Pak. J. Bot., 58(1): 319-324, January 2026.

ARTICLE | DOI: http://dx.doi.org/10.30848/PJB2026-1(11)

INTEGRATED WEED CONTROL: COMBINATION OF WHITE CABBAGE (*BRASSİCA OLERACEA* L.) WITH REDUCED HERBICIDE DOSES ON REDROOT PIGWEED (*AMARANTHUS RETROFLEXUS* L.) AND MAIZE

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Abstract

The aim of the study was to minimize environmental impacts by reducing the amount of herbicides and at the same time to positively affect plant health. In this study, a combination of white cabbage (*Brassica oleracea* L.) extract known to have allelopathic effect with reduced doses of Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) was investigated against maize (*Zea mays* L.) and redroot pigweed (*Amaranthus retroflexus* L.). The study was conducted at the Department of Plant Protection, Van Yüzüncü Yıl University, from 2019 to 2020. In the study, the aqueous extract of white cabbage (15, 30, 45 and 60%), the licensed dose (2000ml/ha of herbicide with active ingredient Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) and reduced doses of this herbicide were used as 100, 50 and 250 ml/ha. In addition, reduced doses were administered with cabbage extracts. According to the results, no phytotoxic effect of applications was observed in maize. In addition, it was determined that there was no statistical difference between the all treatments and control groups. On the other hand, when the dry weight values of redroot pigweed were evaluated statistically, 60% concentration of white cabbage extract was in the same group with 1/4 and 1/8 reduced doses of Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener). In addition, the combination of all extract concentrations and reduced herbicide doses was in the same group with 0.03 g dry weight value in 1/2 reduced herbicide application. In conclusion, the use of white cabbage extract, both alone and in combination with reduced herbicide doses, demonstrated potential as an alternative weed management strategy, effectively suppressing redroot pigweed without causing phytotoxic effects on maize. It is thought that the results obtained will provide a more sustainable and environmentally friendly weed control strategy in agricultural production by offering advantages such as reducing the cost of herbicide use, slowing the development of resistance and increasing food safety by reducing the risk of chemical residues.

Key words: Allelopathy; White cabbage extract; Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl; Redroot pigweed; Maize; Integrated weed control

Introduction

Weeds, diseases, and pests represent significant threats to maize yield and quality, with weeds being the most prominent factor hindering maize cultivation. Weeds, in particular, stand out as a prominent factor impeding maize cultivation. The damage caused by weeds in maize production is approximately 37% (Oerke & Dehne, 2004). Whereas, Chikoye & Ekeleme (2003) have reported maize yield loss of 20 to 80% by weed infestation. Weeds cause damage in maize especially in the early development period. Weeds, which grow rapidly in a short time, suppress the cultivated plant and affect yield and quality negatively (Isık *et al*., 2017; Isık *et al*., 2015). Üremiş (2003) determined that weeds cause 20-30% crop loss in maize. In the study conducted by Doğan (2004) and Isık *et al*., (2006) , this rate was found to be 50-65%. There are several methods for weeds control in maize. Among them, chemical control is very important due to its efficiency in managing large infestations quickly and effectively. Chemical control involves the use of herbicides, which target specific weeds without harming the desired crops when applied correctly. This method is widely used in modern agriculture because it reduces labor costs and provides longer-lasting weed suppression compared to mechanical or manual methods. However, it requires careful management to prevent environmental damage, resistance development in weeds, and harm to non-target species. Herbicides belonging to the sulfonylurea group such as Nicosulfuron, Rimsulfuron and Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) are used for post-emergence weed control in today's maize agriculture (White *et al*., 2002). Correct application of cultural measures is essential to minimize yield losses in maize caused by weeds.

However, as these practices may not always maintain weed density at the desired level, chemical control methods are employed due to their ease of application and reduced labor requirements (Uygur & Şekeroğlu, 1993; Thonke, 1991). Yet, the excessive and improper utilization of synthetic herbicides gives rise to issues such as environmental pollution, the development of resistance in weed biotypes, and risks to human health (Chauhan *et al*., 2007).

In sustainable agricultural systems, weed control techniques as an alternative to herbicides and efforts to reduce the use of herbicides in integrated control have gained momentum (Isık *et al*., 2016). One of these alternative methods is the use of natural compounds that have allelopathic effect on weeds in the control of weeds (Uludağ, 2006).

