

Weed control in kale in terms of reducing herbicide use

ZBIGNIEW ANYSZKA , JOANNA GOLIAN 

The National Institute of Horticultural Research, Weed Science Laboratory, Skierniewice, Poland

*Corresponding author: zbigniew.anyszka@inhort.pl

Citation: Anyszka Z., Golian J. (2026): Weed control in kale in terms of reducing herbicide use. *Plant Protect. Sci.*, 62: 373–385.

Abstract: In studies conducted in 2018–2020 on transplant kale, methods of weed control, including mechanical weeding, flame weeding, mechanical weeding combined with flame weeding, and herbicide use, were tested. Chemical control was based on the use of metamitron alone before planting; metamitron before planting, followed by pyridate 1–3 weeks after planting; pyridate alone at full rate and at a reduced dose with the addition of adjuvant; and pyridate using the split-application method at 14-day intervals. During the studies, weed control, the number and biomass of weeds, secondary weed infestation, the response of kale to non-chemical methods and herbicides, and kale leaf yield were determined. The highest weed control and weed number reduction was achieved after mechanical treatments, slightly lower after metamitron use before planting and pyridate after planting, and after pre-planting pendimethalin application with supplementary flame weeding. The yield of kale leaves for most methods ranged from 48.84 to 50.07 t/ha and was lower only after mechanical treatments supplemented with flame weeding and in the control. The studies showed the usefulness of the tested methods for weed control in kale.

Keywords: kale; weeds; weed control; yield

Kale (*Brassica oleracea* L. var. *sabellica* L.) is a biennial crop from the *Brassicaceae* (Burnett) family, one of the oldest vegetable species known to man. It is characterised by wide leaves along the stem and a strong, deep, well-developed root system. Tall varieties can reach 80–90 cm in height and have a slightly smaller diameter. In the first year, kale produces many large, strongly corrugated, thick leaves on a stocky stem in a spreading rosette, while in the second year, it forms a flower shoot, flowers, and seeds. The leaves are usually dark green, but in some varieties, they can be purple-green, purple, purple-brown, or even variegated. Kale plants contain organic and mineral compounds (Ayaz et al. 2006), and their high nutritional value has led to increased cultivation and consumption. The edible part of kale is the leaves, most often oval or elongated-oval in shape, pinnate, and rich in many basic nutrients (Zdrojewicz et al. 2016).

They are used for freezing or for the fresh market as an ingredient in salads, for cooking, or for decorating dishes (Kapusta-Duch 2020). Small soil requirements, high frost and drought resistance, and moderate requirements contribute to the expansion of its cultivation area. Kale can be harvested from late autumn through winter by breaking off the lower, oldest leaves (Korus 2015).

Kale is moderately sensitive to weed competition, which may negatively affect plant growth and development, leaf size and quality, and make harvesting difficult. It may also contribute to infestations by diseases and pests. Such effects are observed in many vegetable crop species (Rudnicki & Jaskulski 2006). Weeds growing from the beginning to the middle of the vegetation period are particularly harmful (Dobrzański & Adamczewski 2009). There are a few studies on the impact of weeds on kale yield losses. In Great Britain, the yield of kale

grown free of weeds was 20.9–34.5 t/ha, and without weed control decreased by 9.4–18.9 t/ha (Elliott & Cox 2006). Couch grass (*Elymus repens* – AGRRE) can reduce the yield of vegetable crops by more than 30–40%. In crops sensitive to weed infestation, e.g., vegetable crops from seed, losses can be much higher (Adamicki & Dobrzański 1999). The long-term studies carried out by Dobrzański et al. (2003) showed that the average fresh biomass of weeds 30 days after planting pepper was 8.8 t/ha (range 2.6 to 11.6 t/ha) and was mainly determined by weather conditions during the growing season.

Integrated weed management is based on knowledge of weeds' biological and ecological characteristics to understand how cultural practices can modulate their presence. This system, based on the precise use of herbicides adjusted to weed infestation, combined with mechanical, biological, and agrotechnical methods, is the base of sustainable agriculture (Bond & Groundy 2001; Bond et al. 2003; Gołębiowska & Domaradzki 2010). Herbicides cannot be the primary tool for regulating weed infestation in vegetable crops; they should be supplemented by other methods, especially mechanical and physical ones. Such systems are effective and allow the production of healthy products. An important trend influencing improvements in food safety is minimising the use of chemical plant protection products and limiting their adverse impact on people and the environment (Mennan et al. 2009; Pruszyński et al. 2012). Herbicide use is economically the most profitable method, but it has become less socially acceptable.

During the growing season, weeds can be controlled mechanically or manually (Adamczewski & Dobrzański 2008). Kale is grown with wide row spacing, usually 50–75 cm, which allows mechanical weeding until the interrows are covered. Traditional mechanical treatments in the inter-rows should be performed at least 5 cm from the crop rows to avoid damaging the root system (Dobrzański & Adamczewski 2009). Too frequent mechanical weeding can lead to soil drying and degradation (Dobrzański & Adamczewski 2006; Woźnica 2008). Modern weeders equipped with torsion elements can also control weeds in rows, causing little plant damage and no yield reduction (Dobrzański & Adamczewski 2006; Adamczewski & Dobrzański 2008). For practical use, innovative robots can also be implemented for intra-row weeding (van der Weide et al. 2008; Melander et al. 2015).

Flame weeding is a physical method of controlling weeds that utilises propane. This technique is commonly used in organic farming but can also be applied in conventional or integrated farming (Melander et al. 2005; Ascard 2007). However, the effects of flame-weeding are often short-lived. During the treatment, only the aboveground parts of the weeds are damaged, while the roots remain intact, allowing the weeds to regrow. The effectiveness of flame weeding depends on the amount of heat produced by the device, the duration of the plants' exposure to high temperatures, and the weed's growth stage, with younger plants being more sensitive to heat (Dobrzański 1996; Peerzada & Chauhan 2018).

The studies aimed to assess the impact of different weed control methods on kale growth and yield, weed infestation, and to determine whether reducing chemical protection by replacing it with non-chemical methods is possible.

