarium Polonorum, Agricultura 8 (1): 27–35.

Kalaji H.M., Łoboda T. 2010. Fluorescencja chlorofilu w badaniach stanu fizjologicznego roślin. Szkoła Główna Gospodarstwa Wiejskiego, Warszawa, 116 ss. ISBN 978-83-7583-119-1.

Lambert R.J., Mansfield B.D., Mumm R.H. 2014. Effect of leaf area on maize productivity. Maydica 59 (1): 58–63.
Machado F.G., Jakelaitis A., Gheno E.A., de Oliveira R.S., Rios F.A., Franchini L.H.M., Lima M.S. 2016. Performance of herbicides for weed control in sorghum. Revista Brasileira De Herbicidas 15 (3): 281–289. DOI: 10.7824/rhb.v15i3.476
Magalhães P.C., Silva J.B., Durães F.O.M., Ribeiro L.S. 2000. Phytotoxicity caused by herbicides to sorghum crop at early stages of development. Planta Daninha 18 (3): 483–490. DOI: 10.1590/S0100-83582000000300014
Mhlanga B., Chauhan B.S., Thierfelder C. 2016. Weed management in maize using crop competition: A review. Crop Protection 88: 28–36. DOI: 10.1016/j.cropro.2016.05.008
Ofosu R., Agyemang E.D., Márton A., Pásztor G., Taller J., Kazinczi G. 2023. Herbicide resistance: managing weeds in a changing world. Agronomy 13 (6): 1595. DOI: 10.3390/agronomy13061595
Peerzada A.M., Ali H.H., Chauhan B.S. 2017. Weed management in sorghum [*Sorghum bicolor* (L.) Moench] using crop competition: A review. Crop Protection 95: 74–80. DOI: 10.1016/j.cropro.2016.04.019
Sardana V., Mahajan G., Jabran K., Chauhan B.S. 2017. Role of competition in managing weeds: an introduction to the special issue. Crop Protection 95: 1–7. DOI: 10.1016/j.cropro.2016.09.011
Sharma D.K., Andersen S.B., Ottosen C.O., Rosenqvist E. 2015. Wheat cultivars selected for high Fv/Fm under heat stress maintain high photosynthesis, total chlorophyll, stomatal conductance, transpiration and dry matter. Physiologia Plantarum 153 (2): 284–298. DOI: 10.1111/ppl.12245
Sherwani S.I., Arif I.A., Khan H.A. 2015. Modes of action of different classes of herbicides. DOI: 10.5772/61779. W: Herbicides, Physiology of Action, and Safety. InTech, 344 ss. ISBN 978-953-51-2217-3. DOI: 10.5772/59891
Snarska K., Wyrzykowski P., Konecki R. 2012. Analiza działania wybranych herbicydów i ich wpływ na plonowanie sorga w warunkach północno-wschodniej Polski. Progress in Plant Protection/Postępy w Ochronie Roślin 52 (2): 272–275. DOI: 10.14199/ppp-2012-048
Takano H.K., Da Silva Rubin R., Marques L.H., Tranquini S.M., Fadin D.A., Kalsing A., Neves R., Júnior O.P. 2016. Potential use of herbicides in different Sorghum hybrids. African Journal of Agricultural Research 11 (26): 2277–2285. DOI: 10.5897/AJAR20163.11190
Traore S., Manson S.C., Martin A.R., Mortensen D.A., Spotanski J.J. 2003. Velvetleaf interference effects on yield and growth of grain sorghum. Agronomy Journal 95 (6): 1602–1607. DOI: 10.2134/agronj2003.1602
Vranjes F., Vrbcinanin S., Nedeljkovic D., Savic A., Bozic D. 2019. The responce of *Chenopodium album* L. and *Abutilon theophrasti* Medik. to reduced doses of mesotrione. Journal of Enviromental Science and Health, part B, 54 (7): 615–621. DOI: 10.1080/03601234.2019.1616980
Waligóra H., Majchrzak L. 2019. Ocena skuteczności chwastobójczej wybranych herbicydów stosowanych w uprawie sorga zwyczajnego. Fragmenta Agronomica 36 (3): 70–76.
Zai X.M., Zhu S.N., Qin P., Wang X.Y., Che L., Luo F.X. 2012. Effect of *Glomus mosseae* on chlorophyll content, chlorophyll fluorescence parameters, and chloroplast ultrastructure of beach plum (*Prunus maritima*) under NaCl stress. Photosynthetica 50 (3): 323–328. DOI: 10.1007/s11099-012-0035-5
Zheryakov E.V., Zheryakova Y.I. 2021. Changes in the content of chlorophyll in leaves when using pesticides and microfertilizers. IOP Conference Series: Earth and Environmental Science 843: 012043. DOI: 10.1088/1755-1315/843/1/012043