Received: 07-10-2024 | Revised: 16-06-2025 | Accepted: 28 06-2025 | Online: 02 09-2025

Plants in the Brassicaceae family have been reported to be effective in weed control due to their allelopathic effects. It has been reported that allelochemicals are released into the soil through the decomposition of roots, leaves, and plant residues from these Brassicaceae family plants. The conversion of glucosinolates released from the decomposed plants into isothiocyanates by hydrolysis prevents the germination and growth of weeds (Al-Khatıb & Boydston, 1999).

Utilizing allelopathic plant extracts in conjunction with reduced herbicide rates presents an economically feasible and environmentally friendly weed control solution (Cheema *et al*., 2003). Herbicide doses can be reduced by applying lower herbicide rates in combination with allelopathic products (Jabran & Farooq, 2013). Successful weed control in cotton, maize, wheat and rice has been reported when low doses of herbicides are mixed with extracts of allelopathic crops (sorghum, sunflower, rice, etc.) (Azam *et al*., 2018; Cheema *et al*., 2003; Iqbal *et al*., 2009; Javaid *et al*., 2010; Khan *et al*., 2012; Razzaq *et al*., 2012; Rehman *et al*., 2010).

In this study, the aim was to assess the effectiveness of an aqueous extract derived from white cabbage (*Brassica oleracea* L.) leaves in combination with reduced doses of the registered herbicide Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) against maize (*Zea mays* L.) and redroot pigweed (*Amaranthus retroflexus* L.), which is a significant weed in maize cultivation.

Material and Methods

Material: The study was conducted in 2020 in the Phytopathology climate chamber of the Department of Plant Protection, Faculty of Agriculture, Van Yüzüncü Yıl University. The leaves left after the harvest of white cabbage (*Brassica oleracea* L.) were gathered from Van, Turkey. Redroot pigweed (*Amaranthus retroflexus* L.) seeds were used from the stock of Herbology Laboratory of Department of Plant Protection, Faculty of Agriculture, Yüzüncü Yıl University. Maize seeds from the commercially available SY Lucroso variety by Syngenta were chosen for this study due to the widespread production of silage maize in the region and the compatibility with the herbicide employed. For herbicide applications, Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) (30% + 1% + 30%), (Ekipp® Super WG 61, Bayer Agriculture), which is licensed for post-emergence broadleaf weeds in maize, was used.

Method: After harvesting, the lower leaves of white cabbage were rinsed with distilled water and subsequently air-dried in the shade. The dried leaves of the plant were ground in mill and cut into small pieces, then passed through 0.5 mm sieves. The resulting powder was stored at room temperature. Distilled water served as the solvent for preparing the extracts. For the white cabbage plants, 60 grams of ground material were taken and mixed with 100 ml of solvent. The mixture was then placed on an 'orbital' shaker at room temperature, running at 200 rpm, for 24 hours. The resulting mixture was filtered through four layers of sterile cheesecloth and subsequently centrifuged at 3500 rpm for 5 minutes. The aqueous extract was then passed through filter paper once more (Abbasi, 2012; Al-Malki, 2014). Then, the 60% concentration stock solution was diluted to 15, 30 and 45% concentrations and stored at +4°C for maximum two days. Accordingly, there are 15, 30, 45 and 60 g of dried plant samples per 100 ml sprayed to the test plants. The extracts adjusted according to these proportions were sprayed at a rate of 300 L/ha (Rao, 1983).

Establishment of a pot trial: In the study, maize plants were grown in 2 liter pots and redroot pigweed plants were grown in 0.6 liter pots and a mixture of (2*1) peat and (1*1) perlite was used in the pots. Maize and redroot pigweed plants were sown in eight replications for each treatment, with five seeds sown in each pot. After emergence, the plants were thinned to one plant per pot. The climate room was equipped with LED plant growth lights with a light intensity of 6000-8000 lux and a photoperiod of 16 hours light and 8 hours dark. The growing medium was grown in a climate chamber with 25±2°C temperature and 60-70% humidity conditions. Extracts and herbicide were applied when the maize reached the 2-6 leaf stage, as recommended for the registered herbicide. The recommended registered dose of 12.5 g/da+200 ml/da Mero (adjuvant) %30 Foramsulfuron + %1 Iodosulfuron Methyl-Sodium + %30 Isoxadifen-Ethyl (Safener) (2000 $ml.ha^{-1}$) and reduced doses of 1000 ml/ha, 500 ml/ha and 250 ml/ha (1/2, 1/4 and 1/8) were used. In the treatment characters, each concentration of white cabbage extracts was applied both alone and in combination with reduced doses (Table 1). No treatment was applied in the negative control. In the positive control, the authorised dose of Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) was used (Table 1). Spraying method was applied to each plant with a sprayer at 3 atm pressure In combined applications, herbicide and extract were mixed in the sprayer at the specified doses and concentrations. Spray applications with the help of a battery operated back sprayer (0.2-0.4 MPa) with constant pressure and using a fan nozzle. Plant height, wet and dry weights of maize and redroot pigweed were measured 14 days after spraying. Weed biomass (above-ground dry weights) was determined by clipping weeds at the soil surface in each quadrate and dried at 70°C for 48 h.

