

HERBICIDE CONTROL OF *AMBROSIA ARTEMISIIFOLIA* IN SUNFLOWER, SOYBEAN AND MAIZE

PATRÍCIA MÁČAJOVÁ, MONIKA TÓTHOVÁ, VERONIKA KRCHŇAVÁ, ŠTEFAN TÝR,
PETER TÓTH*

Slovak University of Agriculture in Nitra, Slovak Republic

Máčajová, P., Tóthová, M., Krchňavá, V., Týr, Š., and Tóth, P. (2022). Herbicide control of *Ambrosia artemisiifolia* in sunflower, soybean and maize. Review. *Agriculture (Poľnohospodárstvo)*, 68(3), 110–118.

Ambrosia artemisiifolia L. (Asteraceae) has become a major threat to agriculture in many parts of the world. Global agriculture relies on the use of herbicides against *A. artemisiifolia* in the crops most at risk – sunflower, maize and soybean. This paper aims to provide an overview of the chemical control of *A. artemisiifolia* and to summarize the latest knowledge in this field. The sunflower is the crop most threatened by *A. artemisiifolia*, as both plants belong to the same family. The best control level was achieved after the preemergence application of flurochloridone and the combination of dimethenamid-P + pendimethalin. The introduction of the non-GM Clearfield and ExpressSun technologies allowed effective control with postemergence herbicides in sunflower varieties tolerant to imidazolinone and tribenuron-methyl herbicides. In soybean, the highest efficacy was observed in trials with imazamox and bentazone alone and in combination. The combination of imazamox with bentazone had a positive effect on yield compared to untreated stands. The introduction of transgenic soybeans tolerant to glyphosate led to increased glyphosate use and the predictable emergence of weed resistance in America in 1996. Preplant followed by postemergence herbicides were critical for the effective control of glyphosate-resistant *A. artemisiifolia* in glufosinate tolerant soybean. In maize, the highest efficacy was obtained after the application of glufosinate, bromoxynil and mesotrione + atrazine. Of the above substances for the control of *A. artemisiifolia* in maize, only mesotrione is currently registered in the EU.

Key words: common ragweed, chemical control, *Helianthus annuus*, *Glycine max*, *Zea mays*, resistance, tolerance

The introduction of *A. artemisiifolia* into Europe from North America was accidental in the 19th century (Defila & Clot 2001; Clot 2003). The species is the most outstanding invader in European agriculture (Kazinczi & Novák 2014). The expansion of *A. artemisiifolia* in agriculture of Eastern Eu-

rope could be linked to the political transitions after 1990s when many lands ceased to be used and were quickly colonised by *A. artemisiifolia* (Makra *et al.* 2005). *A. artemisiifolia* is most frequent in arable fields, along roads, and railroads (Essl *et al.* 2009; Milakovič *et al.* 2014), construction sites, and with-

Patricia Máčajová, Institute of Agronomic Sciences, Faculty of Agrobiolgy and Food Resources, Slovak University of Agriculture in Nitra, 94976 Nitra, Slovak Republic. E-mail: macajovapatricia@gmail.com

Monika Tóthová, Institute of Agronomic Sciences, Faculty of Agrobiolgy and Food Resources, Slovak University of Agriculture in Nitra, 94976 Nitra, Slovak Republic. E-mail: monika.tothova@uniag.sk

Veronika Krchňavá, Institute of Agronomic Sciences, Faculty of Agrobiolgy and Food Resources, Slovak University of Agriculture in Nitra, 94976 Nitra, Slovak Republic. E-mail: veronika.krchnava@gmail.com

Štefan Týr, Institute of Agronomic Sciences, Faculty of Agrobiolgy and Food Resources, Slovak University of Agriculture in Nitra, 94976 Nitra, Slovak Republic. E-mail: stefan.tyr@uniag.sk

Peter Tóth (*Corresponding author), Institute of Agronomic Sciences, Faculty of Agrobiolgy and Food Resources, Slovak University of Agriculture in Nitra, 94976 Nitra, Slovak Republic. E-mail: phytomyza@gmail.com

in dumping grounds, but it is found rarely in natural habitats (Skjøth *et al.* 2010; Bullock *et al.* 2012). The majority of *A. artemisiifolia* seeds germinate from the upper soil layers (2.6–3 cm) and can lose their viability after four years. Seeds from deeper soil layers (35–45 cm), can keep their viability for 30–40 years (Kazinczi *et al.* 2008). Data on substantial yield losses caused by *A. artemisiifolia* are abundant (Kukorelli *et al.* 2011; Hall *et al.* 2021). These losses are caused by its best competition, and ability to create dense and extensive stands (Béres *et al.* 2002). Soybean yield loss accounted for 84% compared to the weed-free control, on average (Hall *et al.* 2021). *A. artemisiifolia* control is difficult from an agronomic point of view due to its biological characteristics, especially the time of emergence in relation to the crop [sunflower, soybean and maize, e.g., Bertrand & Maupas (1996)], and therefore preemergent active substances are not as effective as post-emergent ones, as described below.

Ambrosia artemisiifolia control options

There are different strategies to control *A. artemisiifolia* – cultural, mechanical, biological, chemical, and integrated weed management. Mowing along roads and ditches in combination with the use of herbicides is a cost-effective strategy to control *A. artemisiifolia* and prevent the spread of its seeds into cultivated fields (Peters & Carlson 2014). It destroys the plants and reduces the amount of *A. artemisiifolia* seeds in the soil. Mowing should be done as low as possible to reduce the regrowth as much as possible (Odero *et al.* 2018), because mown *A. artemisiifolia* can form new shoots and flowers only 10 days later than non-mown plants (Peters & Carlson 2014). When plants with mature seeds are mown, *A. artemisiifolia* spreads via the seeds (Odero *et al.* 2018). The powerful techniques of integrated weed management are harvest weed seed control (HWSC), winter cover, and late planting (Beam *et al.* 2021) or the use herbicide-tolerant varieties e.g., in cultivated sunflower fields (Reisinger *et al.* 2013; Fried *et al.* 2022), soybean, maize (Burke *et al.* 2008; Nandula 2019) or in rice (Chen *et al.* 2021). HWSC is an evolving method to catch, destroy or remove weed seeds during or after crop harvest (Borger *et al.* 2021). Under field conditions, chemical control is the commonly used method to