MATERIAL AND METHODS

The study on kale was conducted in 2018–2020 in Skierniewice, Poland (Latitude: 51.9592° N, Longitude: 20.1468° E). Field experiments were established on luvisol soil containing 1.3–1.5% organic matter and with a pH of 6.3–6.5. The effectiveness of various weed control methods was compared, including: mechanical weeding (2–3 treatments), flame weeding (2 treatments), a combination of mechanical weeding (1 treatment) and flame weeding (1–2 treatments), herbicide application before planting, followed by flame weeding after planting and herbicide application both before and after kale planting. In the combined treatments, pendimethalin [Stomp Aqua 455 CS (BASF Agro B.V., Neetherlands)] was applied at 1 593 g/ha before planting, followed by 1–2 flame weeding treatments after planting. Chemical weed control utilised metamitron [Goltix 700 SC (ADAMA Polska Sp. z o.o. Poland)] at 1 400 g/ha before planting, and also metamitron at 1 400 g/ha combined with pyridate [Lentagran 45 WP (Certis Belchim B.V. Neetherlands)] at 675 g/ha, applied 1–3 weeks after planting. Pyridate was also used alone at dosages of 747 g/ha and 585 g/ha, in conjunction with the adjuvant Olbras 88 EC (Obrol Kulczyński sp. k., Poland) (1.5 L/ha). Additionally, pyridate was applied using a split application method (360 g + 360 g/ha) with a 14-day interval.

The trial was conducted using a completely randomised block design with 4 replications. Kale transplants of the Reflex F1 variety (Winterbor in 2020) were planted on May 16, 2018, May 7, 2019, and May 14, 2020, with a spacing of 50 × 55 cm. The area of the mechanically weeded plots was 12.15 m², while the remaining plots were 12.4 m². Mechanical weed control was performed to a depth of 2–3 cm using the tractor weeder "Ecopielnik EP-4", which was equipped with traditional weeding elements such as hoe blades and ruffle knives, as well as finger and torsion elements. Based on the dynamics of weed emergence, 2–3 mechanical treatments were conducted 18–21, 27–29, and 36 days after planting. Flame weeding in the inter-rows was carried out using a flame weeder with a working width of 16 cm and a pressure of 2 MPa. In plots where flame weeding was the only method of weed control, treatments were applied at 14–21 and 26–34 days after planting; in the remaining plots, at 16–29, 26–28, and 36 days after planting. After flame weeding, supplementary hand weeding of the rows was performed. Herbicides were sprayed using a wheel sprayer equipped with a 2.7 m-wide field boom and DG Tee-Jet (TeeJet Technologies, USA) 110-02 VS flat fan nozzles, applying 230 L/ha of water generated by compressed air. Throughout the experiment, air and soil temperatures, as well as rainfall, were recorded. During periods of water shortage, kale was irrigated using a reel-type sprinkler.

The effectiveness of various weed control methods was evaluated through both estimated assessments and quantitative measurements, using unweeded plots for comparison. The efficacy of individual weed species was assessed 37 to 42 days after planting, when the herbicidal effects were at their strongest,

using a visual estimation method expressed as a percentage (%) of weed control. The number and biomass of weeds were determined after the final assessment of weed control by counting individuals of each species within a 20 × 50 cm frame at 4 randomly selected locations in the plots, at 38–47 days after kale planting. The weeds at that time were at growth stages ranging from BBCH 14–16 to BBCH 39. The secondary weed infestation, expressed as soil weed coverage (%), was assessed 116–138 days after planting, before harvest. Concurrently, the biomass of the aboveground parts of kale, including the biomass of whole leaves and leaf blades, was determined. Sampling 10 plants from each plot was used to measure, and the results were converted to a single plant. Kale leaves were manually harvested at full maturity (118–140 days after planting), and marketable and non-marketable yields per ha were determined. The results were statistically analysed using variance analysis in Statistica (version 13.0). The Newman-Keuls test ($P = 0.05$) was used to assess differences in means, and the analysis was performed on the raw data.

RESULTS

Weather conditions during the experiments varied from year to year. Still, they were moderately favourable for kale development (Figure 1). Temperatures at the beginning of the growing season varied considerably, with a predominance of cool days in April, which may have limited plant growth and initial development. In the middle of the growing season (June and July), higher and more even temperatures were observed, which may have fa-

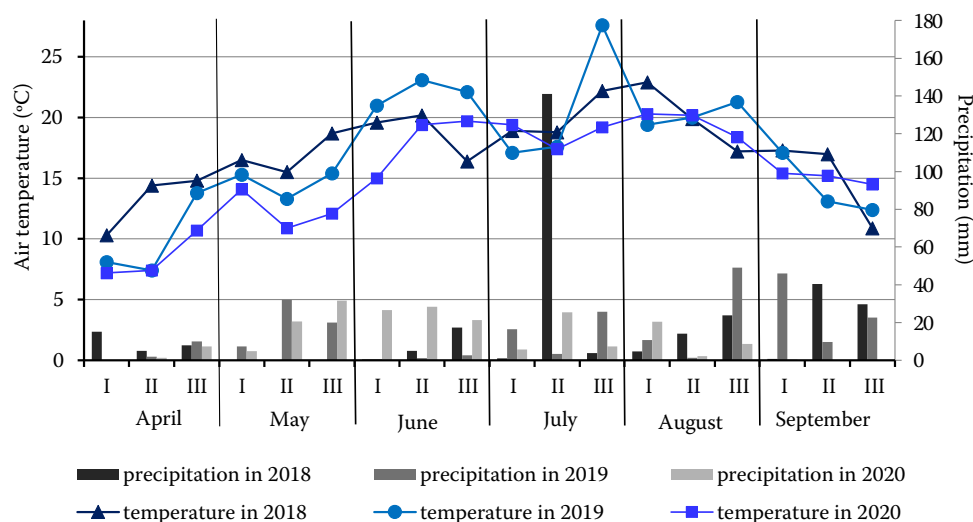


Figure 1. Average daily air temperatures and total precipitation during the growing season (from April to September) in the Skierniewice region, 2018–2020)

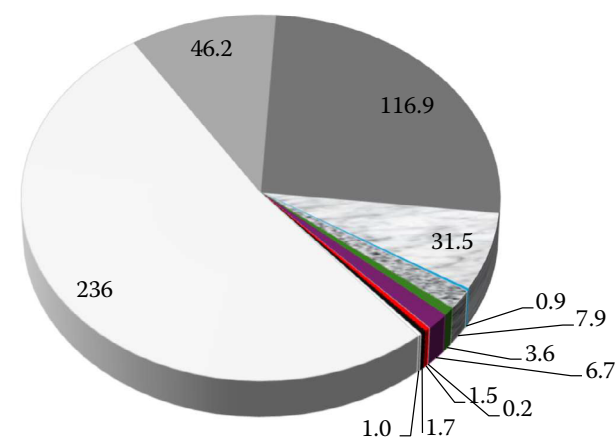
voured more intensive growth and leaf mass development. Toward the end of the growing season (August and September), air temperatures gradually decreased, which may have benefited the quality and final yield of kale. During the analysed period, there were significant variations in total rainfall between years and between individual months of the growing season. During periods of water shortage, the field experiments were irrigated using a reel-type sprinkler.