Table 1. Treatments and doses in maize and redroot pigweed.

Treatments	Concentrations/ Dose
White cabbage extract	15%
White cabbage extract	30%
White cabbage extract	45%
White cabbage extract	60%
White cabbage extract+Foramsulfuron+ Iodosulfuron	15% + ½
White cabbage extract+Foramsulfuron+ Iodosulfuron	15% + ¼
White cabbage extract+Foramsulfuron+ Iodosulfuron	15% + 1/8
White cabbage extract+Foramsulfuron+ Iodosulfuron	30% + ½
White cabbage extract+Foramsulfuron+ Iodosulfuron	30% + ¼
White cabbage extract+Foramsulfuron+ Iodosulfuron	30% + 1/8
White cabbage extract+Foramsulfuron+ Iodosulfuron	45% + ½
White cabbage extract+Foramsulfuron+ Iodosulfuron	45% + ¼
White cabbage extract+Foramsulfuron+ Iodosulfuron	45% + 1/8
White cabbage extract+Foramsulfuron+ Iodosulfuron	60% + ½
White cabbage extract+Foramsulfuron+ Iodosulfuron	60% + ¼
White cabbage extract+Foramsulfuron+ Iodosulfuron	60% + 1/8
Foramsulfuron+ Iodosulfuron	½
Foramsulfuron+ Iodosulfuron	¼
Foramsulfuron+ Iodosulfuron	1/8
Foramsulfuron+ Iodosulfuron (Positive Control)	1/1
Distilled water (Negative Control)	1/1

Statistical analysis

Analyses were performed in SAS (Version 9.4) package program. First of all, it was determined whether the variables had normal distribution according to the Shapiro Wilks normality test applied to fresh and dry weights and height variables (p>0.05). Then, Duncan multiple comparison test was used in the general linear model to determine the differences between doses (Anon., 2020).

Results and Discussion

Effect of reduced doses of foramsulfuron + iodosulfuron methyl-sodium + isoxadifen-ethyl (Safener) with aqueous extract of white cabbage on maize plant: In the study, it was observed that the effect of the treatments on maize plant was not statistically significant (p<0.05). These results indicate that there is no phytotoxicity of the treatments against maize (Table 2).

Effect of reduced doses of foramsulfuron + iodosulfuron methyl-sodium + isoxadifen-ethyl (Safener) with aqueous extract of white cabbage on redroot pigweed: The effect of white cabbage aqueous extract alone and in combination with reduced doses of Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) on redroot pigweed plants was statistically significant (p<0.05) (Table 3, Fig. 1). When aqueous extract of white cabbage was applied alone, the most effective concentration value was determined as 60% of dry weight.

When the aqueous extract of white cabbage plant (15, 30, 45 and 60 %) was applied together with 1/2, 1/4 and 1/8 reduced doses of Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener), all the results obtained were in the same group with 1/2 reduced dose. The dry weight ratio of 60% concentration of white cabbage extract was determined as 0.05 g. This result was statistically in the same group with Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) application reduced by 1/4 and 1/8. Another striking result obtained in the dry weight value was that the combined application of the extracts with reduced doses was in close groups with the positive control, while it was in the same group with the herbicide dose reduced by half (Table 3).

Table 2. Effects of applications on maize plants*.

