

Review

Invasive Characteristics and Impacts of *Ambrosia trifida*

Hisashi Kato-Noguchi *  and Midori Kato

Department of Applied Biological Science, Faculty of Agriculture, Kagawa University,
Miki 761-0795, Kagawa, Japan

* Correspondence: kato.hisashi@kagawa-u.ac.jp

Abstract: *Ambrosia trifida* L. is native to North America, has been introduced into many countries in Europe and East Asia, and is also expanding its habitat in its native ranges. *Ambrosia trifida* grows in sunny and humid environments, such as grasslands, riverbanks, floodplains, abandoned places, and agricultural fields, as an invasive plant species. *Ambrosia trifida* has a strong adaptive ability to adverse conditions and shows great variation in seed germination phenology and plant morphology in response to environmental conditions. Effective natural enemies have not been found in its native or introduced ranges. The species is allelopathic and contains several allelochemicals. These characteristics may contribute to the competitive ability and invasiveness of this species. *Ambrosia trifida* significantly reduces species diversity and plant abundance in its infested plant communities. The species also causes significant yield loss in summer crop production, such as in maize, soybean, sunflower, and cotton production. *Ambrosia trifida* is capable of rapid evolution against herbicide pressure. Populations of *Ambrosia trifida* resistant to glyphosate, ALS-inhibiting herbicides, and PPO-inhibiting herbicides, as well as cross-resistant populations, have already appeared. An integrated weed management protocol with a more diverse combination of herbicide sites of action and other practices, such as tillage, the use of different crop species, crop rotation, smart decision tools, and innovative equipment, would be essential to mitigate herbicide-dependent weed control practices and may be one sustainable system for *Ambrosia trifida* management.

Keywords: adaptation; allelopathy; germination phenology; herbicide resistance; morphology; natural enemy; plasticity; variation



Citation: Kato-Noguchi, H.; Kato, M. Invasive Characteristics and Impacts of *Ambrosia trifida*. *Agronomy* **2024**, *14*, 2868. <https://doi.org/10.3390/agronomy14122868>

Academic Editor: Giovanni Mauromicale

Received: 4 October 2024

Revised: 13 November 2024

Accepted: 22 November 2024

Published: 1 December 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Ambrosia trifida L. (syn. *Ambrosia aptera* DC., *Ambrosia integrifolia* Mulh. ex Willd.), belonging to the Asteraceae family, is a short-day annual plant species. *Ambrosia trifida* shows considerable variations in plant height, size, branching, number of leaves, and structure under different growth conditions. The species grows 1.5 m–6 m in height. The stems are erect and hairy, and branches can be frequent or seldom. It has a dense lateral root system. Opposite leaves are simple, lance-shaped, with 3–5 lobes or without lobes, 4 cm–25 cm long and 3 cm–20 cm wide, and attach to the stems with petioles of 3 cm–12 cm in length. The flowers are unisexual. Male inflorescences are located on the terminal parts of the plants and are up to 30 cm long. Female inflorescences are located in the axis of the upper leaves and at the base of the male inflorescences and are 0.5 cm–1.2 cm long. Fruits are covered with hard involucre with 6–8 blunt teeth and contain achenes (Figure 1) [1–4]. *Ambrosia trifida* produces a great amount of pollen. The pollen contains at least 11 antigens belonging to 8 protein families, which cause one of the main seasonal allergic rhinitis [5].

The native range of *Ambrosia trifida* is in North America. The original distribution of the species is thought to be in east-central USA and southern Canada and is currently observed in 48 US states, 10 Canadian states and regions, and northern Mexico [6,7]. *Ambrosia trifida* is already distributed in more than 30 counties from Western to Central Europe and East Asia (China, Mongolia, South Korea, and Japan) [4,6,7]. The species may be introduced as a

contaminant of fodder and crop grains, such as maize (*Zea mays*), wheat (*Triticum aestivum*), and soybean (*Glycine max*) [8,9].



Figure 1. *Ambrosia trifida*. Photos were provided by the Japan Association for Advancement of Phyto-Regulators (JAPR).

Native plant communities that consist of large species diversity including similar biotypes of the invasive plant species can be more resistant to invasive plant species than plant communities that consist of less species diversity [10]. However, plant diversity does not protect against the infestation of *Ambrosia trifida* [11]. In addition, the interspecific competitive ability of *Ambrosia trifida* is stronger than that of other plant species in agriculture fields, grasslands, riverbanks, floodplains, and roadsides [3,12]. The infestation of *Ambrosia trifida* is reported to cause a significant reduction in crop production in agricultural fields and in biodiversity in natural ecosystems [3,4,6]. However, there has been no review article focusing on the invasive characteristics of *Ambrosia trifida*. This review provides an overview of the invasive characteristics and impact of *Ambrosia trifida* on agricultural production and natural ecosystems. The literature was searched for using a combination of the predominant online search engines Scopus, ScienceDirect, and Google Scholar, using all possible combinations of *Ambrosia trifida* with the following words: invasion, agriculture, adaptation, botany, habitat, plasticity, reproduction, impact, natural enemy, allelopathy, allelochemical, secondary metabolite, herbicide, and management.

2. Invasive Characteristics

Ambrosia trifida shows great variation in its morphology for seed and plant size, growth patterns, nutrient allocation, and the phenology for germination under different growth conditions [3,4,6], which suggests that *Ambrosia trifida* may have high plasticity in response to environmental conditions. Genetic variation in *Ambrosia trifida* was also reported to be high in the populations of native and introduced ranges [13,14]. Different expressions of specific groups of genes, such as those for germination, growth phase change, and phenology, were detected in the populations of *Ambrosia trifida* in native ranges, although the individual genes for these functions were not determined [15].

2.1. Habitat and Climate

Ambrosia trifida grows well in humid and sunny environments, such as roadsides, railroads, abandoned land, agriculture fields, riverbanks, floodplains, grasslands, and forest margins [16–19]. *Ambrosia trifida* often infests summer annual crop fields, such as for maize, soybean, wheat, sorghum (*Sorghum bicolor*), sunflower (*Helianthus annuus*), and cotton (*Gossypium* spp.) [6,20–24].

Suitable climate conditions for *Ambrosia trifida* range from 430 mm to 860 mm for annual precipitation, from 15 °C to 30 °C for the mean maximum temperature of the hottest month, and from −10 °C to 2 °C for the mean minimum temperature of the coldest month. A cold winter is also necessary for breaking seed dormancy [6,7]. Low summer participation and temperature and low solar emission intensity are limiting factors for the distribution of *Ambrosia trifida* [19,25,26]. The species is not well adapted to areas that have long summer droughts [7,8,19]. However, some populations of *Ambrosia trifida* were reported to grow and produce seeds in places with an annual participation of 280 mm [12]. In addition, the drought stress tolerance of *Ambrosia trifida* populations in agriculture fields was greater than those in non-crop areas [27].

Ambrosia trifida can grow in a wide range of soil types and conditions [28]. The shoot length and total dry weight of *Ambrosia trifida* under more fertile soil conditions are greater than those under less fertile soil conditions. Flooding conditions increase the below-ground dry mass and the adventitious root formation of the species [29]. After plant death as an annual plant species, 85% of the organic matter accumulated in *Ambrosia trifida* plants decomposes within 22 months, and 69–98% of nitrogen, phosphorus, potassium, and calcium in these plants returns to the soil [30]. Therefore, nutrient cycles through the decomposition process may contribute to the growth of the next generation of *Ambrosia trifida*. In addition, the populations of *Ambrosia trifida* in the introduced ranges increase adaptability to the respective habitats over time [31]. These observations suggest that the adaptive ability of *Ambrosia trifida* in response to climate and soil conditions is high, and it may also be capable of continuous adaptation to new habitats.

As a plant species of disturbed environments, such as roadsides, railroads, abandoned land, and agricultural fields, the distribution of *Ambrosia trifida* has expanded with the increase in disturbed areas by human activity in both native ranges (USA and Canada) and introduced ranges (Europe and East Asia) [3,4,6,7]. Burning management in riverside vegetation also facilitates the growth and invasion of *Ambrosia trifida* [32]. Global climate change with increasing emission intensity could facilitate the geographic distribution of the species [33,34].

2.2. Seed and Germination

The male flowers of *Ambrosia trifida* appear after the formation of 9–11 pairs of leaves. The female flowers occur several days after the male flowers [35]. Flowering occurs from mid-June to early September in native ranges. The species is wind-pollinating and outcrossing [3,4,6]. *Ambrosia trifida* was recorded to produce 2000 seeds per plant [36] and 5000 seeds per m² [37]. More than 60% of the seeds remained on the mother plants by the end of October. In total, 50–80% of the seeds were viable [21,38].