The floristic assessment conducted 38–47 days after kale planting revealed that the kale experiments were infested with 13 weed species (Figure 2), which were at growth stages ranging from BBCH 14–16 to BBCH 39. Two species were dominant: *Capsella bursa-pastoris* (CAPBP), with a density of 236 pcs/m², and *Chenopodium album* (CHEAL), with a density of 116.9 pcs/m².

The weeds at lower densities, including *Galinsoga parviflora* (GASPA) at 46.2 pcs/m² and *Thlaspi arvense* (THLAR) at 31.5 pcs/m², were also present. The densities of the remaining species ranged from 0.2 to 7.9 pcs/m². Occasionally, weeds such as *Stellaria media* (STEME), *Sinapis arvensis* (SINAR), *Urtica urens* (URTUR), *Geranium pusillum* (GERPU), *Polygonum* spp. (POLSS), and *Poa annua* (POAAN) appeared, but their densities were not assessed. *C. album* is one of the most dangerous weeds for kale, due to rapid growth, inhibition of access to light, and shading the plants.

The weed infestation was assessed by soil coverage of weed species, which reflects their competitive properties. In kale, soil weed coverage varied, but it did not fully correlate with the number of individual weed species present. The weed species with the highest soil coverage were: *C. bursa-pasto-*

(A) The number of weed species in pcs/m²



(B) The ground coverage by weeds in %

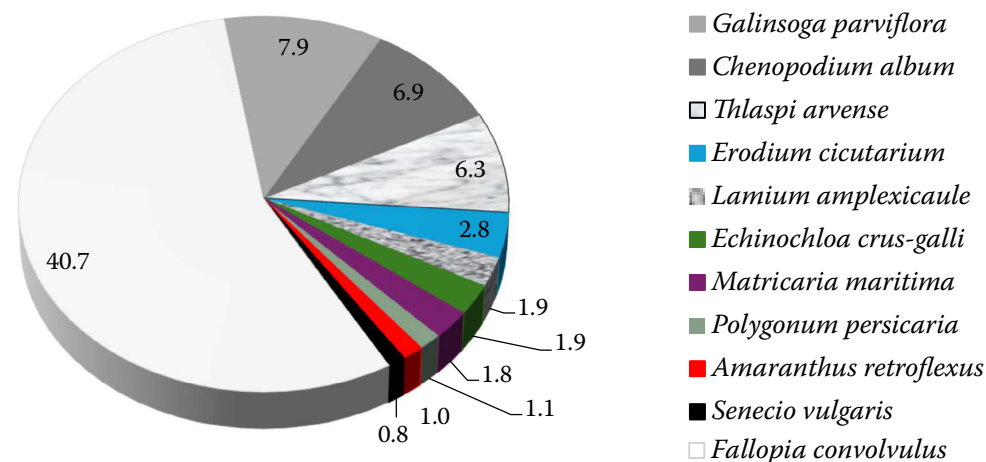


Figure 2. Weeds number (A) and soil coverage by weed species (B), at 37–42 days after kale planting (means from 2018–2020)

ris – 40.7%, *G. parviflora* – 7.9%, *C. album* – 6.9%, and *T. arvense* – 6.3% (Figure 2B). The soil coverage by other weed species ranged from 1.0 to 2.8%. The level of soil coverage is influenced by the number of weeds of a given species and its growth habits, as well as by the crop's competitive effect. The rapid and vigorous growth of weeds results in extensive soil cover, even at low numbers.

The results indicate differences in the effectiveness of weed control methods in managing both general weed populations and specific species. Table 1 shows data collected 37 to 42 days after kale planting. Mechanical weeding proved the most effective method, giving 98% total weed control. The use of herbicide metamiltron before planting, followed by post-planting applications of pyridate, resulted in 96% weed control. Another effective strategy involved applying pendimethalin before planting, followed by one to two treatments of flame weeding after planting the kale, and at weed emergence, resulting in a total weed control of 93%. The efficacy of metamiltron and pyridate at full doses, pyridate at a reduced rate with an oil adjuvant, and pyridate with a split application method were comparable to flame weeding and to the combined mechanical treatment with flame weeding, and all ranged from 81% to 85%.

Weed species responded differently to weeding methods. Mechanical treatments, as well as the use of herbicides metamiltron + pyridate, provided the control of broadleaved weed species, such as: *C. album*, *T. arvense*, *C. bursa-pastoris*, *G. parviflora*, *Matricaria maritima* ssp. *inodora* (MATIN), *Erodium cicutarium* (EROCI), *Amaranthus retroflexus* (AMARE), and *Echinochloa crus-galli* (ECHCG) at the range of 94–100%. The efficacy of remaining weed species ranges from 64 to 67%.

The system based on pendimethalin use before planting, followed by one to two treatments of flame weeding, provided weed control ranging from 94% to 100% for species such as *C. album*, *T. arvense*, and *M. maritima* ssp. *inodora*, *E. cicutarium* and *A. retroflexus*. *Senecio vulgaris* (SENVU) control was 85%, *G. parviflora* 82%, while *Lamium amplexicaule* (LAMAM) and *Polygonum persicaria* (POLPE) 61% and 67%, respectively.

Other methods show greater differences in weed species control, though some are very effective. Metamiltron at the rate of 1400 g/ha completely controlled *M. maritima* ssp. *inodora* (100%), the efficacy of pyridate at the rate of 747 g/ha

against *T. arvense*, *G. parviflora*, *M. maritima* ssp. *inodora*, *E. cicutarium* and *A. retroflexus* ranged from 98 to 100%. Pyridate with an adjuvant has controlled species such as *C. album*, *G. parviflora*, *E. cicutarium*, and *A. retroflexus* at 97–100%, and pyridate with the split application method has controlled *T. arvense*, *G. parviflora*, *M. maritima* ssp. *inodora*, *E. cicutarium* and *A. retroflexus* at 99–100%. Herbicides effectively protected kale against weeds from planting until the inter-rows were covered.

The efficacy of flame weeding ranged from 34% to 94%, while the combined mechanical treatment and flame weeding method ranged from 53% to 100%. Thermal flame weeding was conducted in the inter-rows using a shield to protect the kale plants from the high temperatures generated by the flames during gas combustion. However, these shields did not completely prevent damage to the kale plants, with damage reaching up to 4%. The extent of the damage largely depended on the precision with which the flame nozzle and shield were guided. Although the effectiveness of thermal weeding is slightly lower than that of herbicides, it remains beneficial for kale. While mechanical treatments combined with flame weeding generally demonstrated lower effectiveness than mechanical treatments alone, they were particularly successful in controlling weeds such as *T. arvense*, *M. maritima* ssp. *inodora*, and *E. cicutarium*.