control *A. artemisiifolia*. Herbicides can kill plants quickly and effectively and reduce seed production (Bae *et al.* 2017). However, overuse of herbicides with the same site of action can lead to the development of resistant populations (Tranel & Wright 2002; Powles 2008; Jugulam & Shyam 2019). *A. artemisiifolia* is an excellent target for biological control. It has been successfully controlled with insects in Australia (Palmer *et al.* 2010) and China (Zhou *et al.* 2010). The attempt to regulate *A. artemisiifolia* by insects has failed in Eastern Europe. Worldwide, about fifty different insect species and two mites have been identified in association with *A. artemisiifolia* (Gerber *et al.* 2011). Most of them are generalists and cause limited damage, except for the very voracious oligophagous *A. artemisiifolia* leaf beetle, *Ophraella communa* (Coleoptera: Chrysomelidae) (Kim & Lee 2018). The potential mycoherbicide candidate *Phoma* sp. was used in Canada and the USA, but the fungus lost its virulence (Teshler *et al.* 2002). Another management tool is weed control through competition in cereal fields (Zimdahl 2008) or sowing competitive species to reduce *A. artemisiifolia* germination (Milaković & Karrer 2009).

Herbicide control in sunflower

Plants sown in spring are most frequently infested by *A. artemisiifolia* (Pinke *et al.* 2013). Sunflower is one of the crops most affected by *A. artemisiifolia*, especially in the early growth stages, as both plants belong to the Asteraceae family (Bertrand & Maupas 1996). About 70% of the world's sunflower production comes from the European Union, Russia, and Ukraine, and *A. artemisiifolia* is known to spread rapidly in these countries (Streit 2012). The study from Romania published by Stef (2017) indicates several herbicides tested for *A. artemisiifolia* control in sunflowers. In all cases, these were preemergent herbicides with the active substances s-metolachlor, terbuthylazine, dimethenamid-P, and pendimethalin. Among them, s-metolachlor and dimethenamid-P were less effective. Pendimethalin increased the sunflower seed yield by 146–164% compared to untreated plots (Jursík *et al.* 2020, Pacanoski & Mehmeti 2021). Significant yield reductions (120–128%) were observed in plots treated with dimethenamid-P and s-metolachlor (Jursík *et al.* 2020), however s-metolachlor (and pendimethalin) showed

the lowest phytotoxicity to sunflower (Jursík *et al.* 2020; Pacanoski & Mehmeti 2021). The combination of dimethenamid-P + pendimethalin resulted in 98.4% weed control efficiency. Efficiency of s-metolachlor in combination with terbuthylazine was 92.0%. Preemergent application of s-metolachlor and dimethenamid-P alone was insufficient against *A. artemisiifolia* (Stef 2017). Since terbuthylazine is only approved for use in maize and sorghum in Slovakia, it cannot be applied in sunflowers (ÚKSÚP 2022). The best treatment, therefore, remains the preparation with the active substances dimethenamid-P + pendimethalin (Kurent 2022). The efficacy of preemergence herbicides in the combination dimethenamid-P + pendimethalin + oxyfluorfen was evaluated in sunflower stands in Hungary. The effectiveness of this combination proved to be insufficient, moreover, in the case of a lack of rainfall two weeks after application, *A. artemisiifolia* will be able to cover the whole sown area. This herbicide combination was not sufficient even with the postemergence application of flumioxazin (Kukorelli *et al.* 2011). Flumioxazin and oxyfluorfen may not be used in Slovakia. They are authorised in some countries of the European Union (Lewis *et al.* 2016). Although bifenox is listed as a postemergence herbicide for *A. artemisiifolia* control (Kurent 2022), its effectiveness was questioned by Hodişan and Morar (2008). Their research showed that 14 days after application, *A. artemisiifolia* plants regenerated so rapidly that by the time the sunflower flowered, the *A. artemisiifolia* plants had overtaken the crop. Another preemergent herbicide used to control *A. artemisiifolia* is flurochloridone. It was described as excellent in efficacy against *A. artemisiifolia* (Pilorgé & Mircovich 1998; Kurent 2022). Preemergence application of flurochloridone + s-metolachlor was unsatisfactory (Simić *et al.* 2011). In addition to these methods, mention should be made of Clearfield technology in sunflowers, which allows the use of imidazolinone herbicides as an option for postemergence weed control. This technology is non-GMO. For the Clearfield production system, imazamox has become the cornerstone of imidazolinone herbicides in Europe (Pfenning *et al.* 2008). A remarkably similar ExpressSun technology has been developed in which sunflower varieties are tolerant to tribenuron-methyl (Zollinger 2004). The postemergence application of

imazamox and tribenuron-methyl resulted in good efficacy to *A. artemisiifolia*. The efficacy of tribenuron on *A. artemisiifolia*, was lower compared to imidazolinone herbicides. Therefore, it is necessary to use tribenuron-methyl at early growth stages or in a split application (Tuemmler & Schroeder 2013). Komives *et al.* (2016) showed comparable results in sunflowers with tribenuron-methyl and imazamox. Tribenuron and imazamox have been marketed for control of weeds, including *A. artemisiifolia* in conventional sunflower crops (Sala *et al.* 2012). Their effect weakened in highly infested areas (Yu & Powles 2014). Herbicide resistance was described by Délye *et al.* (2013) and Gaines *et al.* (2020). Recently the occurrence of resistant populations has been confirmed in France (Loubet *et al.* 2021; Meyer *et al.* 2022) and Serbia (Heap 2023). The new auxin herbicide halauxifen-methyl (or Arylex™ active) (Epp *et al.* 2016; Busi *et al.* 2018; Morderer *et al.* 2018; Xu *et al.* 2022) is very effective against *A. artemisiifolia* and other quarantine weeds in sunflower (Maiefisch & Mangelinckx 2021) alone (93%) or in mixture with dicamba; 2,4 D + dicamba or glyphosate and dicamba (97%) (Zimmer *et al.* 2018).

