



Review Article

Herbicide resistance in weeds: current status in Iran

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Abstract

Weeds are a major threat to sustainable production of agricultural products. Introduction of herbicide made the arduous operations of weed control remarkably less challenging. However, repeated application of herbicides with similar modes of action has resulted in herbicide resistance in weeds. Thus, weed control has become more difficult, and meticulous plans should be devised to tackle this issue. In recent decades, crop production in Iran is also seriously affected by herbicide resistance. To confront this challenge, it is essential to be informed of the latest status of herbicide resistance in the country. Therefore, the present paper will review the brief status of herbicide resistance across the world, the history of herbicide resistance in Iran, mechanisms of resistance observed in the country, drivers of resistance evolution in Iran, fitness cost studies carried out in the country, management strategies to overcome herbicide resistance, key challenges and research gaps in Iran, and future directions.

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مقاله مروری

مقاومت به علف کش‌ها در علف‌های هرز: وضعیت کنونی در ایران

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چکیده

علف‌های هرز تهدیدی جدی برای تولید پایدار محصولات کشاورزی هستند. معرفی علف‌کش‌ها موجب تسهیل عملیات کنترل علف‌های هرز شد. با این حال، کاربرد مداوم علف‌کش‌هایی که نحوه عمل یکسانی دارند، موجب بروز مقاومت به علف‌کش‌ها در علف‌های هرز شده است. بنابراین، کنترل علف‌های هرز دشوارتر شده و جهت حل این معضل، نیاز به تدوین برنامه‌های دقیق‌تری می‌باشد. تولید محصولات زراعی در ایران نیز در چند دهه اخیر به شدت تحت تأثیر مقاومت به علف‌کش‌ها قرار گرفته است. جهت مقابله با این چالش، اطلاع از آخرین وضعیت مقاومت به علف‌کش‌ها در کشور ضروری می‌باشد. بنابراین، مقاله حاضر، به بررسی وضعیت کنونی مقاومت به علف‌کش‌ها در دنیا، تاریخچه مقاومت به علف‌کش‌ها در ایران، مکانیسم‌های مقاومت مشاهده شده در کشور، عوامل ایجاد مقاومت، مطالعات شایستگی نسبی انجام شده در ایران، راهبردهای مدیریتی جهت مقابله با مقاومت به علف‌کش‌ها، معضلات اساسی و خلاءهای تحقیقاتی و نیز آینده این تحقیقات خواهد پرداخت.

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حق انتشار این مستند، متعلق به نویسندگان است. © ۱۴۰۴. ناشر این مقاله، انجمن علوم علف‌های هرز ایران و مؤسسه تحقیقات گیاهپزشکی کشور است. این مقاله تحت گواهی زیر منتشر شده و هر نوع استفاده غیرتجاری از آن مشروط بر استناد صحیح به مقاله و با رعایت شرایط مندرج در آدرس زیر مجاز است.



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Introduction

From the dawn of agriculture, weeds have been infesting crop cultivation fields and humans have struggled to mitigate their detrimental impact on crop yield (Gonzalez-Andujar, 2023). Weeds compete with crops over nutrients, water and radiation (Singh et al., 2022; Karlsson et al., 2025). Consequently, they reduce crop yield and quality (Wang et al., 2024), increase the costs of plant production (Nath et al., 2024), act as hosts for diseases and pests (Barman et al., 2022), interfere with harvesting operations (Walsh et al., 2022), and sometimes have allelopathic characteristics (Gam et al., 2024). According to Oerke (2006), weeds can potentially lead to approximately 34% yield loss in crops, whereas yield loss by insects and diseases are 18 and 16%, respectively. This further highlights the detrimental impact of weeds.

Introduction of herbicides to the market enabled the farmers to control weeds more efficiently in a rapid manner (Ofosu et al., 2023). However, over-reliance on herbicides has resulted in the emergence of herbicide-resistant weeds (Rani et al., 2025). Herbicide resistance can be defined as the inherited ability in a plant to withstand and procreate after being exposed to herbicide doses that are lethal for its wild type population (Leon, 2024). This phenomenon has further exacerbated the problems imposed by weeds.

Insufficient control of weeds due to herbicide resistance can result in further yield loss and thus, significant economic losses for farmers. According to Soltani et al. (2016), poor control of herbicide-resistant weeds reduced maize yields up to 50%. Moreover, farmers will be compelled to adopt more intricate and costly methods to manage weeds, including increasing rates of herbicide application or using alternative and more expensive herbicides (Hassanpour-bourkheili et al., 2024).

Herbicide resistance also limits the chemical options for weed management (Cai et al., 2022). Adding to these challenges, introduction of herbicides with new modes of action has proven to be an arduous and time-consuming challenge (Duke & Dayan, 2022). Moreover, they might need to use mechanical or manual weeding methods that require more manual labor and are not cost-effective (Beltran et al., 2012).

Another outcome of herbicide resistance is weed flora shift. Weed species that were once dominant will be replaced by herbicide-resistant weeds that are more difficult to control (Andreasen & Streibig, 2011). Furthermore, excessive use of herbicide due to herbicide resistance threatens the abundance and biodiversity of the environment's fauna (Prosser et al., 2016). Increased energy use and emission of greenhouse gases (Hassanpour-bourkheili et al., 2024) and further environmental toxicity and pollution (Parven et al., 2025) are also among the harmful impacts of herbicide resistance in weeds.

Iran is also among the countries that are struggling with the issues raised by herbicide resistance. Given the aforementioned risks of herbicide resistance, it is necessary to systematically review the status of this issue in the country. Such study was conducted before by Gharekhloo et al. (2016). However, the situation has exacerbated since then and new cases of herbicide resistance have been reported across the country. Therefore, the present paper will review the current status of herbicide resistance in Iran. The paper will discuss the brief status of herbicide resistance across the world, history of herbicide resistance, drivers of resistance evolution, management strategies to overcome herbicide resistance, mechanisms of resistance observed, fitness cost studies, key challenges and research gaps, and future directions in Iran.

Global overview of herbicide resistance

The alarming increase in the number of herbicide resistance cases started in the late 70s and early 80s. Currently, 534 cases of herbicide resistance have been reported across the world so far. This figure includes 273 species, 156 of which are dicots and 117 are monocots. Out of 31 known herbicide sites of action, weeds have shown resistance against 21, and resistance to 168 unique herbicides has been documented. Also, herbicide resistant weeds have been reported in 102 crops in 75 countries (Heap, 2025).

Out of the aforementioned cases, 176 belong to weeds resistant to acetolactate synthase (ALS) inhibitors, making them the most frequent site of action for herbicide resistance (33% of total cases). Photosystem II (PS II), enolpyruvyl shikimate phosphate synthase (EPSPS), and acetyl CoA carboxylase (ACCase) inhibitors, auxin mimics, and photosystem I (PS I) inhibitors are ranked next with 87, 60, 51, 44, and 33 cases, respectively (Heap, 2025).

Approximately two-thirds of herbicide-resistant weeds belong to Poaceae, Asteraceae, Brassicaceae, Cyperaceae, and Amaranthaceae families, with 92, 46, 22, 12, and 11 cases, respectively (Heap, 2025). In addition, 86 cases of herbicide-resistant weeds have been reported in wheat, and maize, rice, and soybean are ranked subsequently with 66, 57, and 53 cases, respectively. Among the herbicide-resistant weeds, annual bluegrass (*Poa annua* L.) is reported to exhibit resistance to herbicides with 10 different sites of action. Rigid ryegrass (*Lolium rigidum* Gaud.) with nine, and palmer amaranth (*Amaranthus palmeri* S. Watson), wild oat (*Avena fatua* L.), and Indian goosegrass (*Eleusine indica* (L.) Gaerten) with seven different sites of action are ranked next (Heap, 2025).

United States has documented the highest number of herbicide resistance cases with 132, followed by Australia, Canada, Brazil, and

China with 91, 56, 50, and 50, respectively. Currently, 13 cases of herbicide resistance have been reported from Iran, out of which one belongs to auxin mimics, seven to ACCase inhibitors and five to ALS inhibitors (Heap, 2025). These figures underline the critical necessity of measures to mitigate herbicide resistance in Iran.

History and Evolution of Herbicide Resistance in Iran

In Iran, research on herbicide resistance in weeds has been ongoing for over two decades (Zand, 2025). The first report of herbicide resistance was published in 2004, when Zand et al. (2004) documented resistance to fenoxaprop-P-ethyl in a wild oat (*Avena ludoviciana*) population collected from wheat fields in Fars Province. Since then, the spread of herbicide-resistant weeds particularly grass species has steadily increased across various crops. Currently, according to a survey in Golestan province, 53.6% of the wheat fields are infested by herbicide-resistant weed species (Gherekhloo and Haghnama, 2021). The situation can more or less be similar in some other provinces. Wheat has received the most attention due to its extensive cultivation and strategic importance. Consequently, research in Iran has primarily focused on detecting resistance in key grass weed species such as wild oat (*Avena* spp.), canary grass (*Phalaris* spp.), and annual ryegrass (*Lolium rigidum*), owing to their prevalence and the challenges associated with chemical control. A map of herbicide resistance in Iran is presented in Figure 1.

Major arable crops include wheat (*Triticum aestivum*), rice (*Oryza sativa*), barley (*Hordeum vulgare*), maize (*Zea mays*), sugar beet (*Beta vulgaris*) legume crops such as chickpea (*Cicer arietinum*), oil crops such as sunflower (*Helianthus annuus*), and industrial crops such as potato (*Solanum tuberosum*) (IPAD, 2025). Herbicides have been a primary

tool for managing weeds in these arable systems due to their efficiency and cost-effectiveness. However, herbicide-resistant weeds have so far been documented mainly in a few crops, most notably wheat and canola (in rotation with wheat), while evidence from other major crops such as rice, sugarcane, barley, or chickpea remains scarce. This indicates a significant knowledge gap, as systematic surveys and resistance monitoring efforts have largely focused on cereals, leaving the status of herbicide resistance in other crop systems underexplored.

Early studies estimated that grass weed resistance to acetyl-CoA carboxylase (ACCase)-inhibiting herbicides the most commonly used group had spread extensively across wheat fields in the provinces of Khuzestan, Fars, Kermanshah, Golestan, and Ilam (Zand et al., 2010). Rastgoo et al. (2006) reported resistance to fenoxaprop, diclofop-methyl, and clodinafop-propargyl in wild oat populations. Gherekhloo et al. (2008) identified 14 and 7 resistant populations of canary grass (*Phalaris minor*) from wheat fields in Fars and Golestan provinces, respectively, with varying levels of resistance to fenoxaprop-P-ethyl and diclofop-methyl. Further studies by Zand et al. (2006), Benakashani et al. (2007a, 2007b) and Sasanfar et al. (2009a, 2009b) on winter wild oat populations revealed different levels of resistance and cross-resistance to ACCase-inhibiting herbicides.

In the most recent nationwide assessment in Iran, 1,174 grass weed populations from wheat fields were analyzed, including 848 wild oat, 205 canary grass, and 121 annual ryegrass samples (Zand et al., 2022). The results confirmed widespread resistance to both ACCase- and acetolactate synthase (ALS)-inhibiting herbicides. Over the past 25 years, resistance was detected in 67% of wild oat, 49% of canary grass, and 59% of annual ryegrass populations. Resistance to ALS inhibitors, often considered an alternative to manage

resistance to Group 1 herbicides, was also detected in 76% of wild oat (293 populations), 24% of canary grass (41 populations), and 65% of annual ryegrass (65 populations). Also, various reports are available on resistance to ACCase (Najjari Kalantari et al., 2013; Tatari et al., 2018; Heravi et al., 2020; Soufizadeh et al., 2022) and ALS (Derakhshan & Gherekhloo, 2012; Hatami Moghaddam et al., 2016; Heravi et al., 2017) inhibiting herbicides.

Moreover, multiple resistance to both ACCase and ALS inhibitors was identified in 62%, 7%, and 54% of wild oat, canary grass, and annual ryegrass populations, respectively (Zand et al., 2022). Similarly, in *E. crus-galli*, resistance was identified in a population from a rice field in Golestan, which showed resistance to the ALS inhibitors, penoxsulam and bispyribac-sodium (Haghnama & Mennan, 2020).

