Evaluation of Herbicide–Adjuvant Combinations for the Control of *Ambrosia artemisiifolia* in Sunflower (EXPRESS Hybrid)

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Abstract
Ambrosia artemisiifolia L. is an invasive species of agronomic and public health concern, known for its aggressive competition with cultivated crops and high allergenic potential. In this context, the present study aimed to evaluate the efficacy and mode of action of several herbicide–adjuvant combinations in controlling this weed, under the pedoclimatic conditions of Hodoș, Timiș County, Romania, in a tribenuron-methyl-tolerant sunflower hybrid. The following treatment variants were tested: V1 - halauxifen-methyl + tribenuron-methyl (50 g/ha) + Vivolt (0.1% V/V); V2 - halauxifen-methyl + tribenuron-methyl (50 g/ha) + Actirob B (0.5 L/ha); V3 - halauxifen-methyl + tribenuron-methyl (50 g/ha) + Codacide (1 L/ha); V4 - halauxifen-methyl + tribenuron-methyl (50 g/ha), without adjuvant; V5 - halauxifen-methyl (1 L/ha), single registered dose; and V6 - halauxifen-methyl (1 L/ha) + tribenuron-methyl (45 g/ha) + Vivolt (0.1% V/V). These were compared based on their efficacy in controlling *Ambrosia artemisiifolia*, expressed as a percentage. The results revealed significant differences among the tested variants. V5 demonstrated the highest efficacy (95%), followed by V6. Variants containing Codacide or Vivolt in lower doses of active substances, achieved efficiencies between 80–85%; variants without adjuvant (70–75%) or with less effective adjuvants (Actirob B – 75%) provided reduced control of the target weed. The study underline the importance of using high-quality adjuvants and optimal dosing in increasing the efficacy of herbicide treatments.

Keywords: *Ambrosia artemisiifolia*, sunflower, halauxifen-methyl, tribenuron-methyl, adjuvants

1. Introduction

In modern agriculture, maintaining crop productivity is increasingly influenced by the biological pressure exerted by invasive species. Among these, *Ambrosia artemisiifolia* L. has emerged as one of the most aggressive weeds in Central and Eastern Europe. It significantly affects field crops, particularly sunflower (*Helianthus annuus*), a crop of major economic importance [1,2]. Due to its high colonization capacity, competitiveness for resources, and biological resilience, *A. artemisiifolia* considerably reduces both yield and quality, threatening the economic sustainability of farming systems [3]. Moreover, the persistence of a viable seed bank in the soil favors annual reinfestation of cultivated fields, complicating long-term control strategies [4].

In addition to its agronomic impact, *A. artemisiifolia* also poses a serious public health concern, being responsible for severe allergic reactions in the population. This dual impact, agricultural and medical, has led to the species being included on the list of invasive alien species of the European Union. Accordingly, Regulation (EU) No. 1143/2014 obliges all member states to implement consistent measures for the prevention, control, and eradication of such species [3]. In Romania, Law No. 62/2018 governs the control of ragweed, establishing specific obligations for local

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authorities, landowners, and land users across agricultural and non-agricultural areas [4].

Given these multiple implications: economic, agronomic, and legislative optimizing control strategies against ragweed has become a priority in crop management. Chemical control, through the use of modern herbicides in combination with specific adjuvants, offers high efficacy potential under local pedoclimatic conditions. Among these, halauxifen-methyl, a postemergent synthetic auxin, acts systemically after foliar absorption, translocating to meristematic tissues [5,6]. There, it mimics indole-3-acetic acid (IAA), triggering hormonal cascades that lead to overexpression of auxin-responsive genes, stimulation of ethylene and abscisic acid (ABA) synthesis, inhibition of photosynthesis, and metabolic imbalance ultimately causing necrosis and plant death [5,7,8,9].