The variations in the seeds in terms of weight, size, color, and dormancy are high. The size of the seeds is 3 mm–15 mm in length, 2 mm–10 mm in width, and 15 mg–50 mg in weight, and the color ranges from gray to brown [39–41]. The seeds are dispersed around the mother plants by wind, over several km by water streams, and to the nearest agricultural fields by attaching to crop cultivation equipment [6]. The seeds of *Ambrosia trifida* in agricultural fields often contaminate agricultural products, such as crop grains and forage, and are carried a long distance between regions, countries, and continents [3,6,8]. The seeds are also carried a short distance by earthworms, *Lumbricus terrestris* [42], and a longer distance by rodents and birds [43–45]. *Ambrosia trifida* establishes seed banks lasting up to 21 years at a depth of less than 20 cm in the soil [7,46]. *Lumbricus terrestris* was reported to bury a large number of the seeds into the soil at depths of 0.5–22 cm [46,47], which may contribute to its seed bank establishment and to the protection of seeds from seed predators.

The germination rate of relatively large seeds (larger than 6.6 mm in diameter) was 49% and that of relatively small seeds (smaller than 4.8 mm in diameter) was 19%. Most of the large seeds germinated during the four years after seed burial treatments, and most of the small seeds germinated during the five years after the treatments [47]. Seed viability

was proportional to the seed size and the burial in soil at a depth of up to 20 cm. Seeds in deep soil and large seeds maintained variability longer than those in shallow soil and small seeds. Some seeds were viable after 9 years of burial in soil at a depth of 20 cm [47,48]. Therefore, seed size may contribute to the viability of *Ambrosia trifida* seeds in the seed bank.

Ambrosia trifida germinates at a wide range of temperatures between 5 °C and 40 °C, with an optimum temperature at 10 °C–25 °C. Soil moisture for germination is suitable between 15% and 55%, with optimum moisture at 20–30% [37,48]. The seeds remain dormant when they are dispersed after maturity. Seed dormancy is primarily broken by cool temperatures (less than 5 °C) for three months [3,49,50]. However, seed dormancy levels vary, and the variation in dormancy contributes to the phenology of seed germination [51,52]. Early germination of *Ambrosia trifida* occurs from the beginning of spring before the emergence of most other annual plant species, including crop plants [47,52,53], which allows *Ambrosia trifida* to use nutrients in the soil before other competitive annual plant species. Some other seeds showed a prolonged germination period between March and August [51,52]. Different germination behavior may reflect the adaptation to different environmental conditions.

2.3. Growth

Ambrosia trifida grows fast and often forms strong clustering stands [3,28,54]. Under optimal conditions, *Ambrosia trifida* reaches 6 m in height, weighs 325 g in dry weight per plant, and weighs 3000 g in dry weight per m² [55]. The species shows a strong clustering distribution characteristic at the ratio of 386 plants per m² [56].

The morphology and biomass allocation of *Ambrosia trifida* vary under environmental conditions. The plant formation of *Ambrosia trifida* was reported to be greatly influenced by the density of the population. A low-density population of *Ambrosia trifida* (10 plants/m²) had 15-fold greater biomass per plant and 30-fold greater leaf area per plant than the high-density population (50 plants/m²). The low-density population of *Ambrosia trifida* branched well, and the high-density population seldom branched. The high-density population of *Ambrosia trifida* allocated more biomass to stem growth than the low-density population [57], and most of the leaves of the high-density population were concentrated at the top of the stems [58,59]. High-density populations of *Ambrosia trifida* may receive lower light irradiation intensity compared to low-density populations. The species also tends to shed unproductive leaves located near the bottom of the stems [55,56].

Shading light conditions increased the stem height, crown width, leaf areas, and leaf biomass per total biomass of *Ambrosia trifida* and decreased the total biomass and the ratio of root biomass to shoot biomass compared to plants in non-shaded conditions [56,57,59]. Therefore, differences in the plant formation of *Ambrosia trifida* were thought to be caused by different light irradiation intensities [3,57]. *Ambrosia trifida* may receive more light as the stems grow taller. In dense populations, the species allocates more biomass to above-ground plant parts, maximizing light precipitation and photosynthesis by increasing its height [56,57,60]. High biomass allocation for stem growth may be an important strategy to cope with adverse conditions in terms of light perception. The density and height of *Ambrosia trifida* may also lead to strong shading effects on neighboring plant species, resulting in significant alterations to the growth conditions of competitive plant species [21,56,57,61]. These accompanying species decrease in number, and their coverage also lessens [56]. In addition, *Ambrosia trifida* was observed to increase in plant size over time in introduced ranges [31].

Intraspecific variation in *Ambrosia trifida* was observed across Ohio (central distribution) to Minnesota (front distribution). The *Ambrosia trifida* population in Minnesota was about four times more prolific and allocated 50% more biomass to reproduction processes compared to the population of Ohio. The increase in fecundity from the Ohio to Minnesota population was thought to be the result of a propagule pressure gradient that increased from the central distribution to the front distribution of *Ambrosia trifida* [62]. The high fecundity of *Ambrosia trifida* might have contributed to the increasing population in

the front distribution. Propagule pressure is known to be one of the drivers of invasion success [63,64].

2.4. Natural Enemy

Specific pathogens and herbivores for certain invasive plant species may be limited in introduced ranges because of the lack of a co-evolutional history between these enemies and the invasive plant species [65]. No natural enemy for *Ambrosia trifida* was reported in countries in Europe where this species was introduced [7]. A North American-originating beetle, *Ophraella communa*, was found in Japan, and it was also observed to feed on *Ambrosia trifida* [66]. However, the beetle does not feed on *Ambrosia trifida* in native ranges [66,67], and its effectiveness in the control of *Ambrosia trifida* as a natural enemy has not yet been evaluated.

Pathogenic fungi, *Cercospora* spp., which causes leafspots, and *Protomyces graminis*, which causes swelling on the stems and leaves of *Ambrosia trifida*, are common in agricultural fields in USA. However, these pathogenic fungi rarely cause significant damage to the growth of *Ambrosia trifida* [6]. An aphid (*Uroleucon ambrosiae*) found in eastern North America specifically feeds on *Ambrosia trifida*, but the aphid in Southwestern America feeds on a variety of other species of the Asteraceae family [68]. The effectiveness of the aphid on the survival of *Ambrosia trifida* has not been reported.

More than 90% of *Ambrosia trifida* seeds are eaten by rodents and birds within the year after seed dispersal in the native ranges of *Ambrosia trifida* [43,45]. The larvae of fruit flies (*Euaestha festiva*), moths (*Chionodes mediofuscella*), and two kinds of weevils (*Smicronyx flavicans* and *Conotrachelus geminatus*) cause seed damage ranging up to 20% [43,69]. A few seeds are considered to be sufficient to keep and increase the population for the next generation of *Ambrosia trifida*, although a large number of *Ambrosia trifida* seeds are eaten by rodents, birds, and insects [3,43,45]. Therefore, any natural enemies, including herbivores and pathogenic fungi, do not cause significant damage to reduce the population and interrupt the regeneration process of *Ambrosia trifida* in native ranges. In the introduced ranges, no apparent natural enemy has been reported.

2.5. Allelopathy

Many invasive plant species have been reported to be allelopathic and contain several allelochemicals [70–73]. Allelopathy is the chemical interaction between donor plants and receiver plants through secondary metabolites defined as allelochemicals. Allelopathic plants release certain allelochemicals into neighboring environments. Released allelochemicals suppress the germination, growth, establishment, and/or regeneration process of neighboring plants, and they increase the competitive ability of the donor plant species [74–77]. These allelochemicals are synthesized and stored in a given plant tissue until the releasing of allelochemicals through the volatilization, root exudation, and decomposition processes of plant residues in rhizosphere soil [78–82]. Therefore, several allelochemicals have been identified in the extracts of plant parts (shoots, leaves, stems, and/or roots), essential oil, volatiles, root exudates, and rhizosphere soil of an invasive plant species [83–85].

Aqueous extracts of *Ambrosia trifida* shoots inhibit the development of the root hairs of the seedlings of wheat and garlic chives (*Allium tuberosum*) [86]. Aqueous extracts of *Ambrosia trifida* shoots also inhibit the germination and growth of soybean, maize, wheat, and rice (*Oryza sativa*). Four monoterpenes, α -pinene, β -pinene, camphene, and cineole, have been identified in extracts as allelochemicals [87]. These observations suggest that *Ambrosia trifida* may be allelopathic and contain allelochemicals.

The rhizosphere soil of *Ambrosia trifida* suppressed growth at the seedling, flowering, and mature stages of wheat. When the plant residues of *Ambrosia trifida* mixed with the cultivation soil, the soil suppressed the growth of wheat. Two sesquiterpenes, 1 α -angeloyloxy-carotol and 1 α -(2-methylbutyroyloxy)-carotol, were identified as allelochemicals in the soil mixed with plant residues and the rhizosphere soil of *Ambrosia trifida* [88]. These observa-

tions suggest that these allelochemicals may be released into rhizosphere soil during the decomposition process of the residues of *Ambrosia trifida*.