Overall, resistance and cross-resistance to ACCase inhibitors were observed in 63% and 17% of 1,174 and 642 studied populations, respectively (Zand et al., 2022). Similarly, resistance and cross-resistance to ALS inhibitors were reported in 69% and 44% of 399 and 360 populations, respectively. Multiple resistance to both ACCase and ALS inhibitors was confirmed in 55% of cases and is suspected to be developing in an additional 13%, accounting for 68% of the 399 studied grass populations (Zand et al., 2022).

Auxinic herbicide resistance, although less commonly reported than resistance to ALS inhibitors, has started to appear in certain broadleaf weed species across Iran. For instance, *G. aparine* populations from western regions have been documented to show resistance to 2,4-D, a widely used auxinic herbicide (Moradi et al., 2024). Similarly, *Malva parviflora* populations from Khuzestan have developed resistance to the 2,4-D + MCPA mixture (Kamaei et al., 2019). Notably, these *M. parviflora* populations were also resistant to the ALS inhibitor tribenuron-methyl (Table 2), indicating the emergence of

multiple resistance in this species. These findings emphasize the increasing threat of auxinic herbicide resistance and highlight the need for diversified weed management strategies to prevent further resistance development.

In Iran, the primary rotational crops in winter wheat systems are canola (*Brassica napus*) and, to a lesser extent, sugar beet (*Beta vulgaris*). However, the dominant grass weeds infesting these rotational crops are often the same as those found in wheat fields. Moreover, the graminicides commonly used in these crops are mainly ACCase inhibitors (Group 1), which share the same site of action as herbicides applied in wheat. The continuous and repeated use of these herbicides across rotational crops has accelerated the development and spread of herbicide resistance, including cross-resistance, among grass weed populations.

In one study, 52 grass weed populations including 29 wild oat (*Avena ludoviciana*), 15 annual ryegrass (*Lolium rigidum*), and 8 canary grass (*Phalaris minor*) populations were collected from canola fields in the provinces of Fars, Mazandaran, and Ardabil. Among the annual ryegrass populations, resistance was confirmed in 86.7%, 66.7%, and 60% of populations to haloxyfop-R-methyl, sethoxydim, and cycloxydim, respectively. In canary grass, 25% of populations were resistant to haloxyfop-R-methyl, and 12.5% showed suspected resistance to sethoxydim. Among the wild oat populations, 31% exhibited resistance to haloxyfop-R-methyl, and one population was resistant to clethodim. No confirmed resistance to the other 'dim' herbicide, including cycloxydim, was observed in wild oat populations (Sasanfar et al., 2021). In a subsequent study (Sasanfar et al., 2024), 45 grass weed populations were collected from canola fields across various provinces including Golestan, Mazandaran, Fars, and Tehran and screened for resistance to commonly used ACCase-inhibiting herbicides. Resistance was

detected in 47%, 47%, and 22% of populations to haloxyfop-R-methyl, sethoxydim, and clethodim, respectively. All populations remained susceptible to cycloxydim. Cross-resistance to ACCase inhibitors was observed in 36% of the tested populations. Additionally, a study by Hassanpour-Bourkheili et al. (2021a) found that among 22 winter wild oat populations within canola fields in Golestan province, five were resistant to haloxyfop-R-methyl. These resistant populations exhibited cross-resistance to clodinafop-propargyl and sethoxydim, but remained susceptible to pinoxaden and the ALS-inhibiting combination of mesosulfuron-methyl + iodosulfuron-methyl. These findings underscore the need for effective herbicide rotation and integrated weed management strategies, particularly in regions with intensive wheat–canola cropping systems (Sarani et al. 2014).

The first documented case of herbicide resistance in broadleaf weeds within Iranian wheat systems dates back to 2010, when wild mustard (*Sinapis arvensis* L.) was reported to exhibit resistance to the ALS-inhibiting herbicide tribenuron-methyl in Golestan Province (Aqqala County) (Derakhshan et al., 2015). Since then, the incidence of resistance has escalated considerably. To date, resistance has been confirmed in 11 broadleaf weed species: *S. arvensis* (wild mustard), *Rapistrum rugosum* L. (All) (turnip weed), *Galium aparine* L. (cleavers), *Malva* spp. (mallow), *Silybum marianum* (L.) Gaertn (milk thistle), *Ammi majus* L. (bishop's weed), *Descurainia sophia* (L.) Webb (flixweed), *Vaccaria* spp. (cowcockle), *Melilotus officinalis* (L.) Pall (yellow sweet clover), *Raphanus raphanistrum* L. (wild radish), and *Lepidium draba* L. (hoary cress) (Table 1).

Geographically, herbicide resistance in broadleaf weeds has been reported in 11 provinces. Khuzestan ranks highest, with six resistant species identified, followed by Ilam and Kermanshah (five species each), Golestan

(two species), and Fars, Ardabil, Razavi Khorasan, Lorestan, Kerman, Tehran, and Markazi (each with at least one confirmed case). Spatial analyses suggest that resistance evolution initially emerged in northern (Golestan), western (Kermanshah), and southwestern (Khuzestan) regions, progressively expanding toward central (Tehran) and eastern provinces (Kerman and Mashhad) (Heap, 2025; Lotfifar et al., 2013; Derakhshan et al., 2012; 2015; Gherekhloo et al., 2016; Khalil Tahmasebi et al., 2024) (Table 1).

Development of herbicide resistance in broadleaf weeds over time in Iran

The temporal progression of herbicide resistance in these systems can be delineated into three distinct phases. The first phase (2001–2011) was characterized by the emergence of single resistance, beginning with *S. arvensis* in Golestan in 2010. Subsequent reports followed in Kermanshah in 2012 (Zand et al., 2019). This phase peaked in 2019 with the detection of *S. arvensis* populations resistant to multiple ALS inhibitors specifically, iodosulfuron + mesosulfuron + mefenpyr-diethyl, tribenuron-methyl, and a four-way mixture including diflufenican in eight provinces (Khalil Tahmasebi et al., 2024). The second phase (2011–2016) marked the onset of cross-resistance. During this period, *S. arvensis* evolved resistance to two ALS-inhibiting herbicides; *Malva* spp. exhibited resistance to three ALS inhibitors in Khuzestan (Elahifard et al., 2017); and *S. marianum* developed cross-resistance to three ALS herbicides across Khuzestan, Golestan, and Kermanshah (Tahmasebi et al., 2019).

The third phase (2016–present) has been defined by the emergence of complex and highly concerning multiple resistance cases.

Noteworthy examples include: *Malva* spp. populations in Ramhormoz (Khuzestan) resistant to four herbicide modes of action (ALS inhibitors, synthetic auxins, photosystem II inhibitors, and carotenoid biosynthesis inhibitors); *S. arvensis* resistant to both ALS inhibitors and synthetic auxins in Kermanshah; *R. raphanistrum* resistant to four herbicide classes in Kerman; and widespread multiple resistance of *Malva* spp. in Khuzestan (Khalil Tahmasebi et al., 2019).

As of 2025, several major challenges hinder the effective identification and management of broadleaf weed resistance in Iran. These include: the lack of comprehensive studies on resistance mechanisms (target-site and non-target-site) in identified species; insufficient resistance surveillance in strategic crops other than wheat; the emergence of new, inherently tolerant species such as *Lepyrrodiclis holosteoides* (C.A. Mey.) Fenzl ex Fisch. & C.A. Mey.) in West Azerbaijan naturally tolerant to ALS inhibitors; the sharp decline in efficacy of inexpensive herbicides like tribenuron-methyl (particularly in Khuzestan and Golestan), and of key commercial herbicides such as iodosulfuron + mesosulfuron and bromoxynil + MCPA (especially in Khuzestan); and the absence of crop rotation or alternative crops in regions heavily infested with resistant broadleaf weeds.

Key drivers of the resistance crisis in Iran include: the overwhelming dominance of continuous wheat monoculture accounting for over 80% of arable land in Khuzestan, Golestan, and Kermanshah without rotation; poor herbicide stewardship, notably overuse of ALS inhibitors (often applied two to three times per season); and the near-complete dependence on chemical control methods, with over 90% of weed management relying on herbicides (Zand et al., 2023).

Table 1. Herbicide-resistant weed species in Iran, classified by mechanism of action (MOA) groups and reported distribution across major agricultural provinces.

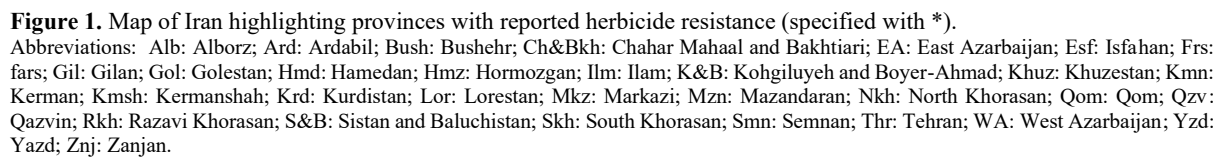
Common name	Scientific name	Site of action	First report	Group	Province
Small canary grass	<i>Phalaris minor</i>	ACCase	2004	1	1,2,3
Winter wild oat	<i>Avena sterilis ssp. ludoviciana</i>	ACCase and ALS	2006	1	1,2,3,4,7
Annual ryegrass	<i>Lolium rigidum</i>	ACCase and ALS	2007	1	1,2,3,4,7
Common wild oat	<i>Avena fatua</i>	ACCase	2007	1	1,2,3,4,7
Awned canary-grass	<i>Phalaris paradoxa</i>	ACCase	2007	1	2
Jungle rice	<i>Echinochloa colona</i>	PS II (triazines)	2009	5	1
Wild mustard	<i>Sinapis arvensis</i>	ALS and Carotenoid inhibitors	2009	2,12	1,2,3,4,5,6,7,8
Turnip weed	<i>Rapistrum rugosum</i>	ALS	2010	2	3,11
Shortspike canarygrass	<i>Phalaris brachystachys</i>	ACCase	2014	2	3
Cleavers	<i>Galium aparine</i>	ALS, Auxin Mimics	2016,2024	2	4,8
Mallow	<i>Malva spp.</i>	ALS, Carotenoid inhibitors, PS II and Auxin Mimics	2024	2,12, 5, 4	1,4
Milk thistle	<i>Silybum marianum</i>	ALS, Carotenoid inhibitors, PS II and Auxin Mimics	2024	2,12, 5, 4	1
Bishop's weed	<i>Ammi majus</i>	ALS	2024	2	1,8
Flixweed	<i>Descurainia sophia</i> (L.) Webb	ALS	2024	2	1,9
Cowcockle	<i>Vaccaria spp.</i>	ALS	2024	2	4,8,10
Yellow sweet clover	<i>Melilotus indicus</i>	ALS	2024	2	1
Wild radish	<i>Raphanus Raphanistrum L.</i>	ALS, Carotenoid biosynthesis inhibitors, PS II and Auxin Mimics	2024	2,12, 5, 4	5,8
Hoary cress	<i>Lepidium draba L</i>	ALS	2024	2	6

1: Khuzestan, 2: Fars, 3: Golestan, 4: Kermanshah, 5: Kerman, 6: Tehran, 7: Ardabil, 8: Ilam, 9: Razavi Khorasan, 10: Lorestan, 11: Markazi (Heap, 2025; Nosrati & Muhammadyari, 2019; Zamanii et al., 2019, 2021; Joumi et al., 2022; Khalil-Tahmasebi et al., 2024).

Mechanisms of Resistance Observed in Iran

In general, mechanisms of resistance are categorized into target-site (TSR) and non-target-site resistance (NTSR) mechanisms. The first involves gene alteration that is able to change the interaction with the encoded target protein/enzyme so that the herbicide fails to bind the target site or gene overexpression. On the other hand, non-target-site resistance (NTSR) mechanisms do not involve the target protein and can reduce the amount of herbicide reaching the site of action to sub-lethal levels, allowing plants to survive. Occasionally, any

mechanism protecting plants from herbicide damage is also referred as NTSR (Torra & Alacantara-de la cruz, 2023). NTSR mechanisms include reduced herbicide uptake/translocation, enhanced metabolism of the herbicide, decreased rate of herbicide activation, and/or sequestration (Jugulam & Shayam, 2019). It must be noted that herbicide metabolism is especially a serious threat. While herbicide metabolism usually results in low resistance factors, the unpredictable nature of this mechanism makes it very difficult to manage (Dimaano & Iwakami, 2021).