Concentrations/Dose	Fresh weights (g) ($\bar{x} \pm SD$)	Dry weights (g) ($\bar{x} \pm SD$)	Height (cm) ($\bar{x} \pm SD$)
Distilled water (NC)	12.82 ± 0.54	0.96 ± 0.07	53.12 ± 2.30
L15	12.33 ± 1.06	0.87 ± 0.12	50.62 ± 4.32
L30	11.86 ± 0.64	0.85 ± 0.05	48.25 ± 2.59
L45	12.20 ± 0.88	0.93 ± 0.08	50.75 ± 3.69
L60	11.64 ± 0.67	0.89 ± 0.06	47.87 ± 2.82
L15 + F1/2	11.76 ± 1.29	0.84 ± 0.08	48.62 ± 5.27
L15 + F1/4	11.93 ± 0.91	0.90 ± 0.07	48.37 ± 3.74
L15 + F1/8	12.11 ± 0.77	0.91 ± 0.07	50.12 ± 3.25
L30 + F1/2	12.21 ± 0.90	0.86 ± 0.08	50.12 ± 3.77
L30 + F1/4	11.84 ± 0.57	0.92 ± 0.03	49.00 ± 2.43
L30 + F1/8	11.99 ± 0.68	0.92 ± 0.06	48.50 ± 2.71
L45 + F1/2	11.88 ± 1.00	0.84 ± 0.09	48.75 ± 4.12
L45 + F1/4	12.25 ± 0.79	0.93 ± 0.04	50.50 ± 3.30
L45 + F1/8	12.25 ± 0.55	0.92 ± 0.03	50.62 ± 2.31
L60 + F1/2	12.81 ± 0.55	0.96 ± 0.02	52.75 ± 2.25
L60 + F1/4	12.20 ± 0.90	0.88 ± 0.07	50.00 ± 3.76
L60 + F1/8	12.43 ± 0.54	0.96 ± 0.07	53.12 ± 2.30
F1 (PC)	11.52 ± 0.87	0.84 ± 0.04	47.50 ± 3.68
F1/2	11.77 ± 0.90	0.81 ± 0.12	48.37 ± 3.86
F1/4	12.18 ± 0.39	0.85 ± 0.03	49.75 ± 1.48
F1/8	11.86 ± 0.94	0.89 ± 0.05	48.75 ± 3.83

*$\bar{x}$: Average of germination; SD – Standard deviation, NC: Negative control, PC: Positive control, L: White cabbage aqueous extract, L15: 15% concentration, L30: 30% concentration, L45: 45% concentration, L60: 60% concentration, F: Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) herbicide, F1/2: 1/2 reduced dose of herbicide, F1/4: 1/4 reduced dose of herbicide, F1/8: 1/8 reduced dose of herbicide

Table 3. Analysis results of the treatments applied to redroot pigweed*.

Concentrations/Dose	Fresh weights (g) $(\bar{x} \pm SD)$	Dry weights (g) $(\bar{x} \pm SD)$	Height (cm) $(\bar{x} \pm SD)$
Distilled water (NC)	1.90 ± 0.17 ^{a}	0.22 ± 0.04 ^{a}	9.37 ± 0.90 ^{a}
L15	0.66 ± 0.06 ^{bc}	0.07 ± 0.00 ^{bc}	3.12 ± 0.35 ^{bcdef}
L30	0.83 ± 0.16 ^{b}	0.09 ± 0.01 ^{b}	4.12 ± 0.76 ^{bc}
L45	0.83 ± 0.14 ^{b}	0.08 ± 0.01 ^{b}	4.75 ± 0.31 ^{b}
L60	0.47 ± 0.05 ^{cd}	0.05 ± 0.00 ^{cd}	2.75 ± 0.31 ^{cdef}
L15 + F1/2	0.35 ± 0.07 ^{de}	0.03 ± 0.00 ^{de}	3.37 ± 0.41 ^{bcde}
L15 + F1/4	0.31 ± 0.03 ^{de}	0.03 ± 0.00 ^{de}	3.25 ± 0.59 ^{bcdef}
L15 + F1/8	0.36 ± 0.08 ^{de}	0.04 ± 0.01 ^{de}	2.75 ± 0.45 ^{bcdef}
L30 + F1/2	0.27 ± 0.04 ^{def}	0.03 ± 0.00 ^{de}	2.87 ± 0.47 ^{cdef}
L30 + F1/4	0.20 ± 0.01 ^{def}	0.02 ± 0.00 ^{de}	2.25 ± 0.16 ^{def}
L30 + F1/8	0.21 ± 0.04 ^{def}	0.02 ± 0.00 ^{de}	1.75 ± 0.31 ^{ef}
L45 + F1/2	0.25 ± 0.04 ^{def}	0.03 ± 0.00 ^{de}	2.25 ± 0.25 ^{def}
L45 + F1/4	0.36 ± 0.10 ^{de}	0.04 ± 0.01 ^{de}	4.12 ± 0.98 ^{bc}
L45 + F1/8	0.26 ± 0.04 ^{def}	0.03 ± 0.00 ^{de}	3.25 ± 0.45 ^{füg}
L60 + F1/2	0.17 ± 0.03 ^{fe}	0.01 ± 0.00 ^{de}	1.50 ± 0.18 ^{füg}
L60 + F1/4	0.21 ± 0.06 ^{def}	0.02 ± 0.00 ^{de}	2.50 ± 0.46 ^{cdef}
L60 + F1/8	0.26 ± 0.04 ^{def}	0.02 ± 0.00 ^{de}	2.50 ± 0.84 ^{cdef}
F1 (PC)	0 ± 0 ^{f}	0 ± 0 ^{e}	0 ± 0 ^{g}
F1/2	0.30 ± 0.09 ^{de}	0.03 ± 0.00 ^{de}	3.62 ± 0.65 ^{bcd}
F1/4	0.42 ± 0.08 ^{cde}	0.04 ± 0.00 ^{cd}	4.12 ± 0.58 ^{bc}
F1/8	0.47 ± 0.07 ^{cd}	0.04 ± 0.00 ^{cd}	4.12 ± 0.61 ^{bc}
p	*	*	*