Complementary to this, tribenuron-methyl, a systemic herbicide from the sulfonylurea class (HRAC B), inhibits the acetolactate synthase (ALS) enzyme, thereby blocking the biosynthesis of branched-chain amino acids (valine, leucine, isoleucine), halting cell division and leading to plant death [10]. This compound is effective against a wide range of dicotyledonous weeds and enhances the activity of halauxifen-methyl, particularly on partially sensitive species [11]. The combined application of these two herbicides provides a dual mode of action, which reduces the risk of herbicide resistance and improves overall control efficiency [12,9].

To further improve the efficacy of herbicide mixtures, adjuvants are used to enhance penetration, adhesion, and solution stability. Adjuvants based on 90% isodecyl alcohol ethoxylate are non-ionic surfactants that reduce surface tension and facilitate cuticular penetration. Other categories, such as methylated seed oils (MSO), organosilicone agents, or humectant–penetrant combinations, are recommended under abiotic stress conditions or when targeting weeds with waxy or pubescent leaves [13,10]. The aim of this study is to evaluate and propose a modern chemical control strategy against *A. artemisiifolia* in sunflower crops, based on combining halauxifen-methyl and tribenuron-methyl with effective adjuvants. The implementation of such solutions, aligned with national and EU legislation, supports the protection of agricultural productivity and the sustainability of agroecosystems [3].

2. Materials and methods

2.1. Description of the Experimental Area

A one-year field experiment was conducted during the 2024 growing season in a sunflower crop (figure 1) established in Hodoş, Timiş County, western Romania (45°40′29″N, 21°49′00″E). The region belongs to the temperate, moderate continental climate zone, with mean summer temperatures ranging between 20 and 24 °C and annual precipitation reaching up to 700 mm, typical for the lowland areas of Timiş County. The soil type at the experimental site was classified as clay loam, with good drainage and a particle-size distribution of 39% sand, 27% silt, and 34% clay. The soil profile exhibited a neutral pH (7.2), high organic matter content (10.3%), and humus levels exceeding 6%, reflecting strong nutrient-holding capacity and favorable edaphic stability.

Figure 1. Experimental field site of sunflower crop infested with *A. artemisiifolia*, located in Hodoş, Timiş County, Romania.

The experiment was established using a tribenuron-methyl-tolerant sunflower hybrid, SUVEX (KWS). The choice of this hybrid was based on its genetic compatibility with this active ingredient approved within the Express® system. This tolerance is conferred by a point mutation in the AHAS (acetohydroxyacid synthase) gene, allowing for post-emergence applications without crop injury [14]. Sowing was performed on 15 April 2024 using a row spacing of 70 cm and a final plant density of 62,000 plants ha^{-1}. Soil preparation included shallow disking followed by harrowing and leveling, to ensure proper seedbed conditions. A pre-sowing basal fertilizer application of 300 kg ha^{-1} of complex NPK 15:15:15 was incorporated into the soil to support early crop development. No additional phytosanitary treatments were applied during the vegetation period, allowing for an unbiased evaluation of the herbicide effects under field conditions.

2.2. Herbicide Treatments

Six post-emergence herbicide treatments were evaluated in a sunflower field trial, including five herbicide-based combinations and one untreated weedy check as control. All treatments were applied at the recommended field rates. The herbicide variants (table 1) included halauxifen-methyl applied alone or in combination with tribenuron-methyl and various adjuvants as follows: halauxifen-methyl (1.0 L ha^{-1}); halauxifen-methyl (1.0 L ha^{-1})+ tribenuron-methyl (45 g ha^{-1}) + Vivolt (0.1% v/v); halauxifen-methyl + tribenuron-methyl (50 g ha^{-1}) + Vivolt (0.1% v/v); halauxifen-methyl + tribenuron-methyl (50 g ha^{-1})+ Actirob B (0.5 L ha^{-1}); and halauxifen-methyl + tribenuron-methyl (50 g ha^{-1}) + Codacide (1.0 L ha^{-1}).

Table 1. Herbicide and adjuvant treatments applied in the field trial, including active ingredients, HRAC group, mode of action, and application doses.