Herbicide control in soybean

A. artemisiifolia has become an important weed in European soybean stands (Stef 2017). In Slovakia, insufficiently effective or ineffective herbicides based on the active substances prosulfocarb, clo-mazone, s-metolachlor, and dimethenamid-P are used in soybean fields (Kurent 2022). Four weeks after application s-metolachlor and dimethenamid-P provided up to 9 and 24% control of *A. artemisiifolia*, respectively (Taziar *et al.* 2016). These two active substances provided a similar level of control in glyphosate-resistant (GR) *A. artemisiifolia* populations (Soltani *et al.* 2018a). In glufosinate tolerant soybean, herbicide programmes containing glufosinate, paraquat, 2,4-D, imazethapyr, cloransulam-methyl, and flumioxazin provided 90–99% control of GR *A. artemisiifolia* 21 days after preplant application. Herbicides incorporated preplant followed by postemergence herbicides were critical and provided effective and economical control of GR *A. artemisiifolia* (Barnes *et al.* 2017). Taylor-Lovell *et al.* (2002) reported that a high-rate mixture of flumioxazin and pendimethalin provided

60% control of *A. artemisiifolia* in soybeans. According to Niekamp *et al.* (1999), the control rate of *A. artemisiifolia* seven weeks after sowing in no tillage soybean reached 92% by flumioxazin alone. The combination of flumioxazin with s-metolachlor had a negative effect on soybean yield due to higher phytotoxicity (Salomão *et al.* 2021). In the last ten years, the problem with *A. artemisiifolia* in soybean stands has also been observed in the western part of Romania (Europe). In this area, a very good level of *A. artemisiifolia* regulation was achieved by imazamox (71.5%) and thifensulfuron-methyl (85%) (Stef *et al.* 2019). According to Kurent (2022) the effectiveness of imazamox is excellent, but the effectiveness of the thifensulfuron-methyl is listed as weak. In Nebraska (USA), thifensulfuron-methyl was not effective in controlling GR and GS (glyphosate susceptible) *A. artemisiifolia* biotypes, resulting in 26 and 18% control, respectively (Ganie & Jhala 2017). The most obvious reason for the lower efficacy of all tested acetolactate synthase (ALS) inhibiting herbicides (thifensulfuron-methyl, chlorimuron-ethyl, imazethapyr, and imazamox) was the emergence of resistant *A. artemisiifolia* populations in the USA and Canada (Heap 2023). Recently, ALS resistant plants were found in a very low frequencies in France (Loubet *et al.* 2021). In Slovakia, the best option is still the use of imazamox, imazamox + pendimethalin, or flufenacet in combination with metribuzin (Kurent 2022). Metribuzin (786 g a.i./ha) reduced the density of GR *A. artemisiifolia* by 95%. Some of the ragweed plants were still able to reach reproductive maturity and produce seeds (Byker *et al.* 2018). Higher rates will provide longer residual weed control at high costs unprofitable for farmers and may result in soybean injury (Askew *et al.* 1999). Flufenacet and metribuzin at a dose of 670 g a.i./ha (54.4 + 13.6% a.i.) were sufficient to control *A. artemisiifolia* throughout the season. The visual damage to soybean after application was minimal with no negative impact on yield (Soltani *et al.* 2005). Hodişan & Morar (2008), and Béres *et al.* (2005) found imazamox as highly effective against *A. artemisiifolia* in peas, soybean, and sunflower when applied in the optimal growth stage. The highest efficacy was observed in experiments with bentazone 93.25% (Stef *et al.* 2019), 95–97% (Hager & Renner 1994; Béres *et al.* 2005) and 99% (Ganie & Jhala 2017).

Bentazon in combination with imazamox achieved the efficiency of 90.5% (Stef *et al.* 2019). Bentazone alone was not effective against GR *A. artemisiifolia* in soybean (Ganie & Jhala 2017). In Slovakia, there is only one herbicide with the active substance bentazone approved for use in soybean crops (ÚKSÚP 2022). Soybeans treated with thifensulfuron-methyl showed the lowest yield. The combination of imazamox with bentazone brought a significant increase in production compared to untreated stands (Stef *et al.* 2019). In America, transgenic soybeans tolerant to glyphosate was launched by Monsanto in 1996. In 2007, 91% of transgenic soybeans were planted in the USA. Initially, this biotechnology-based weed control strategy led to a simplification of weed control and a reduction in the use of herbicides. From 2002, the total amount of herbicides used in soybeans started to increase and thus the efficiency of this weed management strategy decreased (Bonny 2008). The high increase in the use of glyphosate has led to the predictable appearance of weed resistance, multiple herbicide-resistant weeds appeared (Hugh & Hall 2014) and biodiversity continues to decline rapidly (Tschamtkke *et al.* 2021).

Herbicide control in maize

Glyphosate tolerant (GT) maize was marketed for the first time in America by Monsanto in 1998 (Green 2009; Green & Castle 2010). The frequent use of glyphosate in America has led to the development of GR weed populations (Ganie *et al.* 2017; Barnes *et al.* 2018). Glyphosate-resistant *A. artemisiifolia* was recorded for the first time in Ontario in 2011 (Sanders *et al.* 2017). The art of farmers is to find a combination of approved herbicides that can effectively control weeds with tolerance to glyphosate (Barnes *et al.* 2018). In Slovakia, there are many herbicides active substances and their combinations that are approved for use in maize. The active substances s-metolachlor, fluroxypyr, and nicosulfuron + rimosulfuron suppress the weeds only insufficiently or they are not effective at all. The best efficacy was shown by the herbicides with the independently acting active substances foramsulfuron, clopyralid, dicamba, sulcotrione, and mesotrione (Kurent 2022). Very good efficacy (90%) of clopyralid and mesotrione was confirmed by Hodişan & Morar (2008). Williams *et al.* (2014) evaluated the effec-