In the experiments presented, the total weed count of 454 pcs/m² and biomass of 2 084.6 g/m² were recorded in the check at 38–47 days after planting. The number and biomass of weeds varied widely depending on the weed control method (Table 2). The greatest weed reduction was achieved through non-chemical methods, including mechanical treatment, thermal flame weeding, and a combination of mechanical treatment and flame weeding. The use of metamiltron before planting, followed by pyridate after planting, as well as pendimethalin before planting combined with flame weeding after planting, proved effective also. The number of undamaged weeds ranged from 0 to 4.3% compared to the check.

A relatively high weed infestation was observed after herbicide application. Low effectiveness was recorded after the use of pyridate at the rate of 747 g/ha, where the number of remaining weeds was 37.7%, compared to the check, and after the split-application method use, in two doses

Table 1. The impact of weed management methods on weed control in kale, at 37–42 days after planting (means from 2018–2020)

Weed management method, herbicide rates per ha	Weed species control (in %)											
	Total	<i>Chenopo- dium album</i>	<i>Thlaspi arvense</i>	<i>Capsella bursa-pas- toris</i>	<i>Galinsoga parviflora</i>	<i>Matricaria maritima</i> **	<i>Lamium amplexi- caule</i>	<i>Polygonum persicaria</i>	<i>Senecio vulgaris</i>	<i>Erodium cicutarium</i>	<i>Amaranthus retroflexus</i>	<i>Echinochloa crus-galli</i>
Mechanical treatments (3x)*	98	98	100	97	98	100	65	67	67	100	94	97
Metamitron – 1 400 g	83	80	91	86	56	100	28	21	82	93	58	11
Metamitron – 1 400 g + pyridate – 675 g	96	99	100	99	100	100	64	67	67	100	94	20
Pyridate – 747 g	81	93	95	76	98	98	60	47	56	100	100	52
Pyridate – 585 g + Olbras 88 EC – 1.5 L	84	97	94	81	97	91	63	53	68	99	100	48
Pyridate – 360 g + pyridate – 360 g	83	81	99	85	100	99	63	19	54	100	100	24
Pendimethalin – 1 593 g + ... + flame weeding *	93	99	99	90	82	94	61	67	85	100	100	85
Flame weeding *	85	87	94	80	76	78	34	67	77	92	74	70
Mechanical treatments * ... + flame weeding *	83	80	97	81	81	99	55	67	38	100	53	74

* The treatments were supplemented by hand weeding of the rows immediately afterwards; ** *Matricaria maritima* ssp. *inodora*

Table 2. The impact of weed management methods on weeds present in kale, after 38–47 days after planting (means from 2018–2020)

Weed management method, herbicide, rates per ha	Number of weeds		Biomass of weeds		Secondary weed infestation **
	Broadleaved	Total	Broadleaved	Total	
	38–47 days after planting				
Mechanical treatments (3×)*	0.0 ^a	0.0 ^a	0.0 ^a	0.0 ^a	1.1 ^a
Metamitron – 1 400 g	10.9 ^b	12.3 ^b	7.9 ^a	14.5 ^b	1.0 ^a
Metamitron – 1 400 g + pyridate – 675 g	1.6 ^a	3.9 ^a	0.3 ^a	5.0 ^a	0.6 ^a
Pyridate – 747 g	37.7 ^c	38.7 ^c	9.4 ^b	13.0 ^b	0.4 ^a
Pyridate – 585 g + ... + Olbras 88 EC – 1.5 L	23.4 ^c	23.7 ^c	6.9 ^a	7.7 ^a	0.7 ^a
Pyridate – 360 g + pyridate – 360 g	35.1 ^c	36.4 ^c	6.8 ^a	10.7 ^b	0.7 ^a
Pendimethalin – 1 593 g + ... + flame weeding *	3.5 ^a	3.5 ^a	0.5 ^a	0.6 ^a	1.2 ^a
Flame weeding *	4.0 ^a	5.3 ^a	1.2 ^a	1.5 ^a	1.6 ^a
Mechanical treatments * + ... + flame weeding *	4.3 ^a	4.4 ^a	1.2 ^a	1.3 ^a	1.5 ^a
Check	450.4 pcs/m ² (= 100%)	454.0 pcs/m ² (= 100%)	2045.8 g/m ² (= 100%)	2 084.6 g/m ² (= 100%)	1.5 ^a

* The treatments were supplemented by hand weeding of the rows immediately afterwards; ** the assessment was performed 116–138 days after planting; values in columns, followed by the same letter, are not significantly different at the 5% level, according to Newman-Keul's multiple range test

at 360 g/ha (35.1%), and after the use of pyridate at the rate of 585 g/ha, with the addition of Olbras 88 EC adjuvant (23.4%). The biomass of weeds on these objects, compared to the check, was 9.4%, 6.8%, and 6.9%, respectively. The impact of metamitron on weeds was less significant than that of the combined use of metamitron and pyridate.

Metamitron with pyridate effectively reduced both weed numbers and biomass, suggesting this weed control system is optimal.

An important indicator of plant growth is the biomass of the aboveground parts (Table 3). In kale, the average biomass of the aboveground parts ranged from 1.94 to 2.53 kg/plant, representing

Table 3. The impact of weed management methods on the biomass of the aboveground parts of kale, at 116–138 days after planting (means from 2018–2020)

Weed management method, herbicide rates per ha	Biomass of aboveground part of 1 plant		Biomass of leaves per 1 plant		Biomass of leaf blades per 1 plant	
	(kg)	(%)	(kg)	(%)	(kg)	(%)
Mechanical treatments (3×)*	2.53 ^a	142.9	1.76 ^a	141.9	1.21 ^a	155.1
Metamitron – 1 400 g	1.94 ^{cd}	109.6	1.33 ^{cd}	107.3	0.83 ^{bc}	106.4
Metamitron – 1 400 g + pyridate – 675 g	1.97 ^{cd}	111.3	1.36 ^{cd}	109.7	0.85 ^{bc}	109.0
Pyridate – 747 g	1.97 ^{cd}	111.3	1.36 ^{cd}	109.7	0.87 ^{bc}	111.5
Pyridate – 585 g + ... + Olbras 88 EC – 1.5 L	2.08 ^c	117.5	1.42 ^{cd}	114.5	0.92 ^{bc}	117.9
Pyridate – 360 g + pyridate – 360 g	1.95 ^{cd}	110.2	1.35 ^{cd}	108.9	0.84 ^{bc}	107.7
Pendimethalin – 1 593 kg + ... + flame weeding *	2.06 ^c	116.4	1.45 ^c	116.9	0.91 ^{bc}	116.7
Flame weeding *	2.09 ^c	118.1	1.40 ^{cd}	112.9	0.97 ^{bc}	124.4
Mechanical treatments * + ... + flame weeding *	2.32 ^b	131.1	1.62 ^b	130.6	1.01 ^b	129.5
Check	1.77 ^d	100.0	1.24 ^d	100.0	0.78 ^c	100.0