It must be noted that herbicide resistance studies in Iran which contain resistance mechanism are mostly associated with ACCase and ALS inhibitors, and there is only one such report for

Most reports on herbicide resistance in the country concern TSR. However, there are cases reported from Iran that involve NTSR mechanisms. Study of NTSR mechanisms in Iran are rare and include studies on *P. minor* (Gherekhloo et al., 2010; 2012), *P. brachystachys* (Golmohammadzadeh et al., 2020), *R. rugosum* (Hatami et al., 2016), *S. arvensis* (Gherekhloo et al., 2018), *A. ludoviciana* (Hassanpour-bourkheili et al., 2020), and *L. rigidum* (Tavassoli et al., 2023).

This is due to the lack of required facilities and equipment as well as the low level of international collaborations. Resistance to ACCase and ALS inhibitors in *A. ludoviciana* has also been reported by Adim et al. (2021; 2025) in a proteomics-based study. A detailed list of the herbicide resistance cases with their respective mechanisms of resistance is presented in Table 2.

Fitness of Herbicide-Resistant Weeds

The most effective strategies for managing herbicide-resistant weeds (i.e., twelve key recommendations) were outlined by Norsworthy et al. (2012). One of these emphasizes the importance of understanding the biology and ecology (i.e., the fitness) of herbicide-resistant weed populations (Keshtkar et al., 2019). Fitness is defined as the number of offspring produced by a population relative to another population in the same population (Keshtkar et al., 2019; Vila-Aiub et al., 2009). In other words, it refers to a plant's reproductive success under varying environmental conditions (Holt, 1990). From a herbicide-resistance perspective, fitness is defined as the number of offspring produced by a resistant population relative to a non-resistant population (Keshtkar et al., 2019). Fitness of herbicide resistant populations can be positive, negative, or neutral relative to susceptible population. A population with positive fitness will gradually increase in frequency within the population over successive generations, whereas a population with negative fitness will decline due to producing fewer offspring (Keshtkar, 2025). The frequency of populations with neutral fitness remains stable within the population (Cousens & Fournier-Level, 2018). According to evolutionary and ecological theory, herbicide-resistant populations may exhibit lower fitness than susceptible populations in the absence of herbicide application. This fitness reduction of herbicide resistant populations, known as the fitness cost or cost of resistance, reflects potential trade-offs associated with resistance traits (Keshtkar et al., 2019; Vila-Aiub et al., 2009).

Fitness cost is, in fact, the result of negative pleiotropic effects of resistance-conferring alleles (Vila-Aiub et al., 2015). According to this theory, herbicide-susceptible individuals, due to their higher fitness are expected to become dominant in the field after several generations (i.e., growing seasons) without herbicide application. In other words, in the absence of herbicide selection pressure, the frequency of resistant individuals is likely to decline over time as a consequence of their lower fitness that is known as backward selection (Keshtkar et al., 2019). However, fitness costs associated with herbicide resistance cannot always be observed in all resistant weed species. The costs associated with resistance vary depending on the specific mutation and might only occur under certain environmental conditions (Lehnhoff et al., 2013; Vila-Aiub et al., 2009). Therefore, it's vital to evaluate and measure the fitness costs for each herbicide-resistant population individually (Lehnhoff et al., 2013).

Although some researchers, such as Cousens & Fournier-Level (2018), claim that fitness studies should focus merely on the number of offspring produced, understanding separate fitness components is highly useful and necessary. This is because a plant's dominance within a population (i.e., its overall fitness) is ultimately determined by the combined effects of various fitness-related parameters (Keshtkar et al., 2019). Therefore, it is important to examine all components of plant fitness, from pre-germination to reproduction and seed production. These components include seed fitness (e.g., germination percentage, germination rate, dormancy, seed size, seed longevity in soil, and seed dispersal ability); vegetative fitness (e.g., plant height, biomass production, growth rate, establishment ability, competitive ability, competitive response, and competitive effect); and reproductive fitness (e.g., seed yield, pollen viability, pollen production, competition between pollen from resistant and susceptible plants, and ovule size). In other words, finding these components can shed light on the relative strengths and

weaknesses of herbicide-resistant weeds compared to their corresponding susceptible under different environmental conditions. Accordingly, investigating the fitness of herbicide-resistant weeds is essential. One of the main objectives of fitness studies is to identify tools and strategies for managing herbicide-resistant weeds (Cousens and Fournier-Level, 2018). Comprehensive knowledge of the relative fitness of herbicide-resistant weeds in Iran is also a critical issue that can enhance the effectiveness of management strategies (Gherekhlou et al., 2016). However, a review of research conducted in Iran reveals that the fitness of herbicide-resistant weeds has received limited attention from researchers. The authors' investigation indicates that, to date, a limited number of papers has been published by Iranian researchers on the fitness of herbicide-resistant weeds (Table 3). These studies have focused on three grass weed species (*Alopecurus myosuroides*, *Avena sterilis* ssp. *ludoviciana*, and *Lolium rigidum*) and two broadleaf species (*Rapistrum rugosum* and *Sinapis arvensis*) that are resistant to various herbicides. Most of these studies have examined seed fitness, while only two have investigated all three major fitness components seed, vegetative, and reproductive fitness of herbicide-resistant and susceptible weed populations.

In most studies on the fitness of herbicide-resistant weeds, both in Iran and globally, poor experimental design and insufficient attention to the prerequisites of fitness testing have often led to misinterpretation of results (Keshtkar et al., 2019; Neve, 2007). The most common limitation in fitness experiments is the lack of controlling the genetic background of resistant and susceptible populations. Choosing herbicide-resistant and susceptible populations that share a closely related genetic background is a crucial first step when studying relative fitness and estimating the potential cost of herbicide resistance (Holt, 1990; Menchari et al., 2008; Vila-Aiub et al., 2009; Vila-Aiub et al., 2005). This issue is particularly serious in Iran, where only two of the studies by Iranian

researchers have controlled the genetic background of plant materials (Table 3).

When the genetic background of the plant materials is controlled, it reduces variation between the susceptible and resistant populations, so any differences observed in fitness of populations can be more confidently linked to the resistance gene(s) or even to specific resistance alleles (Vila-Aiub et al., 2011). Several strategies for achieving genetic background homogenization and control have been thoroughly compiled and explained by Vila-Aiub et al. (2011).

There are other important prerequisites to consider before studying the fitness of herbicide-resistant populations. Therefore, the authors strongly encourage researchers who want to evaluate the fitness of herbicide-resistant and susceptible populations to closely follow the guidelines and methods described elsewhere (Keshtkar et al., 2019; Keshtkar, 2025; Vila-Aiub et al., 2009; Vila-Aiub et al., 2011; Vila-Aiub et al., 2005).

Strategies for Managing Herbicide-Resistant Weeds in the World: Possibility of use in Iran

Despite the increasing threat of HR weeds, many farmers only adopt resistance management strategies reactively, after experiencing control failures (Beckie, 2006). A paradigm shift toward proactive, diversified, and integrated weed management is essential for sustaining herbicide efficacy and agricultural productivity.

Herbicide-Based Management Strategies

Herbicide Rotation and Sequencing

Rotating herbicides with different modes of action (MOAs) between years and crops can significantly delay the development of resistance. Herbicide sequencing applying multiple herbicides with different MOAs within a single crop season also helps reduce selection pressure by exposing weed populations to varied biochemical targets (Wrubel & Gressel, 1994).

Table 2. Summary of documented resistance cases to ACCase, ALS, and PS II inhibitors in grass weeds, and their corresponding target-site mutations in Iran.

Table 2. Summary of documented resistance cases to ACCase, ALS, and PS II inhibitors in grass weeds, and their corresponding target-site mutations in Iran.									
Mutation	Substitution	Non-target site resistance	Species	APP	CHD	PPZ	Reference		
Resistance Level									
ACCase gene									
Ile 1781	Leu	Metabolism	<i>A. sterilis ludoviciana</i> subsp.	Clodinafop propargyl, Diclofop methyl and Fenoxaprop- P-ethyl (L-H)	Setoxydim (L-H)	Pinoxaden (L-H)	Zand et al., 2009; Zand et al., 2013; Rastgoo et al., 2012; Benakashani et al., 2014; Sasanfar et al., 2017; Akbarabadi et al., 2019		
			<i>Lolium rigidum</i> Guadin.	Clodinafop propargyl, Diclofop methyl and Fenoxaprop- P-ethyl (L-H)	Setoxydim, and Clethodim (L-H)	Pinoxaden (L-H)	Dastoori et al., 2011; Sabet Zangeneh et al., 2018		
	Thr		<i>Phalaris brachystachys</i> Link.	clodinafop propargyl (M-H) diclofop methyl (M)	cycloxydim (L)		Golmohammadzadeh et al., 2019; 2020		
Ile 2041	Asn		<i>Avena sterilis ludiviciiana</i> subsp.	Clodinafop propargyl (L-H)	Setoxydim (L-H)	Pinoxaden (L-H)	Zand et al., 2013; Sasanfar et al., 2017		
			<i>Avena sterilis ludoviciana</i> subsp.	clodinafop propargyl (H) and haloxyfop-R-methyl (H)	Sethoxydim (M)		Akbarabadi et al., 2019; Hassanpour-bourkheili et al., 2021a		
			<i>Lolium rigidum</i> Guadin	Clodinafop propargyl, Diclofop methyl (L-H)	Setoxydim, and Clethodim(L-H)	Pinoxaden (L-H)	Benakashani et al., 2013; Sabet Zangeneh et al., 2018		
Asp 2078	Gly	<i>A. sterilis ludoviciana</i> subsp.	Clodinafop propargyl, Diclofop methyl and Fenoxaprop- P-ethyl (L-H)	Setoxydim (L-H)	Pinoxaden (L-H)	Zand et al., 2013; Benakashani et al., 2014			
		<i>Phalaris minor</i> Retz.	Clodinafop propargyl, Diclofop methyl and Fenoxaprop- P-ethyl (L-M)		Pinoxaden (S/R) ^b	Gherekhloo et al., 2012; 2021			
Trp 2027	Cys	<i>P. minor</i> Retz.	Clodinafop propargyl, Diclofop methyl and Fenoxaprop- P-ethyl (L-M)		Pinoxaden (S/R) ^b	Gherekhloo et al., 2012; 2021			
Asp 2078	Gly	<i>P. minor</i> Retz.	Clodinafop propargyl, Diclofop methyl and Fenoxaprop- P-ethyl (L-M)		Pinoxaden (S/R) ^b	Gherekhloo et al., 2012; 2021			

Mutation	Substitution	Non-target site resistance	Species	APP	CHD	PPZ	Reference
Resistance Level							
<i>ALS</i> gene							
Thr 122	Ala	Metabolism	<i>S. arvensis</i> L	Tribenuron-methyl			Khaledi et al., 2019
Pro 197	Ser		<i>L. rigidum</i> Guadin	Mesosulfuron-methyl+iodosulfuron-methyl			Tavassoli et al., 2023
			<i>R. rugosum</i> L.	Mesosulfuron-methyl+iodosulfuron-methyl (H)			Hatami et al., 2016
				Tribenuron-methyl (H)			
				Flurasulam (H)			
				Flucarbazone (M)			
				Bispyribac-sodium (M)			
	Ala			Tribenuton-methyl			Khaledi et al., 2019
				Mesosulfuron-methyl+iodosulfuron- methyl			
	Thr		<i>L. rigidum</i> Guadin	Mesosulfuron-methyl+iodosulfuron-methyl (Not determined)			Hanifehzadeh Erdi et al., 2024
Asp 376	Glu		<i>S. arvensis</i> L.	Mesosulfuron-methyl+iodosulfuron-methyl(M)			Bahmani Fathabadi et al., 2016
	Gly			Tribenuton-methyl			Khaledi et al., 2019
			<i>S. arvensis</i> L.	Mesosulfuron-methyl+iodosulfuron-methyl			
Trp 574	Leu		<i>S. arvensis</i> L.	Tribenuton-methyl			Khaledi et al., 2019
			<i>L. rigidum</i> Guadin	Mesosulfuron-methyl+iodosulfuron-methyl			Gherekhloo et al., 2018
				Mesosulfuron-methyl+iodosulfuron-methyl (Not determined)			Hanifehzadeh Erdi et al., 2024
<i>psbA</i> gene (PSII inhibitors)							
Ser 264	Gly		<i>E. colona</i> (L.) Link.	Ametryn			Elahifard et al., 2013
				Metribuzin			
Gly 282	Ser		<i>E. colona</i> (L.) Link.	Ametryn			Elahifard et al., 2013
				Metribuzin			

Abbreviations: APP, aryloxyphenoxypropionate; CHD, cyclohexanedione; PPZ, phenylpyrazoline (pinoxaden). ^aResistance level: S = not resistant (<2); L = low resistance (2-5); M = moderate resistance (6-10); H = high resistance (>10); ^bResistance level was not determined.