tiveness of dicamba, which reduced the number of *A. artemisiifolia* from 20.1 plants/m² to 0 plants/m² in GT maize. Ganie & Jhala (2017) evaluated the response of GS *A. artemisiifolia* to postemergence herbicides three weeks after treatment in a greenhouse study conducted at the University of Nebraska–Lincoln. The efficacy of individual active substances application to *A. artemisiifolia* were as follows: primisulfuron-methyl reduced *A. artemisiifolia* by 18%, reduction by glufosinate was 99%, topramezone 96%, carfentrazone 32%, bromoxynil 99%, diflufenzopyr-methyl + dicamba 95%, halo-sulfuron-methyl + dicamba 91%, mesotrione 78%, mesotrione + atrazine 99%, fluthiacet-methyl + mesotrione 87%. The estimated low dose 45 g/ha of mesotrione to achieve a 90% reduction in biomass in Canada was probably influenced by low population density of *A. artemisiifolia* (Nurse *et al.* 2010). Of all the substances mentioned above, only mesotrione and dicamba are currently authorized in the EU. Approval expiration date of mesotrione is 31/05/2032 (Reg. (EU) 2017/725) (2017), approval period of dicamba was extended until 31/12/2023 (Reg. (EU) 2022/1480) (2022). Very good control level was achieved by the active substances tembotrione 98%, 2,4 D 98% and dicamba 94%. The efficacy of thiencazone + tembotrione in the same study was 99% (Ganie & Jhala 2017). Tembotrione + thiencazone-methyl are listed in Slovakia with excellent efficacy against *A. artemisiifolia*. Dicamba and prosulfuron + dicamba were equally good in efficacy, and the active substance 2,4 D had slightly lower efficacy (Kurent 2022). The best regulation of GR *A. artemisiifolia* in GT maize was achieved after application of postemergence herbicides with active substances glufosinate, bromoxynil, diflufenzopyr + dicamba, mesotrione + atrazine (99%) and 2,4 D (92%) three weeks after treatment. These active substances were equally effective in controlling GS and GR *A. artemisiifolia* in Nebraska (Ganie & Jhala 2017). Lower postemergence herbicide efficacy against GR *A. artemisiifolia* in GT maize was reported from Ontario (USA) four weeks after application – dicamba 85%, glufosinate 71%, 2,4 D ester – 58%, mesotrione + atrazine 38% (Soltani *et al.* 2018a). The control level GR *A. artemisiifolia* was higher in trials with preemergence application of dicamba and mesotrione + atrazine, 100% and 94% respectively (Soltani *et al.* 2018b).

CONCLUSIONS

In the EU, there is instant pressure to reduce the use of pesticides in agriculture. The European Union's Pesticides Regulation (EC) 1107/2009 recognizes that pesticides have adverse effects on human and animal health and the environment. For this reason, the authorization of several pesticides including herbicides has not been renewed. At the same time, the discovery and development of new active substances are progressing slowly, creating a gap in the availability of herbicides to meet the current needs of conventional agriculture. Despite the above facts, this report discusses a range of herbicides that can be used to control *A. artemisiifolia* in sunflower, soybean and maize. Sunflowers are the most threatened crops as both plants belong to the Asteraceae family. Therefore, only pre-emergence herbicides have been used to control *A. artemisiifolia*, unless Clearfield and ExpressSun technology has been introduced. Preemergence application of flurochloridone alone and the combination of dimethenamid-P + pendimethalin resulted in excellent weed control efficacy. However, dimethenamid-P and s-metolachlor alone and the combination of flurochloridone + s-metolachlor, did not provide a satisfactory control level. Excellent weed control efficacy was achieved by the preplant application of new auxin herbicide halauxifen-methyl in the following combinations: halauxifen-methyl + dicamba, halauxifen-methyl + 2,4 D + dicamba, halauxifen-methyl + glyphosate + dicamba. The introduction of Clearfield and ExpressSun technologies enabled the postemergence herbicides application in sunflower varieties tolerant to imidazolinone and tribenuron-methyl. Since imazamox and tribenuron were marketed earlier for weed control in conventional sunflower crops, the ALS-resistant *A. artemisiifolia* populations emerged. Their spread is likely to be accelerated by human activities. In soybean, the highest efficacy was observed in trials with imazamox and bentazone alone and in combination. The combination of imazamox + bentazone had a positive effect on yield. The introduction of transgenic soybeans tolerant to glyphosate led to the emergence of weed resistance. Metribuzin reduced the density of GR *A. artemisiifolia* by 95%, bentazone was not effective. In the USA, thifensul-

furon-methyl did not provide satisfactory control either in GR or GS populations of *A. artemisiifolia*. This indicates that further research on multiple herbicide resistance is needed. Preplant followed by postemergence herbicides were critical for effective control of GR *A. artemisiifolia* in glufosinate tolerant soybean. In maize, the highest efficacy was obtained after the postemergence application of dicamba, glufosinate, bromoxynil, tembotrione, thiencazone + tembotrione, and mesotrione + atrazine. The best regulation of GR *A. artemisiifolia* in GT maize was achieved with the postemergence herbicides glufosinate, bromoxynil, diflufenzopyr + dicamba, mesotrione + atrazine, 2,4 D, and the preemergence application of dicamba. These active substances were equally effective in controlling GS and GR *A. artemisiifolia* in Nebraska (USA). In Ontario (USA) lower postemergence herbicide efficacy was reported against GR *A. artemisiifolia* in GT maize. In the future, it will be necessary to ensure progress when resistance occurs and to adapt to an ever-decreasing range of available herbicides. The art for farmers is therefore to find a combination of approved herbicides that can effectively control susceptible and resistant weed populations.

Acknowledgement: The Research was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic VEGA 1/0467/22 and the Slovak Research and Development Agency under the Contract no. SK-SRB-21-0045