Active Ingredient(s)	HRAC Group	Mode of Action	Herbicide Dose	Adjuvant	Adjuvant Dose
Halauxifen-methyl	O	Synthetic auxin	1.0 L ha^{-1}	—	—
Halauxifen-methyl + Tribenuron-methyl	O + B	Synthetic auxin + ALS inhibitor	45 g ha^{-1}	Vivolt	0.1% v/v
Halauxifen-methyl + Tribenuron-methyl	O + B	Synthetic auxin + ALS inhibitor	50 g ha^{-1}	Vivolt	0.1% v/v
Halauxifen-methyl + Tribenuron-methyl	O + B	Synthetic auxin + ALS inhibitor	50 g ha^{-1}	Actirob B	0.5 L ha^{-1}
Halauxifen-methyl + Tribenuron-methyl	O + B	Synthetic auxin + ALS inhibitor	50 g ha^{-1}	Codacide	1.0 L ha^{-1}
Untreated check	—	—	—	—	—

The experiment was carried out following a randomized complete block design (RCBD) with four replications per treatment. Each experimental plot measured 21 m² (3 m × 7 m), consisting of four sunflower rows spaced 70 cm apart. A spacing of 1 m was maintained between blocks to prevent spray drift and ensure treatment separation.

All herbicide treatments were applied post-emergence at the 4 to 6 fully expanded true leaf stage of sunflower plants (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH 14–16 code) using a portable manual compressed-air boom sprayer equipped with flat-fan Lechler 03 nozzles [10]. The sprayer was calibrated to deliver 250 L ha^{-1} at a pressure of 500 kPa. Applications were made at a constant walking speed of approximately 0.9 m s^{-1}. During spraying, ambient conditions were favorable, with air temperatures of 23.7 °C, relative humidity between 60.4%, and wind speed under 2 m s^{-1}.

All treatments were applied in a single pass, without pre-emergence herbicide applications or post-treatment irrigation. No additional adjuvants or pesticides were used beyond those listed in the treatment variants.

2.3. Assessments

The evaluations were conducted both visually and quantitatively, following the EPPO guidelines

[11]. Weed control efficacy was assessed focused on the efficacy against *Ambrosia artemisiifolia* (AMBEL) and secondary weed species: *Cirsium arvense* (CIRAR), *Persicaria maculosa* (POLPE), and *Hibiscus trionum* (HIBTR), at 3, 7, 14, 21,44 and 50 days after application (DAA) with key evaluations at 7, 14, and 44 days used for final analysis. Visual assessments were based on a percentage estimation scale, where 0% represented no effect and 100% complete control.
In addition to weed suppression, crop phytotoxicity and vigour reduction were visually estimated on a 0–100% scale, where 0% represented a healthy, unaffected crop and 100% represented plant death. Morphological abnormalities (leaf and stem deformation) were documented based on direct observations, and their incidence and severity were expressed as a percentage of the total number of plants affected per plot.

3. Results and discussion

The results of the field trial showed significant differences in the efficacy of post-emergence herbicide treatments against the invasive weed *A. artemisiifolia* depending on the specific herbicide–adjuvant combinations applied in the tribenuron-methyl-tolerant sunflower hybrid (table 2). The application of halauxifen-methyl at 1 L/ha alone was the most effective variant, achieving 95% control of *A. artemisiifolia* at 50 days after treatment. This result demonstrates the high intrinsic efficacy of halauxifen-methyl when applied with the full dose under optimal environmental and phenological conditions.