However, adoption of rotation has been historically limited due to economic constraints, lack of farmer knowledge, and inadequate herbicide labeling. For example, in Canada, fewer than 50% of farmers practiced herbicide rotation by 1998, though this increased to 70–90% in some provinces after extension efforts and improved labeling policies. It is important to apply herbicides at full recommended rates to avoid selecting for resistant populations, especially where target-site resistance prevails (Beckie, 2006).

Herbicide Mixtures

Combining herbicides with different MOAs in tank mixtures or pre-formulated products is generally more effective than rotation alone in slowing resistance evolution, provided that all active ingredients are equally efficacious and persistent in the soil. Mixtures reduce the probability that a resistant individual survives any single herbicide. However, improper mixtures such as those including sublethal doses or ineffective components can accelerate the development of multiple resistance (Rubin, 1991; Renton et al., 2014).

Use of Herbicide-Resistant (HR) Crops

The advent HR crops, especially those resistant to glyphosate or glufosinate, has reshaped weed management. While these crops provide flexibility and broad-spectrum weed control, their continuous and exclusive use has led to resistance evolution in key species such as *Conyza canadensis*, *Amaranthus palmeri*, and *Ambrosia artemisiifolia* in North America (Beckie et al., 2006).

To preserve HR crop utility, it is critical to diversify herbicide modes of action within the cropping system, avoid repeated plantings of the same HR crop consecutively, and integrate non-chemical weed control tactics.

Site-Specific and Reduced-Rate Applications

Precision agriculture technologies allow site-specific herbicide application based on weed mapping, which reduces unnecessary herbicide use and selection pressure (Beckie & Harker, 2017). However, applying herbicides at sublethal doses whether intentionally or due to environmental variability can promote quantitative resistance, particularly in outcrossing species such as *Lolium* and *Kochia* (Neve & Powles, 2005; Beckie & Kirkland, 2003). Therefore, maintaining full recommended herbicide rates in targeted areas is advised.

Changing the process of discovering new herbicides

For the future of herbicide discovery, several innovative strategies have been proposed to accelerate the development of new herbicidal compounds for herbicide resistance weeds including:

Development of multi-target herbicides:

Creating active compounds that inhibit two or more enzyme targets simultaneously to reduce the likelihood of resistance development (Gressel, 2020).

Use of metabolomics and proteomics: Applying metabolomics to identify enzyme targets whose inhibition leads to the accumulation of toxic metabolites in vivo, and using proteomics to detect low-abundance targets that can be inhibited with low herbicide doses (Dayan & Duke, 2020).

Design of smart and flexible inhibitors:

Engineering molecules that bind to substrate recognition regions of enzymes or possess conformational flexibility, making them less prone to resistance mutations (Qu et al., 2021).

Integration of advanced technologies:

Employing artificial intelligence, big data analytics, and both in vivo and target-based high-throughput screening methods to identify novel herbicide candidates with the desired activity (Dayan, 2019).

Table 3. Published studies on the fitness cost of herbicide resistance by Iranian scientists up to 2025.

Weed	Herbicide/group	Fitness components			Genetic background control	References
		Seed	Vegetative	Reproductive		
<i>Alopecurus myosuroides</i>	Fenoxaprop ethyl	*			Yes (single population approach)	(Ghazali et al., 2020)
<i>Avena ludoviciana</i>	Aryloxyphenoxypropionate	*			No	(Tahmasebi et al., 2011)
<i>Avena ludoviciana</i>	Clodinafop-propargyl	*			No	(Benakashani et al., 2021; Fakhri et al., 2024)
<i>Avena ludoviciana</i>	Aryloxyphenoxypropionates and Cyclohexanediones	*	*	*	No	(Hassanpour-bourkheili et al., 2018; 2020; 2021b)
<i>Avena ludoviciana</i>	Clodinafop propargyl, Diclofop-methyl		*		No ^a	(Izadi-Darbandi et al., 2014)
<i>Echinochloa colona</i>	PSII inhibitors	*			No	(Elahifard and Mijani, 2014)
<i>Lolium Rigidum</i>	Clodinafop-Propargyl	*			Yes (Multiple population approach)	(Zamani et al., 2023)
<i>Lolium rigidum.</i>	Clodinafop-propargyl	*	*		No	(Sabet Zangeneh et al., 2018)
<i>Lolium rigidum.</i>	Clodinafop-propargyl	*	*	*	No	(Sabet Zangeneh et al., 2016)
<i>Lolium rigidum.</i>	ALS inhibitors	*			No	(Dastoori et al., 2010)
<i>Lolium rigidum.</i>	ACCase and ALS inhibitors	*	*	*	No	(Tavassoli, 2024)
<i>Phalaris brachystachys</i>	ACCase inhibitors	*	*	*	No	(Golmohammadzadeh et al., 2022; 2024)
<i>Rapistrum rugosum</i>	Tribenuron methyl	*			No	(Abdollahipour et al., 2016a)
<i>Sinapis arvensis</i>	Tribenuron methyl, mesosulfuron methyl+Iodosulfuron methyl sodium, metsulfuron-methyl+sulfosulfuron		*	*	No ^a	(Lotfifar et al., 2015)
<i>Sinapis arvensis</i>	Tribenuron methyl	*			No	(Axhgar et al., 2022)
<i>Sinapis arvensis</i>	Tribenuron methyl	*	*	*	No ^a	(Abdollahipour et al., 2016b)
<i>Sinapis arvensis</i>	Tribenuron methyl	*			No ^a	(Abdollahipour et al., 2013)
<i>Sinapis arvensis</i>	Tribenuron methyl, mesosulfuron methyl+Iodosulfuron methyl sodium, metsulfuron-methyl+sulfosulfuron	*	*		No	(Mottaghi et al., 2017)
<i>Sinapis arvensis</i>	Tribenuron Methyl 2,4-D+MCPA		*		No	(Khamani et al., 2023)

^a, Multiple populations approach was used but statistical analysis and interpretation of results were not fulfilled based on the used approach.

Non-Herbicide Approaches as Integrated Weed Management (IWM)

Heavy reliance on herbicides alone often lacks diversity, accelerating resistance evolution. Integrated approaches that combine cultural, mechanical, biological, and chemical controls reduce selection pressure on weeds and prolong herbicide efficacy:

Cultural Control

Crop Rotation and Diversity: Rotations involving diverse crops with different growth habits and herbicide programs disrupt weed life cycles and reduce seedbanks. For example, including legumes, cereals, and broadleaf crops has been shown to suppress problematic species like *Avena fatua* and *Setaria viridis* (Beckie & Harker, 2017; Beckie et al., 2004). Diverse rotations also influence weed germination cues and emergence timing, complicating weed adaptation (Owen, 2016).

Increasing Crop Competitiveness: Practices such as increasing seeding rates, narrowing row spacing, and using competitive cultivars create denser crop canopies, limiting light and nutrients available to weeds. Field studies have demonstrated that dense stands of hybrid canola, barley, and wheat reduce HR weed biomass and seed production significantly (Beckie & Harker, 2017).

Delayed Planting and Stale Seedbed Techniques: Delaying planting allows pre-plant weed control, targeting early-germinating weeds. Stale seedbeds where irrigation or rainfall induces weed germination followed by non-selective control before planting reduce the initial weed population and seedbank inputs (Dyer et al., 1993).

Mulching: Mulching involves applying organic (crop residues, straw, compost) or synthetic (plastic films) materials on soil surfaces. Mulches suppress weed emergence by physically blocking light, modifying soil temperature and moisture, and creating unfavorable conditions for weed seedling establishment. Mulching not only reduces weed pressure but also improves soil moisture retention and health, indirectly enhancing crop

competitiveness. In perennial and specialty cropping systems, mulching has proven effective at limiting weed establishment and seedbank replenishment, thereby reducing selection pressure for herbicide resistance (Owen, 2016; Beckie & Harker, 2017).

Mechanical and Physical Controls

Tillage: Although conservation tillage preserves soil structure and reduces erosion, it often increases reliance on herbicides like glyphosate, potentially exacerbating resistance. Strategic, occasional tillage such as shallow disturbance or moldboard plowing can bury weed seeds deeper in the soil, reducing emergence of surface-germinating species (Beckie, 2006; Owen, 2016).

Harvest Weed Seed Control (HWSC): HWSC techniques such as the Harrington Seed Destructor, chaff carts, and narrow windrow burning mechanically destroy weed seeds retained at harvest, preventing seedbank replenishment. This approach has shown reductions of over 90% in seed return for species with high seed retention, including *Lolium rigidum* (Beckie & Harker, 2017; Owen, 2016).

Patch Management and Sanitation: Targeted management of resistant weed patches before seed set significantly limits spatial spread. A long-term study reported that managed patches of resistant *Avena fatua* expanded 330% less than unmanaged ones (Beckie et al., 2004). Equipment sanitation and border controls further prevent resistant seed dispersal between fields.

Thermal weed control: which uses heat to kill weeds, can be a valuable tool in managing herbicide-resistant weeds. Methods like flaming, steam, hot water, and microwaves can be used to disrupt plant cell structure and cause weed death, offering an alternative to herbicide-based approaches. Thermal weed control relies on the principle of applying heat to plant tissues, causing cellular damage and ultimately plant death. This can be achieved through various methods, including: Flaming: Using flames to quickly heat and disrupt plant cells. Steam/Hot Water: Applying high-temperature steam or hot water to achieve similar effects as

flaming. Microwaves: Using microwave radiation to heat and disrupt plant cells. Hot Foam: Using heated foam to coat and dehydrate weeds (Li et al., 2021).

Biological Control

Biological management uses living organisms or their products to suppress weed populations (Charudattan, 2005). While biological control is an active research area, its use in herbicide resistance management is context-dependent and not yet widespread (Liu et al., 2021).

Although integrated management methods are very effective and essential in controlling herbicide-resistant weeds, but several behavioral and structural barriers hinder adoption of IWM, including:

Short-Term Profit Focus: Farmers often prioritize immediate returns, neglecting long-term sustainability.

Land Tenure Instability: Tenants may lack incentives to invest in IWM practices.

Complexity and Labor Intensity: IWM demands more knowledge and time, which can discourage farmers.

Lack of Policy and Incentives: Few regulatory or financial incentives exist to encourage non-chemical weed control.

Misunderstanding of Herbicide MOAs: Confusion over herbicide groups and labels can impede proper rotation and mixtures (Beckie & Harker, 2017; Owen, 2016).

Further helpful tools: Scouting, Record-Keeping, and Collaborative Management

Early Detection: Regular scouting before and after herbicide applications enables early identification of resistance, facilitating timely intervention (Beckie, 2006).

Technological Advances: Tools such as drone-assisted scouting, GPS mapping, and AI-driven weed identification enhance precision and efficiency (Fernandez-Quintanilla et al., 2022; Beckie & Harker, 2017; Owen, 2016).

Record-Keeping: Maintaining detailed field records including herbicide applications, weed escapes, and cropping history is essential for long-term management planning.

Sanitation: Cleaning machinery and controlling field borders prevent movement of resistant seeds between fields.

Landscape-Level Management: Resistance management requires cooperative action beyond individual farms, including shared scouting, joint investment in HWSC tools, coordinated extension services, and cost-sharing incentives (Owen, 2016).

Decision-support systems (DSS): DSS assist farmers in selecting optimal combinations of integrated weed management (IWM) practices to delay or control herbicide-resistant (HR) weeds. The most advanced example is the RIM (Resistance and Integrated Management) model developed in Australia, which evaluates agronomic and economic outcomes of various management strategies over time (Monjardino et al., 2003; Pannell et al., 2004). When regularly updated, such DSS tools provide valuable guidance for effective HR weed management. **Robotics, Drones, and New Technologies:** Harvest-time weed seed management can reduce seedbanks but is ineffective alone and complicated by multiple resistances. Robotics offers precise, integrated control of individual weeds, improving efficiency, though technical challenges remain. Drones enable faster scouting but face issues in weed-crop differentiation, legal restrictions, and uncertain cost-effectiveness. Ground sensors could enhance postemergence control by identifying weed hotspots. Some Australian seedbank tactics like residue burning are impractical in U.S. high-residue crops. Alternative methods like flame weeding suit organic systems. Overall, emerging technologies promise improved HR weed management but require overcoming technical, economic, and regulatory barriers (Owen et al., 2016).