The infestation of *Ambrosia trifida* affected the populations of the microbes Proteobacteria, such as *Acinetobacter* spp. and *Enterobacter* spp., in rhizosphere soil. Three sesquiterpenes, (1*E*,4*E*)-germacradiene-6 β ,15-diol, (E)-4 β ,5 α -epoxy-7 α H-germacr-1(1*O*)-ene-2 β ,6 β -diol, and (2*R*)- δ -cadin-4-ene-2,10-diol, were identified in the root exudates of *Ambrosia trifida*. These compounds decreased the population of *Acinetobacter* spp. and increased the population of *Enterobacter* spp. The increased *Enterobacter* spp. population stimulated the growth of *Ambrosia trifida* [89]. This observation suggests that *Ambrosia trifida* may release these compounds through root exudation, and these compounds may control the population of microbes in rhizosphere soil.

Chlorogenic acid, caffeic acid, *p*-coumaric acid, and vanillin are known to act as allelochemicals for several other plant species, and they inhibit the germination and growth of their neighboring plant species [90–94]. These compounds have also been identified in the aqueous extracts of whole *Ambrosia trifida* plants. The high concentration of these compounds inhibited the germination of *Ambrosia trifida* itself [95]. The high concentration of these compounds was thought to be attained when *Ambrosia trifida* grew in a high-density manner. High-density populations of *Ambrosia trifida* could suppress germination through the high concentration of these compounds, resulting in contributions to the maintenance of plant density and to the avoidance of intraspecies competition [95]. However, it is not clear how these compounds reached the seeds of *Ambrosia trifida* and caused germination inhibition because these compounds were obtained by the extraction of *Ambrosia trifida*, and no information was provided for the concentration of these compounds surrounding the seeds.

The essential oil of *Ambrosia trifida* inhibited the growth of maize and wheat and showed anti-bacterial activity against *Staphylococcus aureus* and *Klebsiella pneumoniae* and anti-fungal activity against *Asperigillus niger* and *Candida albicans*. The main constituents of the essential oil were bornyl acetate (15.5%), borneol (8.5%), caryophyllene oxide (8.3%), α -pinene (8.0%), germacrene D (6.3%), and β -caryophyllene (4.6%) [96,97]. Another essential oil obtained from *Ambrosia trifida* also inhibited the germination and seedling growth of lettuce (*Lactuca sativa*), watermelon (*Citrullus lanatus*), cucumber (*Cucumis sativus*), and tomato (*Solanum lycopersicum*). The main constituents of this essential oil were limonene (20.7%), bornyl acetate (15.0%), borneol (14.7%), and germacrene D (11.6%) [98]. These essential oils are very volatile [96–98]. Therefore, *Ambrosia trifida* may release these compounds through volatilization, and these volatile compounds may suppress the germination and growth of crop plant species. These compounds also have anti-bacterial activity and anti-fungal activity.

These observations suggest that *Ambrosia trifida* is allelopathic and releases certain allelochemicals through the volatilization, root exudation, and decomposition process of plant residues in rhizosphere soil. These allelochemicals may suppress the germination and growth of several crop species and affect microbe density in rhizosphere soil. Therefore, allelopathy may contribute to increasing the competitive ability of *Ambrosia trifida*, resulting in an increase in species invasiveness.

Global climate change, with increasing temperatures, could affect the cellular metabolism activity of *Ambrosia trifida* and increase the root exudation of several allelochemicals, such as chlorogenic acid and caffeic acid [99]. Therefore, global climate change may increase the allelopathic potential of *Ambrosia trifida* by increasing the root exudation of certain allelochemicals, which may enhance the species' invasiveness even more. The chemical structures of the possible allelochemicals of *Ambrosia trifida* are summarized in Figure 2.

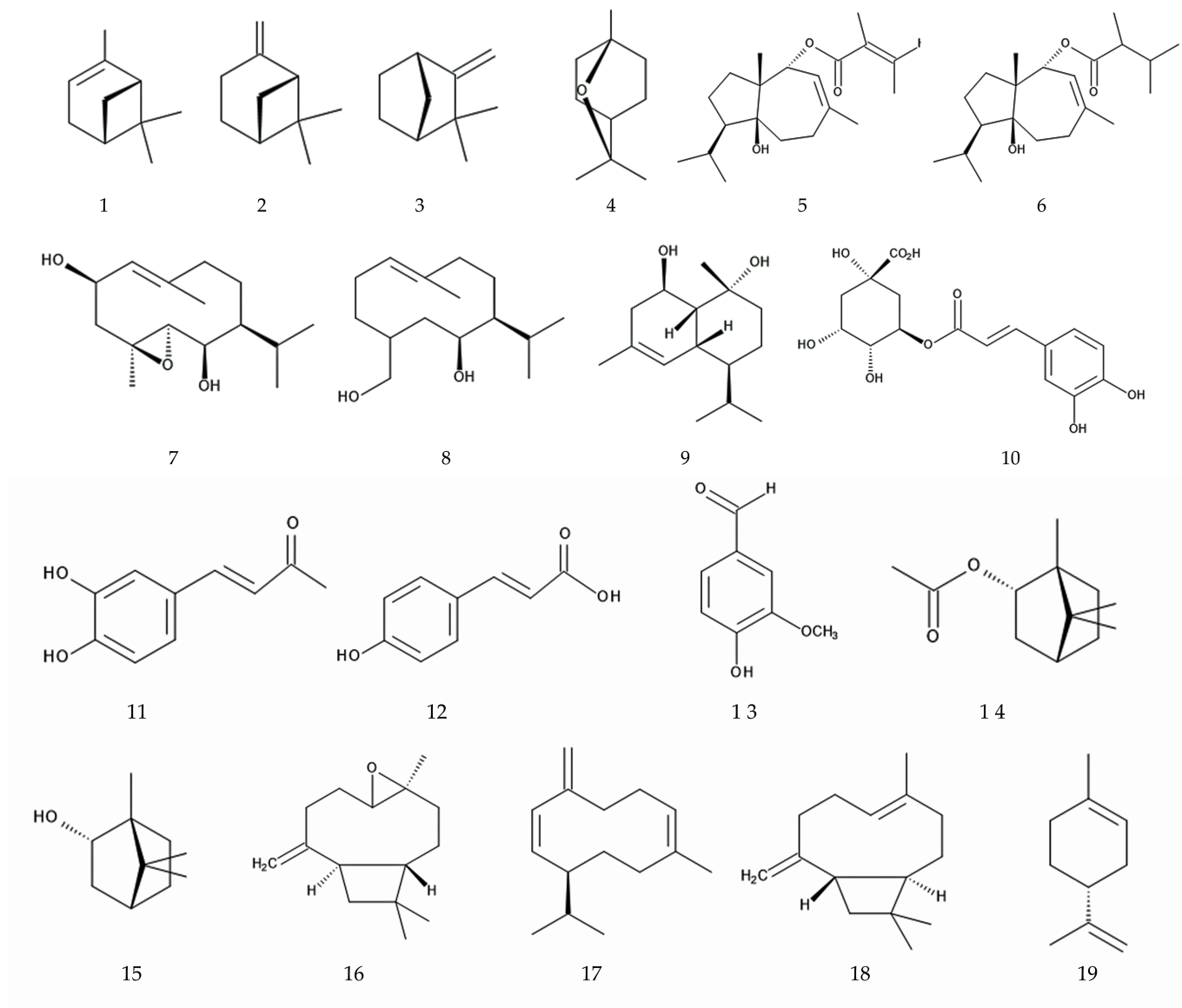


Figure 2. Allelochemicals of *Ambrosia trifida*. 1: α -pinene, 2: β -pinene, 3: camphene, 4: cineole, 5: 1 α -angeloyloxy-carotol; 6: 1 α -(2-methylbutyroyloxy)-carotol; 7: (1E,4E)-germacrdiene-6 β ,15-diol; 8: (E)-4 β ,5 α -epoxy-7 α H-germacr-1(10)-ene-2 β ,6 β -diol; 9: (2R)- δ -cadin-4-ene-2,10-diol; 10: chlorogenic acid; 11: caffeic acid; 12: *p*-coumaric acid; 13: vanillin; 14: bornyl acetate; 15: borneol; 16: caryophyllene oxide; 17: germacrene D; 18: β -caryophyllene; 19: limonene.