REFERENCES

- Askew, S., Wilcut, J. and Langston, V. (1999). Weed management in soybean (*Glycine max*) with preplant-incorporated herbicides and cloransulam-methyl. *Weed Technology*, 13(2), 276–282. DOI:10.1017/S0890037X00041737.
- Bae, J., Nurse, R. E., Simard, M.-J., and Page, E. R. (2017). Managing glyphosate-resistant common ragweed (*Ambrosia artemisiifolia*): effect of glyphosate-phenoxy tank mixes on growth, fecundity, and seed viability. *Weed Science*, 65, 31–40. DOI:10.1614/WS-D-16-00094.1.
- Barnes, E. R., Knezevic, S. Z., Sikkema, P. H., Lindquist, J. L., and Jhala, A. J. (2017). Control of glyphosate-resistant common ragweed (*Ambrosia artemisiifolia* L.) in glufosinate-resistant soybean [*Glycine max* (L.) Merr]. *Frontiers in Plant Science*, 8, 1455. DOI:10.3389/fpls.2017.01455.
- Barnes, E., Lindquist, J., Knezevic, S., and Jhala, A. (2018). Herbicide options for managing glyphosate-resistant common ragweed in liberty link soybean. [online] *University of Nebraska-Lincoln*. Available at: <https://cropwatch.unl.edu/2018/herbicide-options-managing-glyphosate-resistant-common-ragweed-libertylink-soybean> [Accessed 12 Sept. 20022].
- Beam, S. C., Cahoon, C. W., Haak, D. C., Holshouser, D. L., Mirsky, S. B., and Flessner, M. L. (2021). Integrated weed management systems to control common ragweed (*Ambrosia artemisiifolia* L.) in soybean. *Frontiers in Agronomy* 2(598426). DOI:10.3389/fagro.2020.598426.
- Bertrand, P. and Maupas, E. (1996). Ragweed, invasive and allergenic! *Phytoma*, 484, 25–26.
- Béres, I., Kazinczi, G. and Narwal, S. (2002). Allelopathic plants. 4. Common ragweed (*Ambrosia elatior* L. Syn. *A. artemisiifolia*). *Allelopathy Journal*, 9(1), 27–34.
- Béres, I., Kazinczi, G., Lehoczy, É., Tarczal, E., and Nádasy, E. (2005). *Integrated Weed Management of Ambrosia Artemisiifolia* L., 19–23 June, Bari, Italy. Available at: <http://ewrs2005/abstracts/s5kazinczi.pdf>.
- Bonny, S. (2008). Genetically modified glyphosate-tolerant soybean in the USA: adoption factors, impacts and prospects. *Agronomy for Sustainable Development*, 28, 21–32. DOI:10.1051/agro:2007044.
- Borger, C. P. D., Petersen, D. and Gill, G. S. (2021). Modeling the long-term impact of harvest weed seed control for species like *Bromus diandrus* and *Hordeum* spp. that shed a portion of seed prior to harvest. *Weed Research*, 61(4), 307–316. DOI:10.1111/wre.12489.
- Bullock, J. M., Chapman, D., Schafer, S., Roy, D., and Girardello, M. (2012). Assessing and controlling the spread and the effects of common ragweed in Europe. (ENV.B2/ETU/2010/0037) European Commission, *Final Report*.
- Burke, I., Thomas, W., Allen, J., Collins, J., and Wilcut, J. (2008). A Comparison of weed control in herbicide-resistant, herbicide-tolerant, and conventional corn. *Weed Technology*, 22(4), 571–579. DOI:10.1614/WT-07-184.1.
- Busi, R., Goggin, D. E., Heap, I. M., Horak, M. J., Jugulam, M., Masters, R. A., Napier, R. M., Riar, D. S., Satchivi, N. M., Torra, J., Westra, P., and Wright, T. R. (2018). Weed resistance to synthetic auxin herbicides. *Pest Management Science*, 74(10), 2265–2276. DOI:10.1002/ps.4823.
- Byker, H. P., Van Wely, A. C., Jhala, A. J., Soltani, N., Robinson, D. E., Lawton, M. B. and Sikkema, P. H. (2018). Preplant followed by postemergence herbicide programs and biologically effective rate of metribuzin for control of glyphosate-resistant common ragweed (*Ambrosia artemisiifolia*) in soybean. *Canadian Journal of Plant Science*, 98(4), 809–814. DOI:10.1139/cjps-2017-0299.
- Chen, L., Gu, G., Wang, C., Chen, Z., Yan, W., Jin, M., Xie, G., Zhou, J., Deng, X. W., and Tang, X. (2021). Trp548Met mutation of acetolactate synthase in rice confers resistance to a broad spectrum of ALS-inhibiting herbicides. *The Crop Journal*, 9(4), 750–758. DOI:10.1016/j.cj.2020.11.003.
- Clot, B. (2003). Trends in airborne pollen: an overview of 21 years of data in Neuchâtel (Switzerland). *Aerobiologia*, 19, 227–34. DOI:10.1023/B:AERO.0000006572.53105.17.
- Defila, C. and Clot, B. (2001). Phyto phenological trends in Switzerland. *International Journal of Biometeorology*, 45, 203–207. DOI:10.1007/s004840100101.
- Délye, C., Jasieniuk, M. and Le Corre, V. (2013). Deciphering the evolution of herbicide resistance in weeds. *Trends in Genetics*, 29(11), 649–658. DOI:10.1016/j.tig.2013.06.001.
- Epp, J. B., Alexander, A. L., Balko, T. W., and Yerkes, C. N. (2016). The discovery of Arylex™ active and Rinskor™ active: Two novel auxin herbicides. *Bioorganic & Medicinal Chemistry, Bioorganic & Medicinal Chemistry*, 24(3), 362–371. DOI:10.1016/j.bmc.2015.08.011.
- Essl, F., Dullinger, S. and Kleinbauer, I. (2009). Changes in the spatio-temporal patterns and habitat preferences of *Ambro-*