* The treatments were supplemented by hand weeding of the rows immediately afterwards; values in columns, followed by the same letter, are not significantly different at the 5% level, according to Newman-Keul's multiple range test

a 9.6% to 42.9% increase compared to non-weeded plants (1.77 kg/plant). The average biomass of entire leaves per plant also showed a similar trend, ranging from 7.3% to 41.9% higher than the non-weeded control (1.24 kg/plant). There was greater variation in the biomass of the leaf blades per plant, which were obtained by mechanically separating the lamina from the main leaf veins and petioles. The average biomass was found to be 6.4% to 55.1% higher than that of the control leaves. The highest leaf biomass was recorded for kale that was mechanically weeded at 1.21 kg per plant, followed by mechanically combined with flame weeding at 1.01 kg per plant, and flame weeding alone at 0.97 kg per plant. Differences in leaf blade biomass across weed control methods may result from the combined effects of reduced weed competition and stress responses induced by these methods.

The data indicate that different weed management methods can affect leaf and petiole size, but do not significantly affect overall kale yield. Although higher leaf biomass is expected to lead to a higher yield, this is not always the case.

The impact of various weed control methods on kale is summarised in Table 4. The results of the phytotoxicity tests conducted at 14–24 and 21–31 days after planting were presented. The least damage was observed after mechanical treatments (0.1%)

and mechanical treatments combined with flame weeding (0.1% to 0.6%). Flame weeding was conducted using a flame nozzle equipped with a shield that protects the crop from the flame. Damages from flame weeding depend on the precision of the treatment. Key factors are the accurate positioning of the flame nozzle, the growth stage of the kale plants, and the wind power during treatment. The most serious damage was obtained after flame weeding, starting when the kale plants were young.

Phytotoxicity caused by herbicides was highest between 21 and 31 days after planting, ranging from 0.7% with pyridate applied with the split application method to 3.8% with pyridate combined with the adjuvant Olbras 88EC. These results indicate that the addition of an adjuvant can enhance the effectiveness of herbicides, but it may also lead to increased phytotoxicity to the crop. The symptoms of damage caused by the weed control methods gradually disappeared or were masked by the growth of expanding leaves. Overall, these symptoms had no significant long-term impact on kale plant growth, suggesting that any adverse effects were only temporary.

The effectiveness of weed control methods can be evaluated by both the number of weeds removed shortly after treatment and the level of secondary weed infestation, which reflects

Table 4. The impact of weed management methods on kale (means from 2018–2020)

Weed management method, herbicide rates per ha	Phytotoxicity to kale (%)**		The ground coverage by kale (in %) **		Yield of kale leaves		Biomass of whole kale plants	
	14–24 dap	21–31 dap	65–79 dap	116–138 dap **	t/ha	%	t/ha	%
Mechanical treatments (3×)*	0.1	0.0	95.8	93.8	61.37 ^a	132.3	87.67 ^a	134.1
Metamitron – 1 400 g	2.2	1.5	95.2	91.3	49.26 ^b	106.2	70.96 ^b	108.5
Metamitron – 1 400 g + pyridate – 675 g	2.0	2.0	94.9	90.7	50.04 ^b	107.9	72.15 ^b	110.4
Pyridate – 747 g	0.7	1.4	95.7	91.6	49.34 ^b	106.4	71.31 ^b	109.1
Pyridate – 585 g + ... + Olbras 88 EC – 1.5 L	0.9	3.8	95.1	89.4	48.84 ^b	105.3	70.95 ^b	108.5
Pyridate – 360 g + pyridate – 360 g	1.0	0.7	95.1	90.1	49.11 ^b	105.9	70.80 ^b	108.3
Pendimethalin – 1 593 g + ... + flame weeding *	1.5	3.5	96.0	91.9	49.11 ^b	105.9	70.57 ^b	107.9
Flame weeding *	2.9	3.0	95.9	90.3	50.07 ^b	107.9	72.44 ^b	110.8
Mechanical treatment * + ... + flame weeding *	0.2	0.5	95.0	93.1	57.87 ^a	124.7	82.24 ^a	125.8
Check	0.0	0.0	91.5	88.8	46.39 ^b	100.0	65.38 ^b	100.0

* Mechanical treatments were supplemented by hand weeding of the rows immediately afterwards; ** dap – days after planting; values in columns, followed by the same letter, are not significantly different at the 5% level, according to Newman-Keuls multiple range test

the duration of the herbicidal effect of the various methods. The data in Table 2 indicate slight differences in secondary weed infestation among the different weed species. Total weed infestation varied from 0.4% to 1.6%, with the most commonly observed species being *G. parviflora* (0.2–1.2%) and *C. album* (0.1–0.3%). Other species were either present sporadically or absent.

Competition from weeds is one of the major factors reducing crop yield. The yield of kale leaves from weeded plots (Table 4) ranged from 48.84 to 61.37 t/ha, which is a 5.3 to 32.3% increase, compared to the yield from the check (46.39 t/ha). The high yield of kale leaves was obtained from the plants weeded mechanically, and with the combined method of mechanical treatment and flame weeding (61.37 and 57.87 t/ha), respectively. The remaining treatments yielded between 488.4 kg and 50.07 t/ha, but still represented increases of 5.3% to 7.9% compared to the non-weeded control.

The positive effect of mechanical treatments on kale yield supports previous findings on other vegetables, suggesting that this method of weed control should be utilised more widely, despite the higher labour requirements. Burning weeds is also an effective way to control weeds in kale, though it is more expensive than other methods. The results of this study also confirm the significant effectiveness of herbicides for weed control in kale, particularly in larger areas where non-chemical methods might be challenging to implement for logistical reasons. The overall kale plant biomass increased by 7.9% to 34.1% compared to the check. The differences between kale leaf yield and aboveground biomass are similar across all treatments.

DISCUSSION

The reduction of herbicide use is a global trend towards alternative methods of chemical treatment in crop production. Transplanted kale is less sensitive to weed competition than many vegetable crops grown from seeds, but weeds greatly impact the leaf yield losses and its quality. Kale is particularly threatened by *C. album*, which grows rapidly, effectively inhibits light access, and shades the plants. According to Williams (2006), there is an interaction between kale and *C. album*, as the overgrowth of *C. album* reduces both kale plant

biomass and leaf area. Qasem and Hill (1994) note that in crops with high weed density, both interspecific and intraspecific competition are observed. Hammerton (2006) found that among the competing weeds, *Polygonum lapathifolium* was the most competitive with kale, followed by *Polygonum persicaria*, which was slightly less competitive, and *Polygonum aviculare*, the least competitive.