$^{*}\bar{x}$: Average of germination; SD – Standard deviation, NC: Negative control, PC: Positive control, L: White cabbage aqueous extract, L15: 15% concentration, L30: 30% concentration, L45: 45% concentration, L60: 60% concentration, F: Foramsulfuron + Iodosulfuron Methyl-Sodium + Isoxadifen-Ethyl (Safener) herbicide, F1/2: 1/2 reduced dose of herbicide, F1/4: 1/4 reduced dose of herbicide, F1/8: 1/8 reduced dose of herbicide

Fig. 1. Redroot pigweed treatments.

In a laboratory study conducted by Kural and Özkan (2020), the highest efficacy was achieved when applying a 50% concentration of aqueous extracts from white cabbage. Accordingly, it was reported that the germination of *A. retroflexus* seeds inhibited by 95% and the germination of maize seeds reduced by 86%. Results in the current study closely resembled those of the Kural & Özkan (2020) research. Furthermore, there was no observed phytotoxic effect in the maize application. In another study, the effects of methanol and aqueous extracts (30, 40 and 50%) of fresh and dry white cabbage seedlings on the germination of redroot pigweed and maize seeds were investigated. It was reported that none of the treatments applied to maize plants showed any negative effects, while the application of fresh methanol at a 50% concentration inhibited the germination of redroot pigweed by 84.7% (Yilmaz & Yergin Özkan, 2020). Similar results were obtained in this study, where no phytotoxicity was observed in maize plants in both studies.

In another study, the effects of various plant aqueous extracts (sorghum, brassica and sunflower) in combination with reduced herbicide rates (Bromoxynil + MCPA) on wheat (*Triticum aestivum* L.) crops and weeds were investigated. Bromoxynil was reduced by 1/2 and MCPA by 1/3. The results indicated that the aqueous extract combined with 18 L bromoxynil + MCPA 50 g/ha per hectare had 88% effect on total weed density, 90% effect on total weed fresh weight, 95% effect on total weed dry weight and 35% increase in grain yield over the control. They reported that it can be concluded that the use of herbicides can be reduced up to 50% with the use of allelopathic plant aqueous extracts (Javaid *et al*., 2010).

In another study on wheat, the recommended doses of different herbicides and their 70% reduced doses were mixed with sorghum and sunflower aqueous extracts at 18 l/ha each. This reduced herbicide + plant aqueous extract was applied 30 days after sowing for weed control in wheat. The effective treatment for total weed density and dry weight over control was mesosulfuron + idosulfuron with plant aqueous extract at 14.4 g/ha. The results suggest that weeds can be controlled for higher yields in wheat when a reduced herbicide dose of 70% is used in combination with sorghum and sunflower aqueous extracts (Razzaq *et al*., 2012).

In maize production, the combined application of all concentrations of white cabbage extract in reduced ratios (1/2-1/4-1/8) of the licensed doses of herbicides gave common results. In conclusion, white cabbage extract, whether used alone or in combination with reduced herbicide doses, has shown promise as an alternative weed management approach, successfully suppressing redroot pigweed without inducing phytotoxic effects on maize.

Acknowledgement

This study is a M.Sc. thesis titled as the "The effect of white cabbage (*Brassica oleracea* L.) mixture of reduced herbicide doses with aqueous extract on (*Amaranthus retroflexus* L.) and maize (*Zea mays* L.)" conducted with the Institute of Science of Van Yüzüncü Yıl University and funded by the Main Scientific Research Projects Department (Project code: FYL-2020-8870) of the Van Yüzüncü Yıl University. We would like to thank Professor Gazel SER (Van Yüzüncü Yıl University) for his supports during statistical analysis.

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