- sia artemisiifolia* during its invasion in Austria. *Preslia*, 81, 119–133.
- Fried, G., Le Corre, V., Rakotoson, T., Buchmann, J., Germain, T., Gounon, R., Royer, H., Biju-Duval, L., Felten, E., Viere, E., and Chauvel, B. (2022). Impact of new management practices on arable and field margin plant communities in sunflower, with an emphasis on the abundance of *Ambrosia artemisiifolia* (Asteraceae). *Weed Research*, 62(2), 134–148. DOI:10.1111/wre.12522.
- Gaines, T.A., Duke, S.O., Morran, S., Rigon, C.A.G., Tranel, P.J., Küpper, A., and Dayan, F.E. (2020). Mechanisms of evolved herbicide resistance. *Journal of Biological Chemistry*, 295(30), 10307–10330. DOI:10.1074/jbc.REV120.013572.
- Ganie, Z.A. and Jhala, A.J. (2017). Confirmation of glyphosate-resistant common ragweed (*Ambrosia artemisiifolia*) in Nebraska and response to POST corn and soybean herbicides. *Weed Technology*, 31, 225–237. DOI:10.1017/wet.2016.26.
- Ganie, Z.A., Jugulam, M., Varanasi, V.K., and Jhala A.J. (2017). Investigating the mechanism of glyphosate resistance in a common ragweed (*Ambrosia artemisiifolia* L.) biotype from Nebraska. *Canadian Journal of Plant Science*, 97, 1140–1151. DOI:10.1139/cjps-2017-0036.
- Gerber, E., Schaffner, U., Gassmann, A., Hinz, H.L., Seier, M., and Müller-Schärer, H. (2011). Prospects for biological control of *Ambrosia artemisiifolia* in Europe: learning from the past. *Weed Research*, 51, 559–573. DOI:10.1111/j.1365-3180.2011.00879.x.
- Green, J.M. (2009). Evolution of glyphosate-resistant crop technology. *Weed Science*, 57, 108–117. DOI:10.1614/WS-08-030.1.
- Green, J.M. and Castle, L.A. (2010). Transitioning from single to multiple herbicide-resistant crops. In Nandula, V.K. (Ed.) *Glyphosate Resistance in Crops and Weeds: History, Development, and Management*, 1st ed. John Wiley & Sons, Inc., pp. 67–91. DOI:10.1002/9780470634394.
- Hager, A. and Renner, K. (1994). Common ragweed (*Ambrosia artemisiifolia*) control in soybean (*Glycine max*) with bentazon as influenced by imazethapyr or thifensulfuron tank-mixes. *Weed Technology*, 8(4), 766–771. DOI:10.1017/S0890037X00028669.
- Hall, R.M., Urban, B., Wagentristsl, H., Karrer, G., Winter, A., Czerny, R., and Kaul, H.-P. (2021). Common ragweed (*Ambrosia artemisiifolia* L.) causes severe yield losses in soybean and impairs *Bradyrhizobium japonicum* infection. *Agronomy*, 11, 1616. DOI:10.3390/agronomy11081616.
- Heap, I. (2023). The international herbicide-resistant weed database, [online]. Available at: www.weedscience.org [Accessed 2 Jan. 2023].
- Hodişan, N. and Morar, G. (2008). Floarea pusteii *Ambrosia artemisiifolia* L. Oradea: GrafNet, 120p.
- Hugh, J.B. and Hall, R.M. (2014). Genetically modified herbicide resistant (GMHR) crops a two-edged sword? An Americas perspective on development and effect on weed management. *Crop Protection* 66, 40–45. DOI:10.1016/j.cropro.2014.08.014.
- Jugulam, M. and Shyam, C. (2019). Non-target-site resistance to herbicides: recent developments. *Plants*, 8, 417. DOI: 10.3390/plants8100417.
- Jursík, M., Kočárek, M., Kolářová, M. and Tichý, L. (2020). Effect of different soil and weather conditions on efficacy, selectivity, and dissipation of herbicides in sunflower. *Plant, Soil and Environment*, 66(9), 468–476. DOI: 10.17221/223/2020-PSE.
- Kazinczi, G., Béres, I., Novák, R., Biro, K., and Pathy, Z. (2008). Common ragweed (*Ambrosia artemisiifolia*): a review with special regards to the results in Hungary. I. Taxonomy, origin and distribution, morphology, lifecycle, and reproduction strategy. *Herbologia*, 9(1), 55–91.
- Kazinczi, G. and Novák, R. (2014). *Integrated methods for suppression of common ragweed*. National Food Chain Safety Office, Directorate of Plant Protection Soil Conservation and Agri-environment, 226 pp. ISBN 978-963-89968-4-8.
- Kim, H.G. and Lee, D.-H. (2018). Review of the biology and ecology of a ragweed leaf beetle, *Ophraella communa* (Coleoptera: Chrysomelidae), which is a biological control agent of an invasive common ragweed, *Ambrosia artemisiifolia* (Asterales: Asteraceae). *Biocontrol Science and Technology* 29(1), 1–16. DOI:10.1080/09583157.2018.1540032.
- Komives, T., Reisinger, P. and Bittsánszky, A. (2016). Control of common ragweed in ALS herbicide-resistant sunflower hybrids (*Helianthus annuus*). *Julius-Kühn-Archiv*. DOI: 10.5073/jka.2016.455.32.
- Kukorelli, G., Reisinger, P., Torma, M., and Ádamszki, T. (2011). Experiments with the control of common ragweed in imidazoline-resistant and tribenuron-methyl-resistant sunflower. *Herbologia*, 12(2), 15–22.
- Kurent (2022). *Přípravky na ochranu rastlín 2022*. Kurent s.r.o., 490 pp. ISBN: 978-80-87111-94-9.
- Lewis K., Tzilivakis, J., Warner, D.J., and Green, A. (2016). An international database for pesticide risk assessments and management. Human and ecological risk assessment. *An International Journal*, 22(4), 1050–1064. DOI: 10.1080/10807039.2015.1133242.
- Loubet, I., Caddoux, L., Fontaine, S., Michel, S., Pernin, F., Barrès, B., Le Corre, V., and Délye, Ch. (2021). A high diversity of mechanisms endows ALS-inhibiting herbicide resistance in the invasive common ragweed (*Ambrosia artemisiifolia* L.). *Scientific Reports*, 11, Article number: 19904. DOI:10.1038/s41598-021-99306-9.
- Maienfish, P. and Mangelinckx, S. (2021). Recent Highlights in the Discovery and Optimization of Crop Protection Products. Academic Press; 1st edition, 646 pages, ISBN-13: 978-0128210352
- Makra, L., Juhász, M., Béczi, R., and Borsos, E. (2005). The history and impacts of airborne *Ambrosia* (Asteraceae) pollen in Hungary. *Grana*, 44, 57–64. DOI: 10.1080/001731305100100558
- Meyer, L., Pernin, F., Michel, S., Bailly, G., Chauvel, B., Le Corre, V., and Délye, C. (2022). Lab meets field: Accelerated selection and field monitoring concur that non-target-site-based resistance evolves first in the dicotyledonous, allergenic weed *Ambrosia artemisiifolia*. *Plant Science*, 317, 111202. DOI:10.1016/j.plantsci.2022.111202.
- Milakovič, I., Fiedler, K., and Karrer, G. (2014). Management of roadsides population of invasive *Ambrosia artemisiifolia* by mowing. *Weed research*, 54, 256–264. DOI:10.1111/wre.12074.
- Milakovič, I. and Karrer, G. (2009). Sowing of competing vegetation as a control measure for *Ambrosia artemisiifolia* L. *Book of Abstracts: International Congress on Biological Invasions*, Fuzhou, 2.–6.11., p. 279.
- Morderer, Ye.Yu., Sychuk, A.M., Rodzevych, O.P., Pavlenko, V.V., and Sarbash, O.M. (2018). Effectiveness of auxin-like herbicide halauxifen-methyl mixtures with other herbicides for Canada thistle (*Cirsium arvense*) control in wheat crops. *Plant Physiology and Genetics*, 50(6), 508–516. DOI: 10.15407/frg2018.06.508.
- Nandula, V.K. (2019). Herbicide Resistance Traits in Maize and Soybean: Current Status and Future Outlook. *Plants*, 8(9), 337. DOI:10.3390/plants8090337.
- Niekamp, J., Johnson, W. and Smeda, R. (1999). Broadleaf Weed