Under oxidative stress conditions, a significant increase in malondialdehyde (MDA) content and the induction of catalase and superoxide dismutase (SOD) were observed in many plant cells [100]. Oxidative stress causes damage to plant cellular components and physiological processes. High MDA content indicates that plants are undergoing stress. Catalase and SOD convert reactive oxygen species (ROS) to hydrogen peroxide and molecular oxygen, which reduces stress [101–103]. Thus, the oxidative stress is alleviated by the antioxidant defense system, such as catalase and SOD [104,105]. It is also known that certain allelochemicals increase MDA content but suppress the induction of catalase and SOD. Thus, these allelochemicals induce oxidative stress in receiver plants and interrupt their antioxidant defense system [106–108]. When *Ambrosia trifida* and sunflower, maize, or soybean were grown together, the activity of catalase and SOD decreased in sunflower seedlings after 7 days of incubation, which suggests that *Ambrosia trifida* may interrupt the antioxidant defense system of sunflowers. However, MDA content in the sunflower

seedlings was not affected significantly. *Ambrosia trifida* also did not significantly change the activities of the catalase and SOD, nor did it change the MDA content in maize and soybean seedlings [109]. Therefore, it is not clear whether *Ambrosia trifida* interrupts the antioxidant defense systems in sunflower, maize, and soybean.

3. Impacts of *Ambrosia trifida* Infestation

3.1. Impact on Agricultural Production and Control

Ambrosia trifida had already been listed as one of the top twenty worst weed species in the USA at the end of the 19th century [110]. *Ambrosia trifida* has a relatively strong interspecific competitive ability against annual crop plant species, such as maize, soybean, sunflower, and cotton [20–24,111–115]. *Ambrosia trifida* caused yield losses of 14% and 90% in maize at a density of 1.7 and 14 plants per 10 m², respectively [21], and it caused a dry mass loss of 25% in sunflower at two plants per m² [4]. The species also caused a yield loss of 50% in cotton at 0.26 plants per 1 m cotton row [22], and it caused a yield loss of 46–50% in soybean at two plants per 9 m soybean row [112]. The density of *Ambrosia trifida* was 220,000 and 360,000 plants per ha in the years 1988 and 1989, respectively, in Missouri, USA, which resulted in complete soybean yield loss [112]. *Ambrosia trifida* is also known to act as the host of soybean stem borers (*Dectes texanus*), maize stalk borers (*Papaipema nebris*), and plant-feeding stink bugs or southern green stink bugs (*Nzara viridula*) [6]. *Ambrosia trifida* transfers these insects to the respective crops and causes a reduction in crop production.

The emergence phenology of *Ambrosia trifida* populations in the agricultural fields in the U.S. Corn Belt were different from that of non-agricultural populations [28,38,51,111–114]. The non-agricultural populations of *Ambrosia trifida* in Ohio showed an early and brief emergence period, whereas the agricultural populations showed an early and prolonged emergence period (more than 100 days), which allows the species to establish themselves again after early seasonal weed control practices [51,52]. However, both agricultural and non-agricultural populations of *Ambrosia trifida* in Iowa and Nebraska were reported to have an early and brief emergence period [51,113,114]. Genetic variation in emergence phenology was also observed in these populations [51]. Therefore, the emergence phenology of *Ambrosia trifida* in certain local populations may depend on selection factors and the available genetic variations in the populations.

A parasite vine, *Cuscuta japonica* [115], a beetle, *Ophraella communa* [66,67], and a rust pathogenic fungus, *Puccinia xanthii* [116], were previously selected as the potential biological control agents for *Ambrosia trifida*. However, their practical effectiveness to control *Ambrosia trifida* has not been evaluated sufficiently in agricultural fields. Therefore, *Ambrosia trifida* is currently controlled by chemical and mechanical practices [8,28].

Spring tillage is an effective mechanical control practice for *Ambrosia trifida* in cases of high seed densities in the soil. The abundance of *Ambrosia trifida* decreases as the tillage intensity increases, although the tillage cannot eradicate the weeds from agricultural fields [117]. Repeatedly hand weeding and mowing *Ambrosia trifida* at an early stage of growth are also effective control practices, but these practices only work effectively in small fields and during a given year [118–120]. Diversified crop rotation systems, including annual and perennial crops, may be one of the options to reduce the density of *Ambrosia trifida* in agricultural fields [28,54,121,122].

Ambrosia trifida is a cross-fertilizing and genetically variable species, and it is capable of rapid evolution against herbicide pressure [123,124]. Populations of *Ambrosia trifida* resistant to glyphosate (an inhibitor for enolpyruvyl shikimate phosphate synthase) were reported in soybean and cotton fields in 13 U.S. states and in one Canadian province [125]. In addition, two distinct glyphosate resistant biotypes have been found: (1) a rapid-response biotype, which causes cell death within hours after glyphosate treatment but resumes growth in several days [126,127], and (2) a non-rapid response biotype, which shows chlorosis at apical parts but resumes growth in two weeks [127–129]. The rapid-response biotype to glyphosate was not associated with mutations in the sequence of the enolpyruvyl shikimate phosphate synthase [130,131]. Therefore, this glyphosate-resistant biotype may

evolve a non-target-site resistant mechanism. These observations suggest that two different resistant mechanisms may have evolved in *Ambrosia trifida* against glyphosate pressure.

Soil microorganisms are known to play an important role in herbicidal activity and plant tolerance to glyphosate [132–134]. When a glyphosate-susceptible population of *Ambrosia trifida* was grown in unsterile and sterile field soil, the susceptible population in the unsterile soil showed an 8.6-fold greater tolerance to glyphosate application than that grown in sterile soil [134]. The colonization of *Ambrosia trifida* with soil microbe Oomycetes increased their rates of survival against glyphosate application [135,136]. Therefore, the colonization of *Ambrosia trifida* with Oomycetes may increase their tolerance to glyphosate application.

Resistant populations of *Ambrosia trifida* to acetolactate synthase (ALS)-inhibiting herbicides were found in soybean and maize fields in five U.S. states. These ALS-resistant populations showed tolerance to at least two different chemical families of ALS-inhibiting herbicides, such as cloransulam-methyl, imazamox, imazaquin, primisulfuron-methyl, and prosulfuron [125,137,138]. Cross-resistant populations against different herbicide sites of actions (glyphosate and ALS-inhibiting herbicides) were also found in soybean and maize fields in four U.S. states [125]. A population of *Ambrosia trifida* resistant to protoporphyrinogen oxidase (PPO)-inhibiting herbicides was recently found in agricultural fields that were cultivated by maize and soybean rotation with non-GMO soybeans in Wisconsin, USA [131]. Therefore, many types of herbicide-resistant populations have already appeared in agricultural fields. However, it is not clear that these herbicide-resistant populations have appeared simultaneously across the U.S. Corn Belt [139] nor have they followed a westward trajectory from the eastern part of the U.S. Corn Belt [140–142].

These observations suggest that *Ambrosia trifida* causes significant yield loss in annual crop production. *Ambrosia trifida* is capable of rapid evolution against herbicide pressure, and this characteristic of *Ambrosia trifida* makes it difficult to consistently control with a single application of pre-emergence or post-emergence herbicides or multiple applications of herbicides with the same mode of action. The most effective herbicide program can combine pre-emergence and post-emergence herbicide treatments, and two or more herbicide sites of action [28,125,131]. An integrated weed management with a more diverse combination of herbicide sites of action and other practices, such as tillage, different crop species, crop rotation, smart decision tools, and innovative equipment, would be essential to mitigate herbicide-dependent weed control practices, and this may be one of the sustainable systems for *Ambrosia trifida* management [143–150].

3.2. Impact on Natural Environments

Ambrosia trifida can establish strong clustering stands in grasslands, riverbanks, and floodplains [3,6,12,16–19,56]. *Ambrosia trifida* produces most of the plant biomass and suppresses the growth of all other plant species in its dominant community [18,28,55]. *Ambrosia trifida* was reported to produce a greater biomass than other annual plant species, such as *Bilderdykia convolvulus*, *Chenopodium album*, *Echinochloa crus-galli*, *Polygonum aviculare*, *Setaria viridis*, and *Sorghum halepense* [4]. The average height, total coverage, and plant number of the indigenous plant species were significantly lower in the *Ambrosia trifida*-infested plots than in the non-infested plots in riparian ecosystems [151]. Plant diversity in the riverbanks decreased as *Ambrosia trifida* density increased [152]. The aboveground coverage of *Ambrosia trifida* reached 84% of the entire grassland after four years' infestation of *Ambrosia trifida* in the grasslands. *Ambrosia trifida* also changed the seed bank composition of the grassland community in a short time, which affected the regeneration process [153]. *Ambrosia trifida* was reported to reduce species diversity in abandoned farmlands [61]. These observations suggest that *Ambrosia trifida* may significantly reduce plant abundance and species diversity in a native plant community. However, information on the impact of *Ambrosia trifida* on natural environments is limited, and effective management practices in natural ecosystems, such as grasslands, floodplains, and riverbanks, has not yet been suggested.