The weed species observed in the experiments with kale are typical of vegetable crops in Poland, as documented by Anyszka (2004), Dobrzański (2007, 2013), and Golian (2020). Dobrzański (1994) reports that the weed communities associated with vegetable crops tend to be similar because these crops are primarily sown or planted in spring. They are often widely spaced in rows and do not effectively cover the inter-row areas. Additionally, many weed species have adapted their growth cycles to align with the cultivated crops. Kale is challenged by weeds in the *Brassicaceae* family, such as *Capsella bursa-pastoris* and *Thlaspi arvense*, which are not easily controlled by the herbicides used in this crop. Additionally, these weeds can be affected by the same pests and diseases that target kale plants. Recognising the composition of weed communities in different soil types can aid in selecting suitable herbicide systems (Rola & Rola 1997). Dobrzański et al. (2003) analysed long-term data on weed infestation across various vegetable species and reported that, among crops from the *Brassicaceae* family, the average weed biomass during the first half of the growing season was 2.1 t/ha for broccoli, 3.5–6.1 t/ha for cauliflower, and 5.0 t/ha for cabbage. Golian (2020) reported that the average weed biomass in cabbage, measured 37–39 days after planting, was 9.6 t/ha. However, kale grown from transplants is less susceptible to weed infestation due to its rapid growth and effective leaf coverage of the soil, which helps hinder weed growth.

Weeds with vigorous growth cover the soil extensively, even when present in low numbers. High weed coverage can limit light access to the soil, potentially affecting soil temperature and crop growth. Although *C. album* was present in large quantities in the experiments, its soil coverage was similar to that of *G. parviflora*, despite a significant difference in population size. This suggests that kale plants may suppress the growth of *C. album*, consistent with Williams' (2006) findings.

Studies have shown that weed control methods used in kale differ in effectiveness. Mechanical

treatment is one of the most important and easily accessible non-chemical methods. Despite the mechanical method's high effectiveness, its herbicidal effect is short-lived, and weeds quickly regrow, leaving the inter-rows covered with kale leaves. Dobrzański and Adamczewski (2013) suggest that during mechanical treatments, the weed seeds are moved from deeper soil layers to the upper layers, where they can germinate more easily, and the highest effectiveness of this method, reaching up to 100%, may be obtained during sunny weather and targeting germinating weeds. However, for larger weeds, such as those with four true leaves, the effectiveness of this method drops to around 80% under similar conditions. Proper timing and appropriate conditions during treatment can make the mechanical method a primary strategy for weed control in kale or can be a supplement to other methods. Mechanical treatments leave a strip of uncontrolled weeds on either side of the crop row, influencing crop yield (Knezevic et al. 2017). Repeated treatments increase the chance of soil erosion, destroy soil quality, and promote the emergence of new weed flushes (Wszelaki et al. 2007; Ulloa et al. 2010a). Colquhoun et al. (1999) confirmed the effectiveness of mechanical treatments, especially when combined with herbicides.

During the studies, flame weeding in kale was conducted in the inter-row using a flame nozzle equipped with a shield to protect the crop from the flame. However, uneven soil or operating the nozzle too close to the crops can lead to increased damage (Rajkovic et al. 2020). Leaf tissue that is severely affected by the flame will die, making the precision of the treatment crucial. It's important to note that kale plants are less sensitive to flaming than crops like carrots or onions. Flame weeding using propane has been proposed as an alternative to traditional techniques in both organic and conventional agricultural systems (Abou Chehade et al. 2018). This method can be used on the entire field before planting the crops, after sowing the seeds till before emergence, and on inter-row during vegetation (Ascard 1995; Abou Chehade et al. 2018). Plant responses to flaming depend on their heat tolerance, protective layers of hair and wax, lignification, and weather conditions (Ascard 1995; Rajkovic et al. 2011). Flaming has been more effective against broadleaf weeds than grasses (Cisneros & Zandstra 2008). Temperatures in the range of 95–100 °C can be lethal to weed

leaves and stems when applied for at least 0.1 s, leading to cell desiccation and ultimately the loss of cell function (Knezevic et al. 2017). Flaming disrupts weed growth, so it is important to use flame when the plants are dry and when wind speed and direction are favourable. Both moisture and wind can lower the heat obtained from the flame device, reducing the effectiveness of the flaming application (Mutch et al. 2005). The efficacy of flame weeding can be influenced by such factors as the growth stages of the plant (Ascard 1995; Ulloa et al. 2010), the physical location of the growing point at the time of flaming (Knezevic & Ulloa 2007b), the presence of protective layers of hair or wax and lignification (Ascard 1995; Ascard et al. 2007), and the regrowth potential of plant species (Ascard et al. 2007).

Weeds in farmland compete with crops for nutrients, space, light, and moisture, leading to reductions in production of 20–50%, depending on their intensity and duration in the field (Kaur et al. 2019). In Poland, for weed control in transplanted kale, clomazone, pendimethalin and a mixture of metazachlor with dimethenamid-P are used. Presented data indicate varying herbicide effectiveness and show that these compounds protect kale against weeds from planting until the inter-rows are covered. Later, weed pressure on kale is lower, although it is necessary to remove individual weeds growing between the kale plants. Pre-emergence herbicides, applied before weed germination, can prevent weed germination, reduce competition with crops, and increase yields (Oliveira et al. 2020). The impact of herbicides persisted for a significantly longer period, which helped maintain kale with minimal or no weed infestation during the later growth period. The effectiveness of herbicides depends on their active substance, the floristic composition of the weed population, application time and, to a large extent, on soil and climatic conditions (Pornprom et al. 2002). The greater the share of species sensitive to the selected herbicide, the greater its herbicidal effectiveness (Dobrzański & Adamczewski 2001). The results also confirmed the well-known thesis that the adjuvant improves the effectiveness of herbicides. It should be noted that in kale, the greatest weed infestation occurs until the inter-rows are covered by leaves, as confirmed by Dobrzański (1996), who states that in vegetables, the greatest weed infestation is observed at the beginning of vegetation.

A minor secondary weed infestation in the kale experiment is mainly attributed to effective control of the primary weed infestation and to good soil coverage in the inter-rows by kale leaves, which compete with weeds for light. The secondary weed infestation primarily consists of thermophilic species that require high temperatures for germination (Dobrzański et al. 1997), but may also include species that readily adapt to changing environmental conditions (Dobrzański 2013; Gołębiowska & Skorupa 2013).