- Control with Sulfentrazone and Flumioxazin in No-Tillage Soybean (*Glycine max*). *Weed Technology*, 13(2), 233–238. DOI:10.1017/S0890037X0004166X.
- Nurse, R.E., Hamill, A.S., Swanton, C.J., Tardif, F.J., and Sikkema, P.H. (2010). Weed control and yield response to mesotrione in maize (*Zea mays*). *Crop Protection*, 29(7), 652–657. DOI:10.1016/j.cropro.2010.01.010.
- Odero, D.C., Sellers, B.A. and Ferrell, J.A. (2018). Biology and control of common ragweed along ditch and canal banks. University of Florida. Available at: <https://edis.ifas.ufl.edu/publication/AG356>
- Pacanoski, Z. and Mehmeti, A. (2021). Efficacy and selectivity of PRE-em herbicide on dependence of soil types and precipitation in sunflower crop. *Agraarteadus: Journal of Agricultural Science*, 32(1), 100–110. DOI:10.15159/jas.21.08.
- Palmer, W.A., Heard, T. and Sheppard, A.W. (2010). A review of Australian classical biological control of weeds programs and research activities over the past 12 years. *Biological Control*, 52, 271–287. DOI:10.1016/j.biocontrol.2009.07.011.
- Peters, T.J. and Carlson, A.L. (2014). Featured weed-common ragweed controlling common ragweed in fields planted to sugar beet. *Sugar beet Research and Extension Reports*, Southern Minnesota Beet Sugar Cooperative, North Dakota State University, USA.
- Pfenning, M., Palfay G. and Guillet, T. (2008). The CLEAR-FIELD® technology – A new broad-spectrum post-emergence weed control system for European sunflower growers. *Journal of Plant Diseases and Protection*, Special Issue XXI. ISSN 1861-4051.
- Pilorgé, E. and Mircovich, C. (1998). Contrôle de l'Ambrosie à feuilles d'Armoise dans les cultures de tournesol. *International Meeting on Weed Control*, 2, 893–899.
- Pinke, G., Karácsony, P., Botta-Dukát, Z., and Czúcz, B. (2013). Relating *Ambrosia artemisiifolia* and other weeds to the management of Hungarian sunflower crops. *Journal of Pest Science*, 86, 621–631. DOI:10.1007/s10340-013-0484-z.
- Powles, S.B. (2008). Evolved glyphosate-resistant weeds around the world: lessons to be learnt. *Pest Management Science*, 64, 360–365. DOI:10.1002/ps.1525.
- Reg. (EC) 1107/2009 (2009). Regulation (EC) 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC.
- Reg. (EU) 2017/725 (2017). Commission Implementing Regulation (EU) 2017/725 of 24 April 2017 renewing the approval of the active substance mesotrione in accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market and amending the Annex to Commission Implementing Regulation (EU) No 540/2011.
- Reg. (EU) 2022/1480 (2022). Commission Implementing Regulation (EU) 2022/1480 of 7 September 2022 amending Implementing Regulation (EU) No 540/2011 as regards the extension of the approval periods of the active substances 2-phenylphenol (including its salts such as the sodium salt), 8-hydroxyquinoline, amidosulfuron, bensulfuron, bifenox, chlormequat, chlorotoluron, clofentezine, clomazone, daminozide, deltamethrin, dicamba, difenoconazole, diflufenican, dimethachlor, esfenvalerate, etofenprox, fenoxaprop-P, fenpropidin, fenpyrazamine, fludioxonil, flufenacet, flumetralin, fosthiazate, lenacil, MCPA, MCPB, nicosulfuron, paraffin oils, paraffin oil, penconazole, picloram, prohexadione, propaquizafop, prosulfocarb, quizalofop-P-ethyl, quizalofop-P-tefuryl, sodium 5-nitroguaiacolate, sodium o-nitrophenolate, sodium p-nitrophenolate, sulphur, tebufenpyrad, tetraconazole, tri-allate, triflurosulfuron and tritosulfuron
- Reisinger, P., Kukorelli, G., Bittsanszky, A. and Komives, T. (2013). Minireview: importance of herbicide-tolerant sunflower hybrids in suppressing common ragweed (*Ambrosia artemisiifolia*) pollen production. *EQA – International Journal of Environmental Quality*, 12(12), 31–37. DOI: 10.6092/issn.2281-4485/4247.
- Sala, C.A., Bulos, M., Altieri, E., and Ramos, M.L. (2012). Genetics and breeding of herbicide tolerance in sunflower. *Helia*, 35, 57–70. DOI:10.2298/HEL1257057S.
- Sanders, C.H., Joseph, D.D. and Marshall, M.W. (2017). Efficacy of Selected Herbicide Programs in 2,4-D Tolerant Cotton (*Gossypium hirsutum* L.). *Agricultural Sciences*, 8(10). DOI:10.4236/as.2017.810084.
- Simić, M., Dragičević, V., Knežević, S., Radosavljević, M., Dolijanović, Ž., and Filipović, M. (2011). Effects of applied herbicides on crop productivity and on weed infestation in different growth stages of sunflower (*Helianthus annuus* L.). *Helia* 34(54), 27–37. DOI:10.2298/HEL1154027S.
- Salomão, H.M., Trezzi1, M.M., Viecelli, M., De Bortoli Pagnoncelli, F., Patel, F., Damo, L., and Frizzon, G. (2021). Weed management with pre-emergent herbicides in soybean crops. *Communications in Plant Sciences*, 11, 60–66. DOI:10.26814/cps2021008.
- Soltani, N., Brown, L. and Sikkema, P.H. (2018a). Control of glyphosate-resistant common ragweed in corn with postemergence herbicides. *Agricultural Sciences*, 9(6), 670–675. DOI:10.4236/as.2018.96046.
- Soltani, N., Brown, L. and Sikkema, P.H. (2018b). Control of glyphosate-resistant common ragweed in corn with preemergence herbicides. *Canadian Journal of Plant Science*, 98(4), 959–962. DOI:10.1139/cjps-2017-0325.
- Soltani, N., Deen, B., Bowley, S., and Sikkema, P. H. (2005). Effects of pre-emergence applications of flufenacet plus metribuzin on weeds and soybean (*Glycine max*). *Crop Protection*, 24(6), 507–511. DOI:10.1016/j.cropro.2004.09.018.
- Skjøth, A., Smith, M., Šikoparija, B., Stach, A., Myszkowska, D., Kasprzyk, I., Radišić, P., Stjepanović, B., Hrga, I., Apatini, D., Magyar, D., Páldy, A., and Ianovici, N. (2010). A method for producing airborne pollen source inventories: An example of *Ambrosia* (ragweed) on the Pannonian Plain. *Agricultural and Forest Meteorology*, 150(9), 1203–1210. DOI:10.1016/j.agrformet.2010.05.002.
- Stef, R. (2017). Chemical control of the invasive species *Ambrosia artemisiifolia* L. in sunflower agroecosystem. *International Multidisciplinary Scientific Geo Conference-SGEM*, 17, 161–168. DOI:10.5593/sgem2017H/63/S25.021.
- Stef, R., Neacșu, M., Cărbăbet, A., Grozea, I., Manea, D.N., and Ienciu, A.A. (2019). Populational reduction of *Ambrosia artemisiifolia* species from soybean crop. *Annals of the University of Oradea, Fascicle: Environmental Protection* 33, 57–64.
- Streit, L.G. (2012). DuPont TM ExpressSun TM herbicide technology in sunflower. [online] *International Sunflower Conference*. Available at: https://www.isasunflower.org/fileadmin/documents/aaProceedings/18thISAArgentina-voll/invited_speaker_lectures/ExpressSun_TM_Herbicide_Technology_in_Sunflower.pdf [Accessed 11 Oct. 2022].
- Taylor-Lovell, S., Wax, L.M. and Bollero, G. (2002). Preemergence flumioxazin and pendimethalin and postemergence herbicide systems for soybean (*Glycine max*). *Weed Technology*, 16, 502–511. DOI:10.1614/0890-037X(2002)016[0502: PFAPAP]2.0.CO;2.