4. Conclusions

Based on the literature review conducted in this study, this work identified that *Ambrosia trifida* has a strong adaptive ability to various environmental conditions, such as temperature, participation, and soil type. *Ambrosia trifida* also shows variations in seed germination phenology, such as brief and prolonged germination periods, and variations in plant morphology, such as seed size, plant height, branching, leaf formation, and nutrient allocation under different environmental conditions. Effective natural enemies of *Ambrosia trifida* have not been reported in introduced ranges. Several natural enemies, such as pathogenic fungi, herbivore vertebrates, and invertebrates, have been found in native ranges. However, these enemies do not cause significant damage to the regeneration process of *Ambrosia trifida*. *Ambrosia trifida* is allelopathic and contains several allelochemicals. These allelochemicals suppress the germination and growth of neighboring plant species. Therefore, the characteristics of *Ambrosia trifida* described in this article may contribute to their competitive ability and invasiveness, resulting in the expansion of its habitats (Figure 3).

Invasiveness

- A strong adaptive ability: temperature, participation, soil type
- Variations in germination phenology: early and brief, prolonged germination
- Variations in plant morphology: seed size, plant height, branching, leaf formation, and nutrient allocation
- No effective natural enemy
- Allelopathy: Release several allelochemicals

Impact

- Reduction in species diversity and plant abundance
- Significant yield loss in summer crop production
- Rapid evolution against herbicide pressure: Resistant; glyphosate, ALS-inhibiting herbicides with different chemical families, PPO-inhibiting herbicides, cross resistance with different sites of herbicide action

Figure 3. Invasive characteristics and impacts of *Ambrosia trifida*.

Ambrosia trifida often infests agricultural fields and causes significant yield loss in annual crop production in the summer, such as maize, soybean, sunflower, and cotton production in agricultural fields. The species is currently controlled chemically and mechanically. Mechanical management, such as tillage and hand weeding, are effective in small fields and/or within a given year. However, this management cannot eradicate *Ambrosia trifida* from agricultural fields. *Ambrosia trifida* is capable of rapid evolution against herbicide pressure. Populations of *Ambrosia trifida* resistant to glyphosate, ALS-inhibiting herbicides with different chemical families, PPO-inhibiting herbicides, and cross-resistant populations against different sites of herbicide action have already appeared in agricultural fields. The characteristics of *Ambrosia trifida* against herbicides make it difficult to consistently control with a single application of pre-emergence or post-emergence herbicides or multiple applications of herbicides with the same mode of action.

Ambrosia trifida forms strong clustering stands in sunny and humid environments, such as grasslands, floodplains, riverbanks, and abandoned lands. The species was reported to

significantly reduce species diversity and the abundance of native plant species. However, information on the impact of *Ambrosia trifida* on natural ecosystems is limited. Therefore, further investigations into biological and ecological aspects are still required to understand the species in more detail. It is also necessary to develop sustainable systems for *Ambrosia trifida* management in agricultural fields and natural ecosystems.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Royal Botanical Gardens, Kew, *Ambrosia trifida*. Available online: <https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:315739-2> (accessed on 12 September 2024).
2. Bassett, I.J.; Crompton, C.W. The biology of Canada weeds. 55. *Ambrosia trifida* L. *Can. J. Plant Sci.* **1982**, *62*, 1003–1010. [CrossRef]
3. Chauvel, B.; Fried, G.; Follak, S.; Chapman, D.; Kulakova, Y.; Le Bourgeois, T.; Marisavljevic, D.; Monty, A.; Rossi, J.P.; Starfinger, U.; et al. Monographs on invasive plants in Europe N° 5: *Ambrosia trifida* L. *Bot. Lett.* **2021**, *168*, 167–190. [CrossRef]
4. Savić, A. *Ambrosia trifida* L. (giant ragweed). *Matica Srp. J. Nat. Sci.* **2021**, *141*, 35–47. [CrossRef]
5. Yin, L.; Zhang, G.; Zhou, C.; Ou, Z.; Qu, B.; Zhao, H.; Zuo, E.; Liu, B.; Wan, F.; Qian, W. Chromosome-level genome of *Ambrosia trifida* provides insights into adaptation and the evolution of pollen allergens. *Int. J. Biol. Macromol.* **2024**, *259*, 129232. [CrossRef] [PubMed]
6. CABI Compendium. *Ambrosia trifida*. Available online: <https://www.cabidigitallibrary.org/doi/full/10.1079/cabicompendium.4693> (accessed on 12 September 2024).
7. EPPO Global Database. *Ambrosia trifida*. Available online: <https://gd.eppo.int/taxon/AMBTR/documents> (accessed on 12 September 2024).
8. Chauvel, B.; Rodriguez, A.; Moreau, C.; Martinez, Q.; Bilon, R.; Fried, G. Spread of *Ambrosia trifida* L. in France: Historical and ecological knowledge for the eradication of the species. *J. Bot.* **2015**, *71*, 2538.
9. Stoyanov, S.; Vladimirov, V.; Milanova, S. *Ambrosia trifida* (Asteraceae), a new non-native species for the Bulgarian flora. *C. R. Acad. Bulg. Sci.* **2014**, *67*, 1653–1656.
10. Elton, C.S. *The Ecology of Invasions by Animals and Plants*; Springer: Berlin, Germany, 1958; pp. 1–261.
11. Byun, C.; Lee, E.J. Giant ragweed invasion is not well controlled by biotic resistance. *J. Plant Biol.* **2018**, *61*, 301–308. [CrossRef]
12. Dong, H.; Song, Z.; Liu, T.; Liu, Z.; Liu, Y.; Chen, B.; Ma, Q.; Li, Z. Causes of differences in the distribution of the invasive plants *Ambrosia artemisiifolia* and *Ambrosia trifida* in the Yili Valley, China. *Ecol. Evol.* **2020**, *10*, 13122–13133. [CrossRef]
13. Shao, M.; Fu, D.; Wang, X.; Liu, Z.; Qu, B. Genetic diversity of *Ambrosia trifida* L. as revealed by AFLP markers. *Biotechnol. J. Int.* **2018**, *21*, 1–9. [CrossRef]
14. Sharma, H.; Hyvonen, J.; Poczar, P. Development of chloroplast microsatellite markers for giant ragweed (*Ambrosia trifida*). *Appl. Plant Sci.* **2020**, *8*, e11313. [CrossRef]
15. Li, B.; Gschwend, A.R.; Hovick, S.M.; Gutek, A.; McHale, L.; Harrison, S.K.; Regnier, E.E. Evolution of weedy giant ragweed (*Ambrosia trifida*): Multiple origins and gene expression variability facilitates weediness. *Ecol. Evol.* **2022**, *12*, e9590. [CrossRef] [PubMed]
16. Leck, M.; Simpson, R.L. Tidal freshwater wetland zonation: Seed and seedling dynamics. *Aquat. Bot.* **1994**, *47*, 61–75. [CrossRef]
17. Sosnoskie, L.M.; Luschei, E.C.; Fanning, M.A. Field margin and weed-species diversity in relation to landscape attributes adjacent land use. *Weed Sci.* **2007**, *55*, 129–136. [CrossRef]
18. Lee, C.S.; Cho, Y.C.; Shin, H.C.; Kim, G.S.; Pi, J.H. Control of an invasive alien species, *Ambrosia trifida* with restoration by introducing willows as a typical riparian vegetation. *J. Ecol. Field Biol.* **2010**, *33*, 157–164. [CrossRef]
19. Korres, N.E.; Norsworthy, J.K.; Bagavathiannan, M.V.; Mauromoustakos, A. Distribution of arable weed populations along eastern Arkansas Mississippi delta roadsides: Occurrence, distribution, favored growth habitats. *Weed Technol.* **2015**, *29*, 587–595. [CrossRef]
20. Webster, T.M.; Loux, M.M.; Regnier, E.E.; Harrison, S.K. Giant ragweed (*Ambrosia trifida*) canopy architecture and interference studies in soybean (*Glycine max*). *Weed Technol.* **1994**, *8*, 559–564. [CrossRef]
21. Harrison, S.K.; Regnier, E.E.; Schmoll, J.T.; Webb, J.E. Competition fecundity of giant ragweed in corn. *Weed Sci.* **2001**, *49*, 224–229. [CrossRef]
22. Barnett, K.A.; Steckel, L.E. Giant ragweed (*Ambrosia trifida*) competition in cotton. *Weed Sci.* **2013**, *61*, 543–548. [CrossRef]
23. Gibson, K.D.; Johnson, W.G.; Hillger, D.E. Farmer perceptions of weed problems in corn and soybean rotation systems. *Weed Technol.* **2006**, *20*, 751–755. [CrossRef]
24. Soltani, N.; Geddes, C.; Laforest, M.; Dille, J.A.; Sikkema, P.H. Economic impact of glyphosate-resistant weeds on major field crops grown in Ontario. *Weed Technol.* **2022**, *36*, 629–635. [CrossRef]
25. Wortman, S.E.; Davis, A.S.; Schutte, B.J.; Lindquist, J.L.; Cardina, J.; Felix, J.; Sprague, C.L.; Dille, J.A.; Ramirez, A.H.M.; Reicks, G.; et al. Local conditions, not regional gradients, drive demographic variation of giant ragweed *Ambrosia trifida* common sunflower *Helianthus annuus* across Northern U. S. maize belt. *Weed Sci.* **2012**, *60*, 440–450. [CrossRef]