Analysing results, it should be noted that mechanical treatments, flame weeding, mechanical treatments combined with flame weeding, as well as pendimethalin use before planting combined with flame weeding after planting, and also the use of metamiltron before planting followed by pyridate post-planting, allow for maintaining the kale plantations without weeds or with small weed infestation. However, non-chemical methods have a short-term effect, must be repeated, require more labour and energy inputs, and often require additional hand weeding of weeds not removed by these treatments. The high effectiveness of non-chemical methods, repeated if necessary, as well as herbicide application, helps prevent the emergence of new weeds in the field. The findings suggest that effective control of primary weed infestation may be sufficient to keep the kale crop clean and provide suitable conditions for growth and development. The weed control methods do not always eliminate all weeds; therefore, after completing the treatments and before closing the inter-rows, supplementary hand-weeding should be considered. Supplementary treatments will keep the field weed-free after inter-row closure.

CONCLUSIONS

The weed management methods evaluated in the experiments successfully controlled the majority of weeds observed during the trial.

(i) The highest limitation of weeds number and weed biomass was obtained after mechanical treatments, the use of herbicides metamiltron + pyridate and also pendimethalin supplemented by flame weeding.

(ii) Slight, transient phytotoxicity symptoms on kale were observed after using herbicides and flame weeding, but they did not negatively affect the plant's further growth or yield.

(iii) The studies indicate that the dose of pyridate can be reduced in kale without compromising the effectiveness of this substance or the yield of kale leaves.

(iv) The studies indicate that non-chemical methods for weed control in kale from transplants are highly effective, and can be used as an alternative method to chemical weeding.

(v) The effects of non-chemical weed control methods are often short-lived and require repeated applications in a brief period.

REFERENCES

- Abou Chehade L., Fontanelli M., Martelloni L., Frascioni C., Raffaelli M., Peruzzi A. (2018): Effects of flame weeding on organic garlic production. *Horttechnology*, 28: 502–508.
- Adamczewski K., Dobrzański A. (2008): Znaczenie i możliwości wykorzystania metod agrotechnicznych i niechemicznych do regulowania zachwaszczenia w ekologicznej uprawie roślin. In: Matyszczyk E. (ed.): *Poszukiwanie Nowych Rozwiązań w Ochronie Upraw Ekologicznych*. IOR, Poznań: 221–241. (In Polish)
- Adamicki F., Dobrzański A. (1999): Cebula. *Technologia Uprawy i Przechowywania*. Instytut Warzywnictwa, Skiernewice: 76–147. (In Polish)
- Anyszka Z. (2004): Współdziałanie zabiegów mechanicznych i chwastów w integrowanej ochronie kapusty głowiastej przed chwastami. *Nowości Warzywnicze*, 39: 135–140. (In Polish)
- Ascard J. (1995): Effects of flame weeding on weed species at different developmental stages. *Weed Research*, 35: 397–411.
- Ascard J. (2007): Why are some non-chemical weed control method adopted in practice and others not, and what can we learn from this?. 7th EWRS Workshop on physical and Cultural Weed Control. Salem, March 11–14, 2007: 99.
- Ascard J., Hatcher P.E., Melander B., Upadhyaya M.K. (2007): "Thermal weed control" in non-chemical weed management. In: Upadhyaya M.K., Blackshaw R.E. (eds.): *CAB International Publishing*, Wallingford: 155–175.
- Ayaz F.A., Glew R.H., Millson M., Huang H.S., Chuang L.T., Sanz C., Hayirlioglu-Ayaz S. (2006): Nutrient contents of kale (*Brassica oleraceae* L. var. *acephala* DC.). *Food Chemistry*, 96: 572–579.
- Bond W., Grundy A.C. (2001): Non chemical weed management in organic farming systems. *Weed Research*, 41: 383–405.
- Bond W., Turner R.J., Grundy A. C. (2003): A review of non-chemical weed management. HDRA.
- Cisneros J.J., Zandstra B.H. (2008): Flame weeding effects on several weed species. *Weed Technology*, 22: 290–295.