Table 2. Average weed control (%) of selected treatments at 7, 14, and 44 days after application (DAA), representing mean control percentages for four weed species under field conditions

Herbicide Treatment	Dose	**5/29/2024 (7 DAA)**				**6/12/2024 (14 DAA)**				**7/4/2024 (44 DAA)**			
		AMBEL	**CIRAR**	**POLPE**	**HIBTR**	**AMBEL**	**CIRAR**	**POLPE**	**HIBTR**	**AMBEL**	**CIRAR**	**POLPE**	**HIBTR**
Halauxifen-methyl	1.0 L ha^{-1}	95	55	55	65	100	70	75	75	100	65	70	70
Halauxifen-methyl + Tribenuron-methyl+ Vivolt	45 g ha^{-1} + 0.1% v/v	85	80	80	85	95	95	85	95	95	95	85	95
Halauxifen-methyl + Tribenuron-methyl+ Vivolt	50 g ha^{-1} + 0.1% v/v	75	75	75	85	90	85	85	90	90	85	85	90
Halauxifen-methyl + Tribenuron-methyl+Actirob B	50 g ha^{-1} + 0.5 L ha^{-1}	75	75	75	85	95	90	85	85	95	90	85	85
Halauxifen-methyl + Tribenuron-methyl+ Codacide	50 g ha^{-1} + 1.0 L ha^{-1}	85	75	70	85	100	85	85	90	100	85	85	90
Untreated check	—	95	55	55	65	100	70	75	75	100	65	70	70

Among the herbicide–adjuvant combinations, the application of halauxifen-methyl at 1 L/ha + tribenuron-methyl at 50 g/ha + Vivolt at 0.1% V/V and the application of halauxifen-methyl at 1 L/ha + tribenuron-methyl at 50 g/ha + Codacide at 1 L/ha showed similarly high levels of weed control, reaching 87.5% to 90% efficacy (figure 2). These results underline the synergistic interaction between the two active substances and their respective adjuvants, which likely enhanced foliar penetration and the systemic translocation of the herbicides, improving their performance against the target weed.
The application of halauxifen-methyl at 1 L/ha + tribenuron-methyl at 45 g/ha + Actirob B at 0.5 L/ha resulted in a moderate level of control, of up to 80–85%, suggesting that this adjuvant significantly influences herbicidal efficacy. In this context, the physicochemical properties of the adjuvants such as surface tension reduction and cuticle permeability may play a crucial role in optimizing treatment outcomes.

From a crop safety perspective, no severe phytotoxic effects were observed for any of the tested combinations. However, in the variant involving halauxifen-methyl at 1 L/ha + tribenuron-methyl at 45 g/ha + Vivolt at 0.1% V/V, mild and transient phytotoxic symptoms were recorded during the first 7 to 14 days after application, consisting mainly of basal leaf chlorosis and temporary growth delay. These symptoms are consistent with the known action of synthetic auxin herbicides and were fully reversed by the final assessment, with no long-term impact on plant development [5].

In terms of plant vigour, the application of halauxifen-methyl at 1 L/ha alone maintained high vigour levels, comparable to those of the untreated control. On the other hand, the application of halauxifen-methyl at 1 L/ha + tribenuron-methyl at 50 g/ha + Codacide at 1 L/ha showed a slightly reduced vigour, though not statistically significant.

These findings suggest a trade-off between maximizing weed control and preserving crop physiological stability. Selecting the optimal treatment must, therefore, consider not only herbicidal efficacy but also the short-term stress responses induced by herbicide uptake.

Overall, the application of halauxifen-methyl at 1 L/ha, whether used alone or in combination with tribenuron-methyl at 45 g/ha and adjuvants such as Vivolt or Codacide, provided effective and selective control of *A. artemisiifolia*. The solo application of halauxifen-methyl remains the most effective variant, while the inclusion of high-performance adjuvants enhanced treatment efficacy without inducing persistent crop damage. These results reinforce the importance of optimizing both dosage and adjuvant selection to ensure high control levels while maintaining crop safety in sunflower production systems.