26. Follak, S.; Dullinger, S.; Kleinbauer, I.; Moser, D.; Essl, F. Invasion dynamics of three allergenic invasive Asteraceae *Ambrosia trifida*, *Artemisia annua*, *Iva xanthiifolia* in central Eastern Europe. *Preslia* **2013**, *85*, 41–61.
27. Brown, K. Response of Giant Ragweed (*Ambrosia trifida*) Source Populations to Varying Soil Moisture Conditions. Undergraduate Research Thesis, Ohio State University, Columbus, OH, USA, 2024; pp. 1–24.
28. Regnier, E.E.; Harrison, S.K.; Loux, M.M.; Holloman, C.; Venkatesh, R.; Diekmann, F.; Taylor, R.; Ford, R.A.; Stoltenberg, D.E.; Hartzler, R.G.; et al. Certified crop advisors' perceptions of giant ragweed (*Ambrosia trifida*) distribution, herbicide resistance, and management in the Corn Belt. *Weed Sci.* **2016**, *64*, 361–377. [\[CrossRef\]](#)
29. Park, H.J.; Hong, M.G.; Kim, J.G. Effects of soil fertility and flooding regime on the growth of *Ambrosia trifida*. *Landsc. Ecol. Eng.* **2020**, *16*, 39–46. [\[CrossRef\]](#)
30. Mun, S.; Lee, E.J. Litter decomposition rate and nutrient dynamics of giant ragweed (*Ambrosia trifida* L.) in the non-native habitat of South Korea. *Plant Soil* **2020**, *449*, 373–388. [\[CrossRef\]](#)
31. Savić, A.; Matzrafi, M.; Durović, S.; Gentili, R.; Citterio, S. Is *Ambrosia trifida* L. preparing for a wider invasion? Changes in the plant morpho-functional traits over a decade. *Agronomy* **2024**, *14*, 1601. [\[CrossRef\]](#)
32. Shimizu, S.; Yamamura, Y.; Yasuda, T.; Nakano, T.; Ikeguchi, H. The effects of human-induced disturbance and environmental conditions on the growth and developments of an exotic annual, *Ambrosia trifida* L. in riverside vegetation. *Jpn. J. Conserv. Ecol.* **2007**, *12*, 36–44.
33. Xian, X.; Zhao, H.; Wang, R.; Huang, H.; Chen, B.; Zhang, G.; Liu, W.; Wan, F. Climate change has increased the global threats posed by three ragweeds (*Ambrosia* L.) in the Anthropocene. *Sci. Total Environ.* **2023**, *859*, 160252. [\[CrossRef\]](#) [\[PubMed\]](#)
34. Chen, S.; Bai, X.; Ye, J.; Chen, W.; Xu, G. Prediction of suitable habitat of alien invasive plant *Ambrosia trifida* in Northeast China under various climatic scenarios. *Diversity* **2024**, *16*, 322. [\[CrossRef\]](#)
35. Bazzaz, F.A.; Carlson, R.W. Photosynthetic contribution of flowers and seeds to reproductive effort of an annual colonizer. *New Phytol.* **1979**, *82*, 223–232. [\[CrossRef\]](#)
36. Goplen, J.J.; Sheaffer, C.C.; Becker, R.L.; Coulter, J.A.; Breitenbach, F.R.; Behnken, L.M.; Johnson, J.A.; Gunsolus, J.L. Giant ragweed (*Ambrosia trifida*) seed production and retention in soybean and field margins. *Weed Technol.* **2016**, *30*, 246–253. [\[CrossRef\]](#)
37. Abul-Fatih, H.A.; Bazzaz, F.A. The biology of *Ambrosia trifida* L. II. Germination, emergence, growth survival. *New Phytol.* **1979**, *83*, 817–827. [\[CrossRef\]](#)
38. Davis, A.S.; Clay, S.; Cardina, J.; Dille, A.; Forcella, F.; Lindquist, J.; Sprague, C. Seed burial physical environment explains departures from regional hydrothermal model of giant ragweed (*Ambrosia trifida*) seedling emergence in U.S. Midwest. *Weed Sci.* **2013**, *61*, 415–421. [\[CrossRef\]](#)
39. Washitani, I.; Nishiyama, S. Effects of seed size seedling emergence time on the fitness components of *Ambrosia trifida* and *A. artemisiaefolia* var. *elatio* in competition with grass perennials. *Plant Species Biol.* **1992**, *7*, 11–19. [\[CrossRef\]](#)
40. Royer, F.; Dickinson, R. *Weeds of Canada and the Northern United States: A Guide for Identification*; University of Alberta: Edmonton, AB, Canada, 1999; pp. 1–470.
41. Sako, Y.; Regnier, E.E.; Daoust, T.; Fujimura, K.; Harrison, S.K.; McDonald, M.B. Computer image analysis and classification of giant ragweed seeds. *Weed Sci.* **2001**, *49*, 738–745. [\[CrossRef\]](#)
42. Regnier, E.; Harrison, S.K.; Liu, J.; Schmoll, J.T.; Edwards, C.A.; Arancon, N.; Holloman, C. Impact of an exotic earthworm on seed dispersal of an indigenous US weed. *J. Appl. Ecol.* **2008**, *45*, 1621–1629. [\[CrossRef\]](#)
43. Harrison, S.K.; Regnier, E.E.; Schmoll, J.T. Postdispersal predation of giant ragweed (*Ambrosia trifida*) seed in no-tillage corn. *Weed Sci.* **2003**, *51*, 955–964. [\[CrossRef\]](#)
44. Willson, M.F.; Harmeson, J.C. Seed preferences and digestive efficiency of cardinals and song sparrows. *Condor* **1973**, *75*, 225–234. [\[CrossRef\]](#)
45. Davis, A.S.; Raghu, S. Weighing abiotic and biotic influences on weed seed predation. *Weed Res.* **2010**, *50*, 402–412. [\[CrossRef\]](#)
46. Harrison, S.K.; Regnier, E.E.; Schmoll, J.T.; Harrison, J.M. Seed size and burial effects on giant ragweed (*Ambrosia trifida*) emergence and seed demise. *Weed Sci.* **2007**, *55*, 16–22. [\[CrossRef\]](#)
47. Schutte, B.J.; Liu, J.; Davis, A.S.; Harrison, S.K.; Regnier, E.E. Environmental factors that influence the association of an earthworm (*Lumbricus terrestris* L.) and an annual weed (*Ambrosia trifida* L.) in no-till agricultural fields across the eastern US Corn Belt. *Agric. Ecosys. Environ.* **2010**, *138*, 197–205. [\[CrossRef\]](#)
48. Dong, H.; Liu, T.; Liu, Z.; Song, Z. Fate of the soil seed bank of giant ragweed and its significance in preventing and controlling its invasion in grasslands. *Ecol. Evol.* **2020**, *10*, 4854–4866. [\[CrossRef\]](#)
49. Ballard, T.O.; Foley, M.E.; Bauman, T.T. Germination, viability, and protein changes during cold stratification of giant ragweed (*Ambrosia trifida* L.) seed. *J. Plant Physiol.* **1996**, *149*, 229–232. [\[CrossRef\]](#)
50. Davis, W.E. Primary dormancy, after-ripening, the development of secondary dormancy in embryos of *Ambrosia trifida*. *Am. J. Bot.* **1930**, *171*, 58–76. [\[CrossRef\]](#)
51. Schutte, B.J.; Regnier, E.E.; Harrison, S.K. The association between seed size seed longevity among maternal families in *Ambrosia trifida* L. populations. *Seed Sci. Res.* **2008**, *18*, 201–211. [\[CrossRef\]](#)
52. Schutte, B.J.; Regnier, E.E.; Harrison, S.K. Seed dormancy adaptive seedling emergence timing in giant ragweed *Ambrosia trifida*. *Weed Sci.* **2012**, *60*, 19–26. [\[CrossRef\]](#)
53. Ruziev, F.; Park, I.K.; Umurzokov, M.; Khaitov, B.; Bo, A.B.; Jia, W.Q.; Hien, L.T.; Choi, J.S.; Park, K.W. Seed germination ecology of giant ragweed (*Ambrosia trifida*) in Korea. *Weed Turf. Sci.* **2020**, *9*, 21–28.