- Taziar, A.N., Solani, N. and Sikkema, P.H. (2016). Sulfentrazone tank mix partners for weed control in white bean (*Phaseolus vulgaris* L.). *Canadian Journal of Plant Science*, 96, 1037–1044. DOI:10.1139/cjps-2016-0037.
- Teshler, M.P., Ditommaso, A., Gagnon, J.A., and Watson, A.K. (2002). *Ambrosia artemisiifolia* L., common ragweed (Asteraceae). In Huber, J.T. (Ed.) *Biological Control Programs in Canada*, New York, USA: CABI Publishing, pp. 290–294.
- Tranel, P. and Wright, T. (2002). Resistance of weeds to ALS-inhibiting herbicides: What have we learned? *Weed Science*, 50(6), 700–712. DOI:10.1614/0043-1745(2002)050[0700:R-ROWTA]2.0.CO;2.
- Tscharntke, T., Grass, I., Wanger, T. C., Westphal, C., and Batáry, P. (2021). Beyond organic farming – harnessing biodiversity-friendly landscapes. *Trends in Ecology and Evolution*, 36 (10), 919–930. DOI:10.1016/j.tree.2021.06.010.
- Tuemmler, C. and Schroeder, G. (2013). Study on chemical control of common ragweed (*Ambrosia artemisiifolia*) in sunflower and grain legumes. *Conference Proceedings: Ambrosia in Germany – Can the Invasion be Halted?* Berlin, Germany, pp. 105–110.
- ÚKSÚP (2022). List of authorized plant protection products and parallel products permitted for parallel trade 2022. *Vestník MPRV SR*, 54(4), 1–333.
- Williams, M. K., Heiniger, R. W., Everman, W. J., and Jordan, D. L. (2014). Weed control and corn response to planting pattern and herbicide program with high seeding rates in North Carolina. *Advances in Agriculture*, 2014, Article ID 261628. DOI:10.1155/2014/261628.
- Xu, J., Liu, X., Napier, R., Dong, L., and Li, J. (2022). Mode of action of a novel synthetic auxin herbicide halauxifen-methyl. *Agronomy*, 12(7), 1659. DOI:10.3390/agronomy12071659.
- Yu, Q. and Powles, S. B. (2014). Resistance to AHAS inhibitor herbicides: Current understanding. *Pest Management Science*, 70(9), 1340–1350. DOI:10.1002/ps.3710.
- Zhou, Z. S., Guo, J. Y., Chen, H. S., and Wan, F. H. (2010). Effect of humidity on the development and fecundity of *Ophraella communa* (Coleoptera: Chrysomelidae). *BioControl* 55, 313–319. DOI:10.1007/s10526-009-9242-9.
- Zimdahl, R. L. (2008). *Weed-Crop Competition – A Review*. 2nd. Edition. Wiley-Blackwell. 220 pp. ISBN: 978-0-470-29022-4.
- Zollinger, R. K. (2004). Advances in sunflower weed control in the USA. *Proceedings from 16th International Sunflower Conference*, Fargo, USA, pp. 435–439.
- Zimmer, M., Young, B. G. and Johnson, W. G. (2018). Weed control with halauxifen-methyl applied alone and in mixtures with 2,4-D, dicamba, and glyphosate. *Weed Technology*, 32(5), 597–602. DOI:10.1017/wet.2018.48.

Received: November 9, 2022
Accepted: December 22, 2022