Herbicide-Resistant Weed Management in Iran

Although considerable scientific research has enhanced our understanding of resistance mechanisms and potential management approaches, practical implementation of these strategies at the farm level remains insufficient.

This gap highlights the urgent need for a coordinated national strategy that encompasses farmer education, policy-level interventions, and the promotion of integrated weed management (IWM) practices. Key components of IWM such as crop rotation, herbicide rotation, and the use of tank mixtures or sequential applications with different modes of action have been recommended and, to some extent, promoted in wheat-growing regions. Nonetheless, adoption has been limited, largely due to economic constraints, insufficient farmer training, and restricted access to a wider array of herbicide options (Gherekhloo et al., 2016).

Recent research by Iry et al., (2024) demonstrated the effectiveness of pyroxasulfone, a pre-emergence herbicide belonging to the VLCFA (very long-chain fatty acid) synthesis inhibitor group, in managing herbicide-resistant populations of *Lolium rigidum* (annual ryegrass), *Avena ludoviciana* (winter wild oat), and *Phalaris minor* (littleseed canarygrass) in wheat fields. Pyroxasulfone has shown high efficacy in suppressing these problematic species and is considered crop-safe for wheat, meaning that it provides effective weed control without adversely affecting crop growth or yield. In another study in Golestan province, it was revealed that *A. ludoviciana*, *P. minor*, and *L. rigidum* populations that were resistant to ACCase and/or ALS inhibitors were successfully controlled using pyroxasulfone, flumioxazin, chlorotoluron+ isoxaben, and chlorotoluron+ diflufenican herbicides. Common herbicides including pinoxaden and mesosulfuron-methyl+ iodosulfuron-methyl-sodium had still good efficacy in the township of Gonbad-Kavus. This was attributed to the lack of selection pressure imposed by herbicide application, as farmers in this township use herbicides only in years with good rainfall (Gherekhloo & Haghnama, 2022).

Addressing herbicide resistance in Iran requires a paradigm shift from sole reliance on chemical control toward an integrated, knowledge-based

approach. Long-term sustainability will depend on proactive resistance management, diversification of weed control strategies, and strong collaboration among researchers, extension services, policy-makers, and farmers.

Conclusion

This paper reviewed the current status of herbicide resistance in Iran. The rapid proliferation of multiple resistance calls for an urgent paradigm shift in weed management strategies. Knowledge of mechanism of resistance can help to detect the resistance pattern and devise suitable management measures. Also, studying the fitness cost associated with herbicide resistance would be beneficial, as the differences between resistant and susceptible populations can be exploited to manage herbicide resistance. There is a need to adopt proactive measures-as opposed to reactive ones- to mitigate herbicide resistance, i.e. acting before herbicide resistance occurs to prevent or delay this issue. Priorities must include, implementing effective and diversified crop rotations, routinely monitoring resistance mechanisms, and adopting integrated weed management (IWM) approaches particularly in high-risk provinces. Also, these measures should be adopted in low-risk provinces to prevent the onset of herbicide resistance. It can be said that, there is no single tactic can sustainably manage herbicide-resistant weeds. Resilience emerges from diversity in chemical modes of action, cropping systems, mechanical and cultural controls, and collaborative decision-making. Integrated weed management, combining herbicide rotation, mixtures, cultural practices like mulching, mechanical controls such as HWSC, scouting, and landscape-level cooperation, offers the best pathway to delay resistance evolution and sustain agroecosystem health. Fundamental shifts in farmer behavior, policy support, and education are essential complements to technological advances for long-term success.

References

- Abdollahipour, M., Gharakhloo, J., Bagherani, N. (2013). Investigating fitness of tribenuron methyl-resistant biotypes of wild mustard (*Sinapis arvensis* L.) in laboratory conditions. *Weed Res.* 5: 35–48.
- Abdollahipour, M., Gharekhloo, J., Bagherani, N. (2016). Investigating fitness of tribenuron methyl-resistant biotypes of Turnipweed (*Rapistrum rugosum* L.) under laboratory conditions. In: The 4th International Conference on Science and Engineering.
- Abdollahipour, M., Gharekhloo, J., Bagherani, N., Taghvaei, M.R. (2016). Effects relative fitness of susceptible and tribenuron methyl resistant biotypes of wild mustard (*Sinapis arvensis* L.). *Scinzer. J. Agric. Biol. Sci.* 2: 15–23.
- Adim, H., Fahmideh, L., Fakheri, B.A., Zarrini, H.N., Sasanfar, H. (2025). iTRAQ-based quantitative proteomic analysis of herbicide stress in *Avena ludoviciana* Durieu. *Sci. Rep.* 15(1): 577. <https://doi.org/10.1038/s41598-024-75308-1>
- Adim, H., Fahmideh, L., Fakheri, B.A., Najafi Zarrini, H., Sasanfar, H. (2021). Comparative analysis of proteome in herbicides susceptible and resistant winter wild oat (*Avena ludoviciana* Durieu) biotypes using iTRAQ technique. *Iranian J. Weed Sci.* 17(2): 45–63. <https://doi.org/10.22092/ijws.2021.353237.1385>
- Akbarabadi, A., Ismaili, A., Kahrizi, D., Nazarian Firouzabadi, F. (2019). Resistance determination of the ACCase-inhibiting herbicide of clodinafop propargyl in *Avena ludoviciana* (Durieu), and study of their interaction using molecular docking and simulation. *Mol. Biol. Rep.* 46: 415–424. <https://doi.org/10.1007/s11033-018-4493-0>
- Andreasen, C. & Streibig, J.C. (2011). Evaluation of changes in weed flora in arable fields of Nordic countries—based on Danish long-term surveys. *Weed Res.* 51(3): 214–226. <https://doi.org/10.1111/j.1365-3180.2011.00836.x>
- Axhgar, M., Bagheri, A., Nosratti, I., Boroomandan, P. (2022). Tracing resistance of wild mustard (*Sinapis arvensis* L.) to Tribenuron methyl and evaluation of relative fitness of its susceptible and resistant ecotypes in Eslamabad-Gharb, Kermanshah. *Iran. J. Weed Sci.* 18: 15–33.
- Bahmani Fathabadi, A., Zand, E., Lack, S., Naderi, A., Masoumi, M. (2024). Investigating the resistance mechanisms of wild mustard (*Sinapis arvensis*) to the herbicide tribenuron- methyl. *Iran. J. Weed Sci.* 20(1): 133–146.
- Bahmani Fathabadi, A., Zand, E., Masoumi, M., Naderi, A., Lack, S. (2016). Evaluation of resistance to acetolactate synthase inhibiting herbicide in wild mustard (*Sinapis arvensis* L.). *J. Exp. Biol. Agric. Sci.* 4:581-587.
- Barman, A.K., Roberts, P.M., Prostko, E.P., Toews, M.D. (2022). Seasonal occurrence and reproductive suitability of weed hosts for sweetpotato whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae), in South Georgia. *J. Entomol. Sci.* 57(1): 1–11. <https://doi.org/10.18474/JES21-16>
- Beckie, H.J. (2006). Herbicide-Resistant Weeds: Management Tactics and Practices. *Weed Technol.* 20(3): 793–814. <https://doi.org/10.1614/WT-05-084R1.1>
- Beckie, H.J. & Harker, K.N. (2017). Our Top 10 Herbicide-Resistant Weed Management Practices. *Pest. Manag. Sci.* 73(6): 1045–1052. <https://doi.org/10.1002/ps.4495>
- Beckie, H.J. & Kirkland, K.J. (2003). Implications of reduced herbicide rates on resistance evolution in wild oat (*Avena fatua*). *Weed Technol.* 17(1): 138–148. [https://doi.org/10.1614/0890-037X\(2003\)017\[0138:IORHRR\]2.0.CO;2](https://doi.org/10.1614/0890-037X(2003)017[0138:IORHRR]2.0.CO;2)
- Beckie, H.J., Hall, L.M., Meers, S., Laslo, J.J., Stevenson, F.C. (2004). Management practices influencing herbicide resistance in wild oat. *Weed Technol.* 18: 853–859. [https://doi.org/10.1614/0890-037X\(2004\)018\[0853:MPIHRW\]2.0.CO;2](https://doi.org/10.1614/0890-037X(2004)018[0853:MPIHRW]2.0.CO;2)
- Beltran, J.C., Pannell, D.J., Doole, G.J. (2012). Economic implications of herbicide resistance and high labour costs for management of annual barnyardgrass (*Echinochloa crus-galli*) in Philippine rice farming systems. *Crop Prot.* 31(1): 31–39. <https://doi.org/10.1016/j.cropro.2011.09.006>
- Benakashani, F., Alizadeh, H.M., Zand, E. (2007a). Investigating the resistance of wild oat (*Avena ludoviciana* Durieu.) to fenoxaprop-p-ethyl by whole plant bioassay and seed bioassay. *Pak. J. Biol. Sci.* 10(1): 72-77. <https://doi.org/10.3923/pjbs.2007.72.77>
- Benakashani, F., Gonzalez-Andujar, J. L., Soltani, E. (2021). Differences in germination of ACCase-resistant biotypes containing isoleucine-1781-Leucine mutation and susceptible biotypes of wild oat (*Avena sterilis* ssp. *ludoviciana*). *Plants.* 10(11): 2350. <https://doi.org/10.3390/plants10112350>
- Banakashani, F., Zand, E., Mohammadalizadeh, H. (2007b). Resistance of wild oat (*Avena ludoviciana*) biotypes to clodinafop-propargil herbicide. *Appl. Entomol. Phytopathol.* 74(2): 127-149.
- Benakashani, F., Zand, E., Razmi, A. (2013). Molecular detection of resistance mechanisms in resistant rye grass (*Lolium rigidum* L.) biotypes. In: 5th Iranian Weed Science Congress, Karaj, Iran.