54. Page, E.R.; Nurse, R.E. Cropping systems and the prevalence of giant ragweed (*Ambrosia trifida*): From the 1950's to present. *Field Crops Res.* **2015**, *184*, 104–111. [[CrossRef](#)]
55. Abul-Fatih, H.A.; Bazzaz, F.A.; Hunt, R. The biology of *Ambrosia trifida* L. III. Growth biomass allocation. *New Phytol.* **1979**, *83*, 829–838. [[CrossRef](#)]
56. Zhao, W.; Liu, T.; Liu, Y.; Wang, H.; Wang, R.; Ma, Q.; Dong, J.; Bi, X. The significance of biomass allocation to population growth of the invasive species *Ambrosia artemisiifolia* and *Ambrosia trifida* with different densities. *BMC Ecol. Evol.* **2021**, *21*, 175. [[CrossRef](#)]
57. Jurik, T.W. Population distributions of plant size and light environment of giant ragweed (*Ambrosia trifida* L.) at three densities. *Oecologia* **1991**, *87*, 539–550. [[CrossRef](#)] [[PubMed](#)]
58. Abul-Fatih, H.A.; Bazzaz, F.A. The biology of *Ambrosia trifida* L. IV. Demography of plant leaves. *New Phytol.* **1980**, *84*, 107–111. [[CrossRef](#)]
59. Wang, R.; Sun, B.; Li, J.D.; Wang, G.J.; Sun, J.N.; Wang, X.R.; Zhong, R.T. Effects of light intensity on the phenotypic plasticity of invasive species *Ambrosia trifida*. *Ying Yong Sheng Tai Xue Bao = J. Appl. Ecol.* **2012**, *23*, 1797–1802.
60. Chu, C.J.; Maestre, F.T.; Xiao, S.; Weiner, J.; Wang, Y.S.; Duan, Z.H.; Wang, G. Balance between facilitation and resource competition determines biomass-density relationships in plant populations. *Ecol. Lett.* **2008**, *11*, 1189–1197. [[CrossRef](#)]
61. Bo, Q.; Xue, C.Y.; Xu, Y.F.; Gao, Y.M.; Xian, C.X.; Wang, W.J. Effects of *Ambrosia trifida* on the early spring plant community in abandoned farmland. *J. Shenyang Agric. Univ.* **2019**, *50*, 358–364.
62. Hovick, S.M.; McArdle, A.; Harrison, S.K.; Regnier, E.E. A mosaic of phenotypic variation in giant ragweed (*Ambrosia trifida*): Local-and continental-scale patterns in a range-expanding agricultural weed. *Evol. Appl.* **2018**, *11*, 995–1009. [[CrossRef](#)]
63. Lockwood, J.L.; Cassey, P.; Blackburn, T. The role of propagule pressure in explaining species invasions. *Trend Ecol. Evol.* **2005**, *20*, 223–228. [[CrossRef](#)]
64. Simberloff, D. The role of propagule pressure in biological invasions. *Annu. Rev. Ecol. Evol. Syst.* **2009**, *40*, 81–102. [[CrossRef](#)]
65. Mitchell, C.E.; Power, A.G. Release of invasive plants from fungal and viral pathogens. *Nature* **2003**, *421*, 625–627. [[CrossRef](#)]
66. Miyatake, T.; Ohno, T. Seasonal abundance of exotic leaf beetle *Ophraella communa* LeSage (Coleoptera: Chrysomelidae) on two different host plants. *Appl. Entomol. Zool.* **2010**, *45*, 283–288. [[CrossRef](#)]
67. Fukano, Y.; Doi, H. Population abundance host use pattern of *Ophraella communa* (Coleoptera: Chrysomelidae) in its native and introduced range. *Biocontrol Sci. Technol.* **2013**, *23*, 595–601. [[CrossRef](#)]
68. Bernays, E.A.; Funk, D.J. Specialists make faster decisions than generalists: Experiments with aphids. *Proc. R. Soc. Lond. B. Biol. Sci.* **1999**, *266*, 151–156. [[CrossRef](#)]
69. Vitolo, D.B.; Stiles, E.W. The effect of density of *Ambrosia trifida* L. on seed predation *Euaresta festiva* (Loew) (Diptera: Tephritidae). *J. N. Y. Entomol. Soc.* **1987**, *95*, 491–494.
70. Kato-Noguchi, H. Involvement of allelopathy in the invasive potential of *Tithonia diversifolia*. *Plants* **2020**, *9*, 766. [[CrossRef](#)] [[PubMed](#)]
71. Kato-Noguchi, H.; Kurniadie, D. Allelopathy and allelochemicals of *Leucaena leucocephala* as an invasive plant species. *Plants* **2022**, *11*, 1672. [[CrossRef](#)] [[PubMed](#)]
72. Kato-Noguchi, H.; Kurniadie, D. Allelopathy of *Lantana camara* as an invasive plant. *Plants* **2021**, *10*, 1028. [[CrossRef](#)]
73. Kato-Noguchi, H. Allelopathy of knotweeds as invasive plants. *Plants* **2022**, *11*, 3. [[CrossRef](#)]
74. Rice, E.L. *Allelopathy*, 2nd ed.; Academic Press: Orlando, FL, USA, 1984; pp. 1–422.
75. Bonanomi, G.; Sicurezza, M.G.; Caporaso, S.; Esposito, A.; Mazzoleni, S. Phytotoxicity dynamics of decaying plant materials. *New Phytol.* **2006**, *169*, 571–578. [[CrossRef](#)] [[PubMed](#)]
76. Belz, R.G. Allelopathy in crop/weed interactions—An update. *Pest Manag. Sci.* **2007**, *63*, 308–326. [[CrossRef](#)]
77. Kato-Noguchi, H. Defensive molecules momilactones A and B: Function, biosynthesis, induction and occurrence. *Toxins* **2023**, *15*, 241. [[CrossRef](#)]
78. Bais, H.P.; Weir, T.L.; Perry, L.G.; Gilroy, S.; Vivanco, J.M. The role of root exudates in rhizosphere interactions with plants and other organisms. *Annu. Rev. Plant Biol.* **2006**, *57*, 233–266. [[CrossRef](#)] [[PubMed](#)]
79. Kato-Noguchi, H. Allelopathy and allelochemicals of *Imperata cylindrica* as an invasive plant species. *Plants* **2022**, *11*, 2551. [[CrossRef](#)] [[PubMed](#)]
80. Kato-Noguchi, H. The impact and invasive mechanisms of *Pueraria montana* var. *lobata*, one of the world's worst alien species. *Plants* **2023**, *12*, 3066.
81. Kato-Noguchi, H. Isolation and identification of allelochemicals and their activities and functions. *J. Pestic. Sci.* **2024**, *49*, 1–14. [[CrossRef](#)]
82. Cappuccino, N.; Arnason, J.T. Novel chemistry of invasive exotic plants. *Biol. Lett.* **2006**, *2*, 189–193. [[CrossRef](#)]
83. Kato-Noguchi, H.; Kato, M. Allelopathy and allelochemicals of *Solidago canadensis* L. and *S. altissima* L. for their naturalization. *Plants* **2022**, *11*, 3235. [[CrossRef](#)]
84. Kato-Noguchi, H. Invasive mechanisms of one of the world's worst alien plant species *Mimosa pigra* and its management. *Plants* **2023**, *12*, 1960. [[CrossRef](#)]
85. Kato-Noguchi, H.; Kurniadie, D. The invasive mechanisms of the noxious alien plant species *Bidens pilosa*. *Plants* **2024**, *13*, 356. [[CrossRef](#)] [[PubMed](#)]
86. Kil, J.H.; Shim, K.C.; Park, K.A.; Kim, K. Inhibitory effects of *Ambrosia trifida* L. on the development of root hairs and protein patterns of radicles. *World Acad. Sci. Eng. Technol. Int. J. Environ. Ecol. Eng.* **2014**, *8*, 608–611.