- Colquhoun J.B., Bellind R.R., Kirkwyland J.J. (1999): Efficacy of mechanical cultivation with and without herbicides in broccoli (*Brassica oleracea*), snap bean (*Phaseolus vulgaris*), and sweet corn (*Zea mays*). *Weed Technology*, 13: 244–252.
- Dobrzański A. (1994): Wpływ niektórych czynników środowiska, ze szczególnym uwzględnieniem wilgotności, na zachwaszczenie upraw warzyw. 17. Krajowa Konferencja "Przyczyny i źródła zachwaszczenia pól uprawnych". Olsztyn, June 28–29, 1994: 117–124. (In Polish)
- Dobrzański A. (1996): Krytyczne okresy konkurencji chwastów a racjonalne stosowanie herbicydów w uprawie warzyw. *Progres in Plant Protection/Postępy w Ochronie Roślin*, 36: 110–116. (In Polish)
- Dobrzański A. (2007): Wpływ regulowania zachwaszczenia roślin ogrodniczych na różnorodność biologiczną. *Zeszyty Naukowe Wydziału Ogrodniczego, Wyższa Szkoła Ekonomiczno-Humanistyczna w Skierniewicach*, 7: 60–75. (In Polish)
- Dobrzański A. (2013): Biologiczne i agrotechniczne aspekty regulowania zachwaszczenia. In: Hołownicki R., Kuboń M. (eds): *Współczesna Inżynieria Rolnicza - Osiągnięcia i Nowe Wyzwania*. Polskie Towarzystwo Inżynierii Rolniczej, Kraków: 27–54. (In Polish)
- Dobrzański A., Adamczewski K. (2001): Fazy rozwojowe roślin a racjonalne zwalczanie chwastów. *Progress in Plant Protection*, 38: 57–63. (In Polish)
- Dobrzański A., Adamczewski K. (2006): Perspektywy wykorzystania nowych narzędzi i maszyn do regulacji zachwaszczenia w integrowanej i ekologicznej produkcji roślinnej. *Progres in Plant Protection*, 46: 11–18. (In Polish)
- Dobrzański A., Adamczewski K. (2009): Wpływ walki z chwastami na bioróżnorodność agrofitytocoenoz. *Progress in Plant Protection*, 49: 982–995. (In Polish)
- Dobrzański A., Adamczewski K. (2013): Niechemiczne metody zwalczania chwastów. Stan obecny i perspektywy. In: Hołownicki R., Kuboń M. (eds): *Współczesna inżynieria rolnicza - osiągnięcia i nowe wyzwania*. Polskie Towarzystwo Inżynierii Rolniczej, Kraków: 55–92. (In Polish)
- Dobrzański A., Anyszka Z., Pałczyński J. (1997): Niektóre aspekty wtórnego zachwaszczenia w uprawie warzyw. 21. Krajowa Konferencja Naukowa z cyklu "Rejonizacja chwastów segetalnych w Polsce" pt. Zachwaszczenie wtórne roślin okopowych i ściernisk, 22–23 września, Puławy, 13: 89–101. (In Polish)
- Dobrzański A., Anyszka Z., Pałczyński J. (2003): Biomasa chwastów w zależności od gatunku roślin warzywnych i sposobu uprawy. *Pamiętnik Puławski*, 134: 51–58. (In Polish)
- Elliott J.G., Cox T.I. (2006): The development of selective herbicides for kale in the United Kingdom. I. The crop, the weeds and the problem. *Weed Research*, 5: 257–265.
- Golian J. (2020): Wpływ metody ochrony na plon i jakość wybranych gatunków warzyw. Instytut Ogrodnictwa-PIB [Ph.D. thesis]. (In Polish)
- Gołębiowska H., Domaradzki K. (2010): Systemy chemicznej regulacji zachwaszczenia upraw rolniczych w aspekcie rolnictwa zrównoważonego. *Fragmenta Agronomica*, 27: 32–43. (In Polish)
- Gołębiowska H., Skorupa M. (2013): The problem of secondary weed infestation in integrated production of corn. *Progress in Plant Protection*, 53: 465–470.
- Hammerton J.L. (2006): A preliminary study of the competition between kale and three weed species of the genus *Polygonum*. *Weed Research*, 2: 274–282.
- Kapusta-Duch J. (2020): Właściwości prozdrowotne warzyw kapustnych na przykładzie jarmużu (*Brassica oleracea* L. var. *acephala*). In: Kowalski S., Zięć G., Drożdż I. (eds): *Żywność a oczekiwania współczesnego konsumenta*. Uniwersytet Rolniczy w Krakowie, Kraków: 67–75. (In Polish)
- Kaur P., Kaur P., Bhullar M.S. (2019): Environmental aspects of herbicide use under intensive agriculture scenario of Punjab. *Herbicide Residue Research in India*. Springer, Cham: 105–157.
- Knezevic S.Z. (2017): Flame weeding in corn, soybean and sunflower. In: *Proceedings of the 8th International Conference of Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2017)*, Chania, Greece, September, 21–24 2017: 390–394.
- Knezevic S.Z., Ulloa S.M. (2007): Flaming: potential new tool for weed control in organically grown agronomic crops. *The Journal of Agricultural Science*, 52: 95–104.
- Korus A. (2015): Jarmuż – cenne warzywo kapustne. Cz. II. Wartość odżywcza jarmużu. *Przemysł Fermentacyjny i Owocowo-Warzywny*, 2: 13–15. (In Polish)
- Melander B., Lattanzi B., Pannacci E. (2015): Intelligent versus non-intelligent mechanical intra-row weed control in transplanted onion and cabbage. *Crop Protection*, 72: 1–8.
- Melander B., Rasmussen I.A., Barberi P. (2005): Integrating physical and cultural methods of weed control examples from European Research. *Weed Science*, 53: 369–381.
- Mennan H., Ngouajio M., Kaya E., Isik D. (2009): Weed management in organically grown kale using alternative cover cropping systems. *Weed Technology*, 23: 81–88.
- Mutch D., Simmons J., Monroe J., Vogel G. (2005): Some helpful tips on flaming weeds in corn and soybeans. *The New Agricultural Network*, 3, volume 2.
- Oliveira M.C., Osipitan O.A., Begcy K., Werle R. (2020): Cover crops, hormones and herbicides: priming an integrated weed management strategy. *Plant Science*, 301: 110550.
- Peerzada A.M., Chauhan B.S. (2018): Thermal weed control: History, mechanisms, and impacts. In: Jabran K., Chauhan B.S. (eds): *Thermal Weed Control: History, Mechanisms, and Impacts*. Springer, Cham: 1–15.

- han B.S. (eds): Non – Chemical Weed Control, Elsevier, Academic Press, 23: 9–31.
- Pruszyński S., Bartkowski J., Pruszyński G. (2012): Integrowana ochrona roślin w zarysie. Centrum Doradztwa Rolniczego w Poznaniu, Poznań: 47–53. (In Polish)
- Pornprom T., Hayes M., Pramote Saridnirun P. (2002): Competition and control of weeds in kale leaf crop. *Kasetsart Journal Natural Sciences*, 36: 1–10.
- Qasem J.R., Hill T.A. (1994): Inter and intraspecific competition of fat-hen (*Chenopodium album* L.) and groundsel (*Senecio vulgaris* L.). *Weed Research*, 34: 109–118.
- Rajkovic M., Malidža G., Gvozdenovic D., Vasic M., Gvozdanovic-Varga J. (2011): Susceptibility of bean and pepper to flame weeding. *Acta Herbologica*, 19: 67–76.
- Rajkovic M., Malidža G., Stepanovic S., Kostic M., Petrovic K., Urošević M., Vrbnicanin S. (2020): Influence of burner position on temperature distribution in soybean flaming. *Agronomy*, 10: 391.
- Rola J., Rola H. (1997): Strategia postępu w herbologii. *Progress in Plant Protection*, 37: 66–71. (In Polish)
- Rudnicki E., Jaskulski D. (2006): Ocena wzajemnego oddziaływania konkurencyjnego pomiędzy roślinami uprawnymi a chwastami w łąkach. *Acta Scientiarum Polonorum Agricultura*, 5: 45–52. (In Polish)
- Ulloa S., Datta A., Malidža G., Leskovsek R., Knezevic S. (2010a): Timing and propane dose of broad cast flaming to control weed population influenced yield of sweet maize (*Zea mays* L.var. *rugosa*). *Field Crops Research*, 118: 282–288.
- Ulloa S.M., Datta A., Knezevic S.Z. (2010b): Tolerance of selected weed species to broadcast flaming at different growth stages. *Crop Protection*, 29: 1381–1388.
- van der Weide RY., Bleeker PO., Achten V.T.J.M., Lotz L.A.P., Fogelberg F., Melander B. (2008): Innovation in mechanical weed control in crop rows. *Weed Research*, 48, 215–224.
- Williams T. (2006): A study of the competitive ability of *Chenopodium album* L. *Weed Research*, 4: 283–295.
- Woźnica Z. (2008): Metody walki z chwastami. s. 87–127. In: Krupa M. (ed.): *Herbologia. Podstawy biologii, ekologii i zwalczania chwastów*, PWRiL, Poznań. (In Polish)
- Wszelaki A.L., Doohan D.J., Alexandrou A. (2007): Weed control and crop quality in cabbage [*Brassica oleracea* (capitata group)] and tomato (*Lycopersicon lycopersicum*) using a propane flamer. *Crop Protection*, 26: 134–144.
- Zdrojewicz Z., Kosowski W., Stebnicki M., Stebnicki M. (2016): Jarmuż – stare, a zapomniane warzywo. *Medycyna Rodzinna*, 19: 21–25. (In Polish)

Received: March 19, 2025

Accepted: March 12, 2026

Published online: September 8, 2026