- Benakashani, F., Zand, E., Naghavi, M.R., Sasanfar, H. (2014). Mutations in acetyl-CoA carboxylase enzyme, mechanism of cross resistance in wild oat (*Avena ludoviciana* Deuri.) biotypes to ACCase Inhibitor herbicides. *Iran. J. Weed Sci.* 10: 179–190.
- Cai, X., Chen, J., Wang, X., Gao, H., Xiang, B., Dong, L. (2022). Mefenacet resistance in multiple herbicide-resistant *Echinochloa crus-galli* L. populations. *Pestic. Biochem. Phys.* 182: 105038. <https://doi.org/10.1016/j.pestbp.2021.105038>
- Charudattan, R. (2005). Ecological, practical, and political inputs into selection of weed targets: what makes a good biological control target?. *Biological Control.* 35: 183–196. <https://doi.org/10.1016/j.biocontrol.2005.09.007>
- Cousens, R. D. & Fournier-Level, A. (2018). Herbicide resistance costs: what are we actually measuring and why?. *Pest. Manag. Sci.* 74: 1539–1546. <https://doi.org/10.1002/ps.4830>
- Dastoori, M., Rahimian, H., Zand, E., Alizadeh, H., Bahrami, S. (2011). Molecular basis for resistance of *Lolium rigidum* populations to aryloxyphenoxy propionate herbicide through dCAPS. *Iran. J. Field Crop Sci.* 41: 677–684.
- Dastoori, M., Rahimian, H., Zand, E., Alizadeh, H., Bahrami, S. (2010). Relative fitness of resistant and susceptible *Lolium rigidum* biotypes to ACCase inhibiting herbicides in drought stress. In: The 3rd Iranian Weed Science Congress, Babolsar, Iran.
- Dayan, F.E. (2019). Current status and future prospects in herbicide discovery. *Plants.* 8(9): 341. <https://doi.org/10.3390/plants8090341>
- Dayan, F.E. & Duke, S.O. (2020). Discovery for new herbicide sites of action by quantification of plant primary metabolite and enzyme pools. *Engineering.* 6(5): 509–514. <https://doi.org/10.1016/j.eng.2019.06.006>
- Delye, C. (2013). Unravelling the genetic bases of non-target-site-based resistance (NTSR) to herbicides: a major challenge for weed science in the forthcoming decade. *Pest. Manag. Sci.* 69: 176–187. <https://doi.org/10.1002/ps.3318>
- Derakhshan, A. & Gherekhloo, J. (2012). Tribenuron-methyl resistant turnipweed (*Rapistrum rugosum*) from Iran. In: 6th International Weed Science Congress, Hangzhou, China.
- Derakhshan, A., Najari-Kalantari, N., Gherekhloo, J., Kamkar, B. (2015). Resistance of wild mustard (*Sinapis arvensis*) and turnipweed (*Rapistrum rugosum*) to tribenuron-methyl in Aqqala region. *Journal of Plant Protection*, 29(2): 199–205.
- Dimaano, N.G. & Iwakami, S. (2021). Cytochrome P450-mediated herbicide metabolism in plants: current understanding and prospects. *Pest. Manag. Sci.* 77(1): 22–32. <https://doi.org/10.1002/ps.6046>
- Duke, S.O. & Dayan, F.E. (2022). The search for new herbicide mechanisms of action: Is there a ‘holy grail’?. *Pest Manag Sci.* 78(4): 1303–1313. <https://doi.org/10.1002/ps.6726>
- Dyer, W.E., Chee, P.W., Fay, P.K. (1993). Rapid germination of sulfonylurea-resistant *Kochia scoparia* accessions is associated with elevated seed levels of branched chain amino acids. *Weed Sci.* 41: 18–22.
- ElahiFard, A., Derakhshan, A., Zarrinjoub, H.A. (2017). Monitoring of weed resistance to acetyl-CoA carboxylase (ACCase), acetolactate synthase (ALS), and synthetic auxin herbicides in wheat fields of Shushtar County. *Iranian J. Plant. Prot. Res.* 31(2): 284–295.
- Elahifard, E., Ghanbari, A., Rashed Mohassel, M.H., Zand, E., Mirshamsi Kakhki, A., Mohkami, A. (2013). Characterization of triazine resistant populations of junglerice (*Echinochloa colona* (L.) Link.) found in Iran. *Aust. J. Crop Sci.* 7: 1302–1308.
- Elahifard, E. & Mijani, S. (2014). Effect of temperature and light on germination behavior of PSII inhibiting herbicide resistant and susceptible junglerice (*Echinochloa colona*) populations. *Aust. J. Crop Sci.* 8(9): 1304–1310.
- Fakhri, F., Bagheri, A., Sarabi, V., Nosratti, I. (2024). Evaluation of resistance of wild oats (*Avena ludoviciana* L.) to Clodinafop-propargyl and evaluation of relative fitness of susceptible and resistant wild oat biotypes in wheat fields located in Eslamabad-Gharb, Kermanshah. *Appl. Entomol. Phytopathol.* 91: 135–148.
- Fernandez-Quintanilla, C., Dorado, J., Andújar, D., Peña-Barragán, J.M. (2022). Advanced detection technologies for weed scouting. In: Advances in integrated weed management (pp. 143–162). *Burleigh. Dodds. Science Publishing.* <https://doi.org/10.19103/AS.2021.0098.09>
- Gam, H.J., Injamum-Ul-Hoque, M., Kang, Y., Ahsan, S.M., Hasan, M.M., Shaffique, S., Kang, S.M., Lee, I.J. (2024). Allelopathic effect of the methanol extract of the weed species-red sorrel (*Rumex acetosella* L.) on the growth, phytohormone content and antioxidant activity of the cover crop-white clover (*Trifolium repens* L.). *BMC Plant Biol.* 24(1): 523. <https://doi.org/10.1186/s12870-024-05230-1>

- Ghazali, Z., Keshtkar, E., AghaAlikhani, M., Kudsk, P. (2020). Relative Fitness of Acetyl-CoA Carboxylase susceptible and resistant *Alopecurus myosuroides* biotypes: germinability and seedling pre-emergence growth under salinity and drought stress conditions. *Iranian J. Weed Sci.* 16: 49–61.
- Gherekhloo, J. & Haghnama, K. (2021). Application of management program for ACCase and ALS - resistant weeds in wheat fields of Golestan province: Phase I. [Ratified Research Project]. Gorgan University of Agricultural Sciences and Natural Resources.
- Gherekhloo, J. & Haghnama, K. (2022). Application of management program for ACCase and ALS - resistant weeds in wheat fields of Golestan province: Phase II. [Ratified Research Project]. Gorgan University of Agricultural Sciences and Natural Resources.
- Gherekhloo, J., Hassanpour-bourkheili, S., Hejazirad, P., Golmohammadzadeh, S., Vazquez-Garcia, J.G., De Prado, R. (2021). Herbicide resistance in *Phalaris* species: A review. *Plants*. 10: 2248. <https://doi.org/10.3390/plants10112248>
- Gherekhloo, J., Hatami, Z.M., Alcántara-de la Cruz, R., Sadeghipour, H.R., De Prado, R. (2018). Continuous use of tribenuron-methyl selected for cross-resistance to acetolactate synthase-inhibiting herbicides in wild mustard (*Sinapis arvensis*). *Weed Sci.* 66(4): 424–432. <https://doi.org/10.1017/wsc.2018.19>
- Gherekhloo, J., Osuna, M.D., De Prado, R. (2012). Biochemical and molecular basis of resistance to ACCase-inhibiting herbicides in Iranian *Phalaris minor* populations. *Weed Res.* 52: 367–372. <https://doi.org/10.1111/j.1365-3180.2012.00923.x>
- Gherekhloo, J., Oveisi, M., Zand, E., De Prado, R. (2016). A review of herbicide resistance in Iran. *Weed Sci.* 64: 551–561. <https://doi.org/10.1614/WS-D-15-00190.1>
- Gherekhloo, J., Rashed Mohasel, M., Nasiri mahalati, M., Zand, E., Ghanbari, A., De Prado, R. (2008). Greenhouse assay to investigate resistance of littleseed canary grass (*Phalaris minor*) to aryloxyphenoxy propionate herbicides. *Iran. J. Field Crops Res.* 6(2): 353–362.
- Gherekhloo, J., Rashed mohassel, M.H., Nasiri Mahalati, M., Zand, E., Ghanbari, A., De Prado, R. (2010). Study the non-target site-based mechanisms of resistance in aryloxyphenoxy propionate resistant-*Phalaris minor* Retz. Biotypes. *Iranian J. Weed Sci.* 10: 79–89.
- Golmohammadzadeh, S., Gherekhloo, J., Ghaderi-Far, F., Kamkar, B., Osuna, M.D., De Prado, R. (2024). Germination biology of susceptible and target-site (Ile-1781-Thr) herbicide resistant short-spiked canary grass (*Phalaris brachystachys*) subpopulations. *Acta Physiol. Plant.* 46(1): 9. <https://doi.org/10.1007/s11738-023-03639-z>
- Golmohammadzadeh, S., Gherekhloo, J., Osuna, M.D., Ghaderi-Far, F., Kamkar, B., Alcántara-de la Cruz, R., De Prado, R. (2022). Physiological fitness associated to ACCase target-site resistance enhances growth and reproduction in *Phalaris brachystachys*. *Agronomy*. 12(5): 1206. <https://doi.org/10.3390/agronomy12051206>
- Golmohammadzadeh, S., Gherekhloo, J., Rojano-Delgado, A.M., Osuna-Ruiz, M.D., Kamkar, B., Ghaderi-Far, F., De Prado, R. (2019). The first case of short-spiked canarygrass (*Phalaris brachystachys*) with cross-resistance to ACCase-inhibiting herbicides in Iran. *Agronomy*. 9(7): 377. <https://doi.org/10.3390/agronomy9070377>
- Golmohammadzadeh, S., Rojano-Delgado, A.M., Vázquez-García, J.G., Romano, Y., Osuna, M.D., Gherekhloo, J., De Prado, R. (2020). Cross-resistance mechanisms to ACCase-inhibiting herbicides in short-spike canarygrass (*Phalaris brachystachys*). *Plant Physiol. Biochem.* 151: 681–688. <https://doi.org/10.1016/j.plaphy.2020.04.016>
- Gonzalez-Andujar, J.L. (2023). Integrated weed management: A shift towards more sustainable and holistic practices. *Agronomy*. 13(10): 2646. <https://doi.org/10.3390/agronomy13102646>
- Gressel, J. (2020). Perspective: present pesticide discovery paradigms promote the evolution of resistance—learn from nature and prioritize multi target site inhibitor design. *Pest. Manag. Sci.* 76(2): 421–425. <https://doi.org/10.1002/ps.5649>
- Haghnama, K. & Mennan, H. (2020). Herbicide resistant barnyardgrass in Iran and Turkey. *Planta Daninha*. 38: e020220060. <https://doi.org/10.1590/S0100-83582020380100060>
- Hanifehzadeh Erdi, S., Alebrahim, M.T., Zand, E., Sasanfar, H., Mohsenpour, M. (2024). Simultaneous occurrence of two Proline-197-Threonine (Pro-197-Thr) and Tryptophan-574-Leucine (Trp-574-Leu) mutations associated with resistance to iodosulfuron-methyl-sodium+mesosulfuron-methyl in annual ryegrass (*Lolium rigidum* Gaudin). *Iran. J. Weed Sci.* 20(1): 147–164.
- Hassanpour-bourkheili, S., Gherekhloo, J., Kamkar, B., Ramezanpour, S.S. (2018). A comparison of cardinal temperatures between haloxyfop R methyl ester- resistant and susceptible winter wild oat (*Avena ludoviciana* Durieu.) biotypes. *Weed Res J.* 9(2): 63–81.