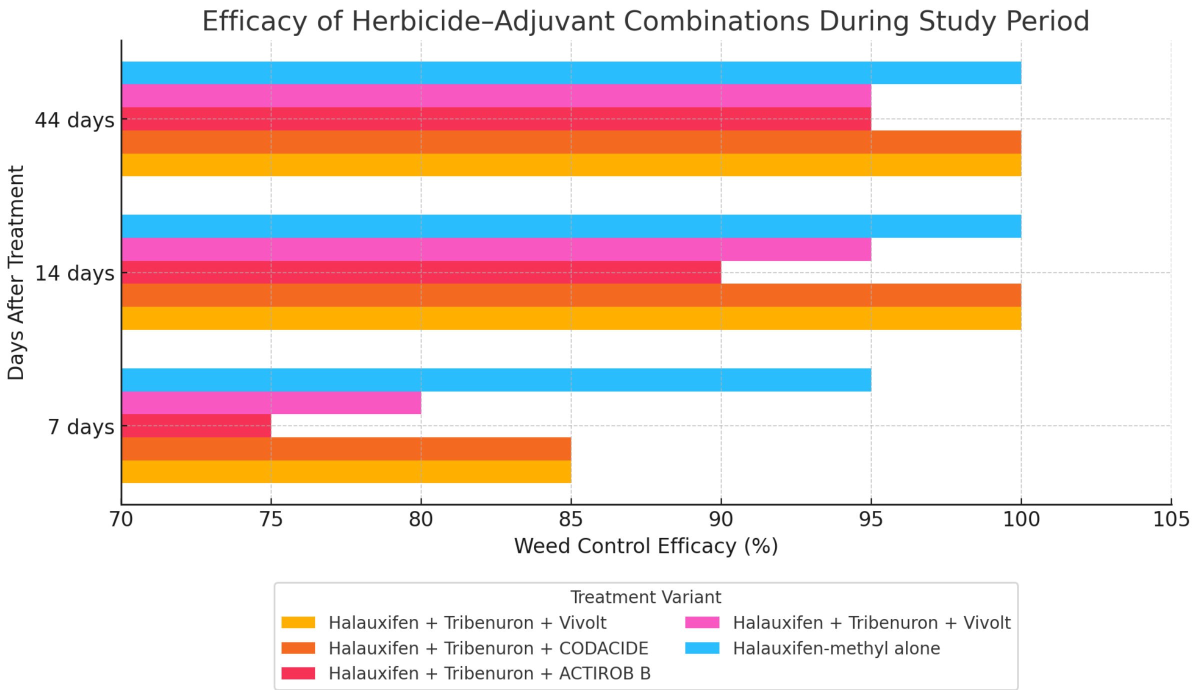

Figure 2. The efficacy of herbicide treatments in controlling the target species *A. artemisiifolia*, evaluated at different time points (3, 7, 14, 21, 44 and 50 days after application).

4. Conclusions

This study confirms that halauxifen-methyl, applied alone at 1 L/ha or in combination with tribenuron-methyl and specific adjuvants, offers an effective and selective strategy for controlling *A. artemisiifolia* in tribenuron-methyl tolerant sunflower crops. The results of this study demonstrate that herbicidal efficacy is strongly influenced not only by active ingredient dosage, but also by the type of adjuvant used. While halauxifen-methyl alone ensured the highest control levels with minimal crop stress, certain combinations, particularly those including Vivolt or Codacide, enhanced performance without compromising plant safety. No persistent phytotoxic effects were observed, reinforcing the suitability of these treatments under field conditions.

The importance of this research lies in its contribution to the optimization of weed control protocols in sunflower crops, offering farmers and agronomists evidence-based guidance for selecting efficient and safe treatments. Moreover, the study has strong implications for integrated weed management by demonstrating how efficacy can be enhanced without compromising crop safety or increasing phytotoxicity risks.

From an economic perspective, improved weed control strategies can lead to increased yield stability and reduced treatment costs by limiting the need for repeat applications.

In conclusion, the findings support the adoption of scientifically validated herbicide-adjuvant combinations as part of a sustainable and integrated weed management approach in sunflower cultivation, with measurable benefits across agronomic, economic, and environmental domains.

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