- Hassanpour-bourkheili, S., Gherekhloo, J., Kamkar, B., Ramezanpour, S.S. (2020). Comparing fitness cost associated with haloxyfop-R methyl ester resistance in winter wild oat biotypes. *Planta Daninha*. 38: e020213759. <https://doi.org/10.1590/S0100-83582020380100059>
- Hassanpour-Bourkheili, S., Gherekhloo, J., Kamkar, B., Ramezanpour, S.S. (2021b). No fitness cost associated with Asn-2041-Ile mutation in winter wild oat (*Avena ludoviciana*) seed germination under various environmental conditions. *Sci. Rep.* 11(1): 1572. <https://doi.org/10.1038/s41598-021-81206-7>
- Hassanpour-bourkheili, S., Gherekhloo, J., Kamkar, B., Ramezanpour, S.S. (2021a). Mechanism and pattern of resistance to some ACCase inhibitors in winter wild oat (*Avena sterilis* subsp. *ludoviciana* (Durieu) Gillet & Magne) biotypes collected within canola fields. *Crop Protec.* 143: 105541. <https://doi.org/10.1016/j.cropro.2020.105541>
- Hassanpour-bourkheili, S., Gherekhloo, J., Soltani, A., Haghnama, K., Sohrabi, S., Ziaee, F., Taheri, M., Tavasoli, A., Kazemi, H., Trezzi, M.M., De Prado, R. (2024). Impact of herbicide resistance on energy use and greenhouse gas emission in wheat fields: A case study in Golestan province, Iran. *Advances in Weed Sci.* 42: e020240016. <https://doi.org/10.51694/AdvWeedSci/2024;42:00009>
- Hatami, Z.R., Gherekhloo, J., Rojano-Delgado, A.M., Osuna, M.D., Alcántara, R., Fernández, P., Sadeghipour, H., De Prado, R. (2016). Multiple mechanisms increase levels of resistance in *Rapistrum rugosum* to ALS herbicides. *Front. Plant Sci.* 7: 169. <https://doi.org/10.3389/fpls.2016.00169>
- Hatami Moghaddam, Z., Gherekhloo, J., De Prado, R., Sadeghipour, H.R. (2016). Tracing resistance to tribenuron-methyl in populations of wild mustard (*Sinapis arvensis* L.) and turnipweed (*Rapistrum rugosum* L.) collected from wheat fields of golestan province and introduction a new method in order to detect their resistant population. *J. Plant Prot.* 30(2): 347-358.
- Heap, I. (2025). The International Herbicide-Resistant Weed Database. Retrieved from www.weedscience.org
- Heravi, M., Gherekhloo, J., Siahmarguee, A., Kazemi, H., Hassanpour-Bourkheili, S. (2017). Investigating the resistance of wild mustard (*Sinapis arvensis* L.) biotypes to tribenuron methyl herbicide in wheat fields of Ramiyan Township. *Weed Res. J.* 10(1): 46-59.
- Heravi, M., Gherekhloo, J., Siahmarguee, A., Kazemi, H., Hassanpour-Bourkheili, S. (2020). Investigating the resistance of winter wild oat biotypes to accase inhibitor herbicide in wheat fields of Ramian County. *J. Plant Prot. Res.* 34(3): 385-399. <https://doi.org/10.22067/jpp.v34i3.86187>
- Holt, J.S. (1990). Fitness and ecological adaptability of herbicide-resistant biotypes. In: M. B. Green, H. M. LeBaron, and W. K. Moberg (Eds.), Managing resistance to agrochemicals (pp. 419–429). *American Chemical Society*. <https://doi.org/10.1021/bk-1990-0421.ch025>
- International Production Assessment Division (IPAD) (2025). Commodity intelligence reports. Foreign Agricultural Service, U.S. Department of Agriculture. Retrieved from <https://ipad.fas.usda.gov/>
- Iry, A., Gherekhloo, J., Zand, E., Soltani, A., Hassanpour-bourkheili, S., Haghnama, K., Sohrabi, S., Heravi, M. in press. Investigating the efficacy of pyroxasulfone herbicide in controlling herbicide-resistant and susceptible biotypes of ryegrass (*Lolium rigidum* Gaud.), winter wild oat (*Avena ludoviciana* Dur.) and little seed canarygrass (*Phalaris minor* Retz.) in wheat. *Iran. J. Weed Sci.* <https://doi.org/10.22034/ijws.2024.365766.1458>
- Izadi-Darbandi, E., Nezami, A., Abbasian, A., Heydari, M. (2014). Investigation the relationship between herbicide resistance in wild oat biotypes (*Avena ludoviciana* L.) and their freezing tolerance. *Field Crops Res.* 27: 127–133.
- Joumi, A., Keshtkar, E., Zand, E., Sasanfar, H. (2022). Evaluation of resistance to mesosulfuron methyl + iodosulfuron methyl and mesosulfuron methyl + iodosulfuron methyl + diflufenican herbicides in winter wild oat (*Avena sterilis* subsp. *ludoviciana*) populations collected from wheat fields of Khuzestan province and preparing distribution map of populations. *Iran. J. Weed Sci.* 18(1): 115–127.
- Jugulam, M. & Shyam, C. (2019). Non-target-site resistance to herbicides: recent developments. *Plants*. 8(10): 417. <https://doi.org/10.3390/plants8100417>
- Kamaei, A., Elahifard, E., Siahpoosh, A., Tabib, H. (2021). Tracing the resistance to acetolactate synthase and synthetic auxins in little mallow (*Malva parviflora*) in wheat fields of Khuzestan province. *Iran. J. Field Crop Sci.* 52(4): 13–23.
- Karlsson, M., Carrié, R., Wetterlind, J., Bergkvist, G., Ekroos, J., Smith, H.G. (2025). Weed–crop competition under improved nutrient management reveals trade-off between yields and weed diversity in organic farming. *Biological Agriculture & Horticulture*. *Advance online publication*. <https://doi.org/10.1080/01448765.2025.2412339>

- Keshtkar, E., Abdolshahi, R., Sasanfar, H., Zand, E., Beffa, R., Dayan, F.E., Kudsk, P. (2019). Assessing fitness costs from a herbicide-resistance management perspective: A review and insight. *Weed Sci.* 67: 137–148. <https://doi.org/10.1017/wsc.2018.93>
- Keshtkar, E., Kudsk, P., Beffa, R. (2025). Fitness and eco-physiological cost of herbicide metabolic resistance. In: V. K. Nandula (Ed.), *Herbicide metabolism and weed resistance*. John Wiley & Sons, Inc.
- Khaledi, R., Fayaz, F., Kahrizi, D., Talebi, R. (2019). PCR-based identification of point mutation mediating acetolactate synthase-inhibiting herbicide resistance in weed wild mustard (*Sinapis arvensis*). *Mol. Biol. Rep.* 46: 2429–2434. <https://doi.org/10.1007/s11033-019-04967-5>
- Khalil Tahmasebi, B., Zand, E., Soltani, H., Roozkhosh, M., Sasanfar, H. (2024). First report of *Vaccaria* sp. from Iran exhibiting in wheat fields. *J. Adv. Plant. Prot.* 1(2): 35–44.
- Khalil-Tahmasebi, B., Zand, E., Yousefi, A., Babaei, S., Sadeghpour, A. (2024). Surveillance and mapping of tribenuron-methyl-resistant weeds in wheat fields. *Sci. Rep.* 14: 28626. <https://doi.org/10.1038/s41598-024-75308-1>
- Khalil-Tahmasebi, B., Zand, E., Sasanfar, H. M. (2019). Monitoring and mapping the distribution of broadleaf herbicide-resistant weeds in major wheat-growing regions of Iran (Final Research Report, Approved Code: 980464-071-16-70-2). *J. Appl. Res. Plant Protect.*
- Khamani, B., Nosratti, I., Bagheri, A. (2023). Evaluation the fitness and competitive ability of wild mustard (*Sinapis arvensis*) susceptible and with multiple resistance to Tribenuron Methyl and 2,4-D+MCPA with wheat. *J. Appl. Res. Plant Protect.* 12: 273–284.
- Lehnhoff, E.A., Keith, B.K., Dyer, W.E., Menalled, F.D. (2013). Impact of biotic and abiotic stresses on the competitive ability of multiple herbicide resistant wild oat (*Avena fatua*). *PLoS ONE*. 8(5): e64478. <https://doi.org/10.1371/journal.pone.0064478>
- Leon, R.G. (2024). Resistance or tolerance: distinction without a difference. *Weed Sci.* 72(2): 113–116. <https://doi.org/10.1017/wsc.2023.67>
- Liu, X., Merchant, A., Xiang, S., Zong, T., Zhou, X., Bai, L. (2021). Managing herbicide resistance in China. *Weed Sci.* 69: 4–17. <https://doi.org/10.1017/wsc.2020.68>
- Lotfifar, A., Allahdadi, A., Zand, E., Akbari, Gh.A. (2013). Investigation of resistance in wild mustard (*Sinapis arvensis*) populations to acetolactate synthase-inhibiting herbicides in wheat fields of Khuzestan, Gorgan, and Kermanshah provinces. *Iran. J. Weed Sci.* 9(2): 141–157.
- Lotfifar, O., Alahdadi, I., Zand, E., Akbari, G.A., Mottaghi, S. (2015). Study fitness of resistant and susceptible biotypes of wild mustard (*Sinapis arvensis*) biotypes to acetolactate synthase (ALS) inhibitor in competition and non-competition with wheat. *Iran. J. Weed Sci.* 11: 61–76.
- Menchari, Y., Chauvel, B., Darmency, H., Délye, C. (2008). Fitness costs associated with three mutant acetyl-coenzyme A carboxylase alleles endowing herbicide resistance in black-grass *Alopecurus myosuroides*. *J. Appl. Ecol.* 45: 939–947. <https://doi.org/10.1111/j.1365-2664.2008.01486.x>
- Monjardino, M., Pannell, D.J., Powles, S.B. (2003). Multispecies resistance and integrated management: a bioeconomic model for integrated management of rigid ryegrass (*Lolium rigidum*) and wild radish (*Raphanus raphanistrum*). *Weed Sci.* 51: 798–809. <https://doi.org/10.1614/P2002-138A>
- Moradi, M., Babaei, S., Nosrati, I., Tahmasebi, I. (2024). Evaluation of the resistance of *Galium aparine* to common herbicides in wheat fields of Western and Southwestern Iran. *J. Appl. Res. Plant Protect.* 13(4): 373–385.
- Mottaghi, S., Mostafavi, K., Lotfifar, O., Mirtaheri, S. (2017). Study vigour and early growth of resistant and susceptible biotypes of wild mustard (*Sinapis arvensis* L.) to acetolactate synthase inhibitors under different environmental conditions. *Weed Res. J.* 8(1): 1–16.
- Najjari Kalantari, N., Gherekhloo, J., Kamkar, B. (2013). Tracing and map of canary grass (*Phalaris minor*) and hood grass (*P. paradoxa*) biotypes resistant to clodinafop-propargyl herbicide in wheat fields of Aq-qala. *Weed Res. J.*, 5: 85–97.
- Nath, C.P., Singh, R.G., Choudhary, V.K., Datta, D., Nandan, R., Singh, S.S. (2024). Challenges and alternatives of herbicide-based weed management. *Agronomy*. 14(1): 126. <https://doi.org/10.3390/agronomy14010126>
- Neve, P. (2007). Challenges for herbicide resistance evolution and management: 50 years after Harper. *Weed Res.* 47: 365–369. <https://doi.org/10.1111/j.1365-3180.2007.00581.x>
- Neve, P. & Powles, S.B. (2005). Recurrent selection with reduced herbicide rates leads to resistance. *Theor. Appl. Genet.* 110(6): 1154–1166. <https://doi.org/10.1007/s00122-005-1947-2>
- Norsworthy, J.K., Ward, S.M., Shaw, D.R., Llewellyn, R.S., Nichols, R.L., Webster, T.M., Bradley, K.W. Frisvold, G., Powles, S.B., Burgos, N.R., Witt, W.W., Barrett, M. (2012). Reducing the risks of herbicide resistance:

- Best management practices and recommendations. *Weed Sci.* 60: 31–62. <https://doi.org/10.1614/WS-D-11-00155.1>
- Nosrati, I. & Muhammadyari, A. (2019). First report of multiple resistance in *Galium aparine* to ALS – inhibiting and auxin analog herbicides in Kermanshah, Iran. *Planta Daninha*. 37: e019214599. <https://doi.org/10.1590/S0100-83582019370100084>
- Oerke, E.C. (2006). Crop losses to pests. *J. Agric. Sci.* 144(1): 31–43. <https://doi.org/10.1017/S0021859605005708>
- Ofori, R., Agyemang, E.D., Márton, A., Pásztor, G., Taller, J., Kazinczi, G. (2023). Herbicide resistance: Managing weeds in a changing world. *Agronomy*. 13(6): 1595. <https://doi.org/10.3390/agronomy13061595>
- Owen, M.D.K. (2016). Diverse approaches to herbicide-resistant weed management. *Weed Technol.* 30(2): 291–297. <https://doi.org/10.1614/WT-D-15-00117.1>
- Pannell, D.J., Stewart, V., Bennett, A., Monjardino, M., Schmidt, C., Powles, S.B. (2004). RIM: a bioeconomic model for integrated weed management of *Lolium rigidum* in Western Australia. *Agric. Syst.* 79: 305–325. [https://doi.org/10.1016/S0308-521X\(03\)00089-1](https://doi.org/10.1016/S0308-521X(03)00089-1)
- Parven, A., Meftaul, I.M., Venkateswarlu, K., Megharaj, M. (2025). Herbicides in modern sustainable agriculture: environmental fate, ecological implications, and human health concerns. *Int. J. Environ. Sci. Technol.* 22(2): 1181–1202. <https://doi.org/10.1007/s13762-024-05866-4>
- Powles, S.B. & Yu, Q. (2010). Evolution in action: plants resistant to herbicides. *Annu. Rev. Plant Biol.* 61: 317–347. <https://doi.org/10.1146/annurev-arplant-042809-112119>
- Prosser, R.S., Anderson, J.C., Hanson, M.L., Solomon, K.R., Sibley, P.K. (2016). Indirect effects of herbicides on biota in terrestrial edge-of-field habitats: A critical review of the literature. *Agric. Ecosyst. Environ.* 232: 59–72. <https://doi.org/10.1016/j.agee.2016.07.009>
- Qu, R.Y., He, B., Yang, J.F., Lin, H.Y., Yang, W.C., Wu, Q.Y., Li, Q.X., Yang, G.F. (2021). Where are the new herbicides?. *Pest. Manag. Sci.* 77(6): 2620–2625. <https://doi.org/10.1002/ps.6285>
- Rani, P., Rajak, B.K., Mahato, G.K., Rathore, R.S., Chandra, G., Singh, D.V. (2025). Strategic lead compound design and development utilizing computer-aided drug discovery (CADD) to address herbicide-resistant *Phalaris minor* in wheat fields. *Pest. Manag. Sci.* 81(5): 2469–2479. <https://doi.org/10.1002/ps.8063>
- Rastgoo, M., Rashed Mohassel, M.H., Kavooosi, H.R., Mirshamsi Kakhki, A., Zand, E. (2012). Molecular evaluation of resistant to aryloxyphenoxypropionate herbicides in winter wild oat (*Avena ludoviciana* Durieu.) in wheat field of Khuzestan. *Iran. J. Field Crops Res.* 10: 270–276.
- Rastgoo, M., Rashed, M.H., Zand, E., Nasiri, M. (2006). Resistance of winter wild oat (*Avena ludoviciana* Durieu.) to aryloxyphenoxy propionate herbicides in wheat fields of Khuzestan province: first screening test. *Iran. J. Weed Sci.* 2: 96–104.
- Renton, M., Busi, R., Neve, P., Thornby, D., Vila-Aiub, M. (2014). Herbicide resistance modelling: past, present and future. *Pest. Manag. Sci.* 70(9): 1394–1404. <https://doi.org/10.1002/ps.3773>
- Rubin, B. (1991). Herbicide resistance in weeds and its implications. *Phytoparasitica*. 19(3): 187–194. <https://doi.org/10.1007/BF02980958>
- Sabet Zangeneh, H., Mohammaddust Chamanabad, H.R., Zand, E., Asghari, A., Alamisaieid, K.H., Travlos, I.S., Alebrahim, M.T. (2018). Cross- and multiple herbicide resistance *Lolium rigidum* Gaud. (Rigid ryegrass) biotypes in Iran. *J. Agric. Sci. Technol.* 20: 1187–1200.
- Sabet Zangeneh, H., Mohammaddust Chamanabad, H. R. Zand, E. Asghari, A. Alamisaieid, K. Travlos, I.S. & Alebrahim, M.T. (2016). Study of fitness cost in three rigid ryegrass populations susceptible and resistant to acetyl-CoA carboxylase inhibiting herbicides. *Front. Ecol. Evol.* 4: 87. <https://doi.org/10.3389/fevo.2016.00087>
- Sabet Zangeneh, H., Mohammaddust Chamanabad, H., Zand, E., Alcántara-de la Cruz, R., Travlos, I., De Prado, R., Taghi Alebrahim, M. (2018). Clodinafop-Propargyl resistance genes in *Lolium rigidum* Guad. populations are associated with fitness costs. *Agronomy*, 8(6): 106. <https://doi.org/10.3390/agronomy8060106>
- Sarani, M., Oveisi, M., Mashhadi, H.R., Alizade, H., Gonzalez-Andujar, J.L. (2014). Interactions between the tillage system and crop rotation on the crop yield and weed populations under arid conditions. *Weed Biol. Manag.* 14(3):198-208.
- Sasanfar, H., Zand, E., Zamani, M.H., Keshtkar, E., Jouri, A. (2021). Resistance of the problematic grass weeds to some commonly used herbicides in canola (*Brassica napus* L.) fields in three provinces of Iran. *Iran. J. Weed Sci.* 17(2): 79–98.
- Sasanfar, H.R., Zand, E., Baghestani, M.A., Mirhadi, M.J. (2009a). Resistance of wild oat (*Avena ludoviciana*) populations to clodinafop-propargyl herbicide in Fars province. *Environmental Sci.* 7(1): 109–118.
- Sasanfar, H.R., Zand, E., Baghestani, M.A., Mirhadi, M.J. (2009b). Resistance of winter wild oat (*Avena ludoviciana*) populations to pinoxaden in Fars province. *Iran. J. Weed Sci.* 5: 1–13.

- Sasanfar, H., Khalil Tahmasebi, B., Zand, E., Zamani, M.H., Keshtkar, E. (2024). Cross- and multiple – resistance of the problematic grass weeds to the commonly used herbicides of wheat and canola. *Iran. J. Field Crop Sci.* 55(1): 89–104.
- Sasanfar, H., Rastgoo, M., Zand, E., Bagheri, A., Rashed Mohassel, M.H. (2017). Role of Ile-2041-Asn in conferring high-level resistance to clodinafop-propargyl in winter wild oat (*Avena ludoviciana*) populations. *Iran. J. Weed Sci.* 12(2): 133–150.
- Singh, M., Kukal, M.S., Irmak, S., Jhala, A.J. (2022). Water use characteristics of weeds: a global review, best practices, and future directions. *Front. Plant Sci.* 12: 794090. <https://doi.org/10.3389/fpls.2021.794090>
- Soltani, N., Dille, J.A., Burke, I.C., Everman, W.J., VanGessel, M.J., Davis, V.M., Sikkema, P.H. (2016). Potential corn yield losses from weeds in North America. *Weed Technol.* 30(4): 979–984. <https://doi.org/10.1614/WT-D-16-00046.1>
- Soufizadeh, T., Gharekhloo, J., Sohrabi, S., Bagherani, N., Siahmarguee, A. (2022). Mapping the distribution of winter wild oat (*Avena ludoviciana* Durieu.) biotype resistant to clodinafop-propargyl, diclofop-methyl and fenoxaprop-P ethyl herbicides in wheat fields of Kalaleh. *Iran. J. Weed Sci.* 18(1): 101–113. <https://doi.org/10.22092/ijws.2022.127707.1349>
- Tahmasebi, I., Mohasel, M.R., Moghaddam, P.R., Ghanbari, A., Zand, E. (2011). Germination and emergence of aryloxyphenoxypropionate resistant and susceptible accessions of wild oat (*Avena ludoviciana*) from Andimeshk and Dezful. *Iran. J. Field Crops Res.* 9: 406–415.
- Tatari, S., Gharekhloo, J., Siahmarguee, A., Kazemi, H. (2018). Identification of resistant *Avena ludoviciana* Dur accessions to ACCase inhibitor herbicides in Gonbad-E Kavus wheat fields and mapping their distribution. *Plant Productions.* 41(2): 103–116. <https://doi.org/10.22055/ppd.2017.21015.1439>
- Tavassoli, A. (2024). Tracing ryegrass (*Lolium rigidum* Gaud) biotypes resistant to ACCase and ALS inhibitor herbicides in Golestan province and investigating some of their resistance mechanisms and relative fitness. [Doctoral dissertation, Gorgan University of Agricultural Sciences and Natural Resources]. Gorgan University of Agricultural Sciences and Natural Resources Repository.
- Tavassoli, A., Gharekhloo, J., Ghaderi-Far, F., Zand, E., Osuna, M.D., De Prado, R. (2023). Rigid ryegrass (*Lolium rigidum* Gaud) resistant to ACCase and ALS inhibitors in northeastern Iran. *Advances in Weed Sci.* 41: e020230008. <https://doi.org/10.51694/AdvWeedSci/2023;41:00008>
- Torra, J. & Alcantara-De la Cruz, R. (2022). Molecular mechanisms of herbicide resistance in weeds. *Genes.* 13(11): 2025. <https://doi.org/10.3390/genes13112025>
- Vila-Aiub, M.M., Gundel, P.E., Preston, C. (2015). Experimental methods for estimation of plant fitness costs associated with herbicide-resistance genes. *Weed Sci.* 63: 203–216. <https://doi.org/10.1614/WS-D-14-00062.1>
- Vila-Aiub, M.M., Neve, P., Powles, S.B. (2009). Fitness costs associated with evolved herbicide resistance alleles in plants. *New Phytol.* 184: 751–767. <https://doi.org/10.1111/j.1469-8137.2009.03055.x>
- Vila-Aiub, M.M., Neve, P., Roux, F. (2011). A unified approach to the estimation and interpretation of resistance costs in plants. *Heredity.* 107: 386–394. <https://doi.org/10.1038/hdy.2011.29>
- Vila-Aiub, M.M., Neve, P., Steadman, K.J., Powles, S.B. (2005). Ecological fitness of a multiple herbicide-resistant *Lolium rigidum* population: dynamics of seed germination and seedling emergence of resistant and susceptible phenotypes. *J. Appl. Ecol.* 42: 288–298. <https://doi.org/10.1111/j.1365-2664.2005.01017.x>
- Walsh, M.J., Powles, S.B., Rengel, Z. (2022). Harvest weed seed control: impact on weed management in Australian grain production systems and potential role in global cropping systems. *Crop and Pasture Science.* 73(4): 313–324. <https://doi.org/10.1071/CP21647>
- Wang, D., Ma, B., Liu, H., Bao, Y., Niu, Y., Li, M. (2024). Effects of weeding frequency on the yield and quality of *Glycyrrhiza uralensis* Fisch in an arid and semi-arid area of northwest China. *Agronomy.* 14(3): 433. <https://doi.org/10.3390/agronomy14030433>
- Wrubel, R.P. & Gressel, J. (1994). Are herbicide mixtures useful for delaying the rapid evolution of resistance?. *Weed Technol.* 8(3): 635–648.
- Zamani, M., Keshtkar, E., Zand, E., Sasanfar, H. (2019). Cross and multiple resistance of ryegrass (*Lolium rigidum*) to some common ACCase and ALS inhibitor herbicides in wheat fields of Fars province. In: 8th Iranian Weed Science Congress, Mashhad, Iran.
- Zamani, M., Keshtkar, E., Zand, E., Sasanfar, H. (2021). Monitoring the resistance status of canarygrass (*Phalaris minor*) accessions to some commonly used herbicides in wheat fields of five provinces in Iran. *Iran. J. Weed Sci.* 17(1): 111–121.
- Zamani, M.H., Keshtkar, E., Sasanfar, H., Zand, E. (2023). Seed germination and seedling emergence fitness of clodinafop-propargyl-resistant *Lolium rigidum* populations. *Gesunde Pflanzen.* 75: 1531–1539.

<https://doi.org/10.1007/s10343-023-00837-0>

- Zand, E. (2025). A quarter century of research on herbicide resistance in weeds. Unpublished manuscript.
- Zand, E., Baghestani, M.A., Labafi, H.M.R., Atri, A.R., Minbashi, M.M. (2010). Monitoring of the herbicide resistant weeds in Iran. *Environ. Sci.* 7: 119–128.
- Zand, E., Baghestani, M. A., Soufizadeh, S., Eskandari, A., PourAzar, R., Veisi, M., Mousavi, K., Barjasteh, A. (2007). Evaluation of some newly registered herbicides for weed control in wheat (*Triticum aestivum*) in Iran. *Crop Protect.* 26(9): 1349–1358. <https://doi.org/10.1016/j.cropro.2006.11.012>
- Zand, E., Benakashani, F., Alizadeh, H.M., Soufizadeh, S., Ramezani, K., Maknali, A., Fereydounpoor, M. (2006). Resistance to Aryloxyphenoxypropionate herbicides in wild oat (*Avena ludoviciana*). *Iran. J. Weed Sci.* 2(1): 17-31.
- Zand, E., Moosavi, M.R., Deihim Fard, R., Maknali, A., Bagherani, N., Fridonpoor, M., Tabatabaei, R. (2004). A survey for determining weeds resistance to herbicides in some provinces of Iran. *Environmental Sci.* 5: 43–53.
- Zand, E., Razmi, A., Benakashani, F., Nezam Abadi, N., Gherekhloo, J., Sasanfar, H. (2013). Using CAPS and dCAPS methods to detect some mutations that cause resistance to acetyl coenzyme A carboxylase inhibiting herbicides in wild oat (*Avena ludoviciana*). *J. Plant Protect.* 9: 79–91.
- Zand, E., Razmi, A., Benakashani, F., Nazari, F., Gherekhloo, J. (2009). Using the dCAPS method to detect the resistance of wild oat (*Avena ludoviciana* Durieu.) to clodinafop-propargyl in comparison with current methods. *Iran. J. Weed Sci.* 5: 33–52.
- Zand, E., Sasanfar, H., Jamali, M., Sharifi-Ziveh, P., Maknali, A., Haghighi, A., Sabet Zanganeh, H., Veisi, M., Pourazar, R. (2022). Collecting, screening and mapping of herbicide-resistant grass weeds in wheat fields. Final Report of Research Project (04-16-16-081-980545), Iranian Research Institute of Plant Protection. 341 Pp.
- Zand, E., Sasanfar, H.R., Khalil-Tahmasebi, B., Foroozesh, A., Mighani, F., Keshtkar, A. (2019). A review of some advances in the field of herbicide resistance in weeds. In: 8th Iranian Weed Science Congress, Mashhad, Iran.
- Zand, E., Sasanfar, H.R., Ramazani, M.K., Khalil-Tahmasebi, B. (2023). Pesticide use in agriculture, a double-edged sword! Which side is sharper?. In: 10th National Iranian Weed Science Congress, Iran.