87. Wang, D.I.; Zhu, X.Z. Allelopathic research of *Ambrosia trifida*. *Acta Phytoecol. Sinica* **1996**, *20*, 330–337.
88. Kong, C.H.; Wang, P.; Xu, X.H. Allelopathic interference of *Ambrosia trifida* with wheat (*Triticum aestivum*). *Agric. Ecosyst. Environ.* **2007**, *119*, 416–420. [[CrossRef](#)]
89. Li, H.; Kang, Z.; Hua, J.; Feng, Y.; Luo, S. Root exudate sesquiterpenoids from the invasive weed *Ambrosia trifida* regulate rhizospheric Proteobacteria. *Sci. Total Environ.* **2022**, *834*, 155263. [[CrossRef](#)] [[PubMed](#)]
90. Dalton, B.R. The occurrence and behavior of plant phenolic acids in soil environments and their potential involvement in allelochemical interference interactions: Methodological limitations in establishing conclusive proof of allelopathy. In *Principals and Practices in Plant Ecology: Allelochemical Interactions*; Inderjit, Dakshini, K.M.M., Foy, C.L., Eds.; CRC Press: Boca Raton, FL, USA, 1999; pp. 57–74.
91. Inderjit. Plant phenolics in allelopathy. *Bot. Rev.* **1996**, *62*, 186–202. [[CrossRef](#)]
92. Einhellig, F.A. Mode of action of allelochemical action of phenolic compounds. In *Chemistry and Mode of Action of Allelochemicals*; Macías, F.A., Galindo, J.C.G., Molino, J.M.G., Cutler, H.G., Eds.; CRC Press: Boca Raton, FL, USA, 2004; pp. 217–238.
93. Li, Z.H.; Wang, Q.; Ruan, X.; Pan, C.D.; Jiang, D.A. Phenolics and plant allelopathy. *Molecules* **2010**, *15*, 8933–8952. [[CrossRef](#)]
94. Kato-Noguchi, H.; Kato, M. Evolution of the secondary metabolites in invasive plant species *Chromolaena odorata* for the defense and allelopathic functions. *Plants* **2023**, *12*, 521. [[CrossRef](#)]
95. Su, P.; Liu, X.; Wang, R.; Liu, T.; Zhao, W.; Sun, M.; Wang, H.; Liu, Y.; Wu, Q. Autotoxicity of *Ambrosia artemisiifolia* and *Ambrosia trifida* and its significance for the regulation of intraspecific populations density. *Sci. Rep.* **2022**, *12*, 17424. [[CrossRef](#)]
96. Wang, P.; Liang, W.; Kong, C.; Jiang, Y. Allelopathic potential of volatile allelochemicals of *Ambrosia trifida* L. on other plants. *Allelopathy J.* **2005**, *15*, 131–136.
97. Wang, P.; Kong, C.H.; Zhang, C.X. Chemical composition and antimicrobial activity of the essential oil from *Ambrosia trifida* L. *Molecules* **2007**, *11*, 549–555. [[CrossRef](#)]
98. Sarić-Krsmanović, M.; Umiljendić, J.G.; Radivojević, L.; Rajković, M.; Šantrić, L.; Đurović-Pejčev, R. Chemical composition of *Ambrosia trifida* essential oil and phytotoxic effect on other plants. *Chem. Biodivers.* **2000**, *17*, e1900508. [[CrossRef](#)]
99. Xu, K.; Liu, X.; Zhao, C.; Pan, Q.; Chen, X.; Jiang, N.; Du, C.; Xu, Y.; Shao, M.; Qu, B. Nitrogen deposition further increases *Ambrosia trifida* root exudate invasiveness under global warming. *Environ. Monit. Assess.* **2023**, *195*, 759. [[CrossRef](#)]
100. Morales, M.; Munné-Bosch, S. Malondialdehyde: Facts and artifacts. *Plant Physiol.* **2019**, *180*, 1246–1250. [[CrossRef](#)] [[PubMed](#)]
101. Perry, J.J.P.; Shin, D.S.; Getzoff, E.D.; Tainer, J.A. The structural biochemistry of the superoxide dismutases. *Biochim. Biophys. Acta* **2010**, *1804*, 245–262. [[CrossRef](#)] [[PubMed](#)]
102. Miao, L.; Clair, D.K.S. Regulation of superoxide dismutase genes: Implications in disease. *Free Radic. Biol. Med.* **2009**, *47*, 344–356. [[CrossRef](#)] [[PubMed](#)]
103. Heck, D.E.; Shakarjian, M.; Kim, H.D.; Laskin, J.D.; Vetrano, A.M. Mechanisms of oxidant generation by catalase. *Ann N. Y. Acad. Sci.* **2010**, *1203*, 120–125. [[CrossRef](#)] [[PubMed](#)]
104. Arora, A.; Sairam, R.K.; Srivastava, G.C. Oxidative stress and antioxidative system in plants. *Curr. Sci.* **2002**, *82*, 1227–1238.
105. Demidchik, V. Mechanisms of oxidative stress in plants: From classical chemistry to cell biology. *Environ. Exp. Bot.* **2015**, *109*, 212–228. [[CrossRef](#)]
106. Gniazdowska, A.; Krasuska, U.; Andrzejczak, O.; Soltys, D. Allelopathic compounds as oxidative stress agents: YES or NO. In *Reactive Oxygen and Nitrogen Species Signaling and Communication in Plants*; Gupta, K.J., Igamberdiev, A.U., Eds.; Springer: Berlin, Germany, 2015; pp. 155–176.
107. Šoln, K.; Klemenčič, M.; Koce, J.D. Plant cell responses to allelopathy: From oxidative stress to programmed cell death. *Protoplasma* **2022**, *259*, 1111–1124. [[CrossRef](#)]
108. Kato-Noguchi, H.; Kato, M. Defense molecules of the invasive plant species *Ageratum conyzoides*. *Molecules* **2024**, *29*, 4673. [[CrossRef](#)]
109. Šučur, J.; Konstantinović, B.; Crnković, M.; Bursić, V.; Samardžić, N.; Malenčić, Đ.; Prvulović, D.; Popov, M.; Vuković, G. Chemical composition of *Ambrosia trifida* L. and its allelopathic influence on crops. *Plants* **2021**, *10*, 2222. [[CrossRef](#)]
110. Halsted, B.D. Our worst weeds. *Bot. Gaz.* **1889**, *14*, 69–71. [[CrossRef](#)]
111. Williams, M.M. Biological significance of low weed population densities on sweet corn. *Agron. J.* **2010**, *102*, 464–468. [[CrossRef](#)]
112. Baysinger, J.A.; Sims, B.D. Giant ragweed (*Ambrosia trifida*) interference in soybeans (*Glycine max*). *Weed Sci.* **1991**, *39*, 358–362. [[CrossRef](#)]
113. Werle, R.; Sandell, L.D.; Buhler, D.D.; Hartzler, R.G.; Lindquist, J. Predicting emergence of 23 summer annual weed species. *Weed Sci.* **2014**, *62*, 267–279. [[CrossRef](#)]
114. Kaur, S.; Sandell, L.D.; Lindquist, J.L.; Jhala, A.J. Glyphosateresistant giant ragweed (*Ambrosia trifida*) control in glufosinate-resistant soybean. *Weed Technol.* **2014**, *28*, 569–577. [[CrossRef](#)]
115. Wang, W.B.; Gao, F.F.; Feng, W.W.; Wu, Q.Y.; Feng, Y.L. The native stem holoparasitic *Cuscuta japonica* suppresses the invasive plant *Ambrosia trifida* and related mechanisms in different light conditions in northeast China. *Front. Plant Sci.* **2022**, *13*, 904326. [[CrossRef](#)]
116. Batra, S.W.T. *Puccinia xanthii* forma specialis ambrosid-trifidiae. A microcyclic rust for the biological control of giant ragweed, *Ambrosia trifida* (Compositae). *Mycopathologia* **1981**, *72*, 61–64. [[CrossRef](#)]

117. Goplen, J.J.; Sheaffer, C.C.; Becker, R.L.; Coulter, J.A.; Breitenbach, F.R.; Behnken, L.M.; Johnson, G.A.; Gunsolus, J.L. Giant ragweed emergence pattern influenced by spring tillage timing in Minnesota. *Crop Forage Turfgrass Manag.* **2018**, *4*, 1800025. [CrossRef]
118. Byun, C.; Choi, H.; Kang, H. Effects of cutting and sowing seeds of native species on giant ragweed invasion and plant diversity in a field experiment. *J. Ecol. Environ.* **2020**, *44*, 1–8. [CrossRef]
119. Byun, C. Role of priority effects in invasive plant species management: Early arrival of native seeds guarantees the containment of invasion by Giant ragweed. *Ecol. Evol.* **2023**, *13*, e9940. [CrossRef]
120. Byun, C.; Singh, K.; Hong, S.H.; Lee, J.; Yoon, T.K.; Kang, H. Uprooting is a promising tool to control invasive giant ragweed and recover native diversity. *NeoBiota* **2024**, *94*, 311–331. [CrossRef]
121. Liebman, M.; Nichols, V.A. Cropping system redesign for improved weed management: A modeling approach illustrated with giant ragweed (*Ambrosia trifida*). *Agronomy* **2020**, *10*, 262. [CrossRef]
122. Goplen, J.J.; Sheaffer, C.C.; Becker, R.L.; Moon, R.D.; Coulter, J.A.; Breitenbach, F.R.; Behnken, L.M.; Gunsolus, J.L. Giant ragweed (*Ambrosia trifida*) emergence model performance evaluated in diverse cropping systems. *Weed Sci.* **2018**, *66*, 36–46. [CrossRef]
123. Patzoldt, W.L.; Tranel, P.J. Molecular analysis of cloransulam resistance in a population of giant ragweed. *Weed Sci.* **2002**, *50*, 299–305. [CrossRef]
124. Brabham, C.B.; Gerber, C.K.; Johnson, W.G. Fate of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in the presence absence of glyphosate. *Weed Sci.* **2011**, *59*, 506–511. [CrossRef]
125. International Herbicide Resistant Weed Database. Available online: <https://www.weedscience.org/Pages/Species.aspx> (accessed on 12 September 2024).
126. Sikkema, P.; Soltani, N.; Shropshire, C.; Smith, P.; Lawton, M.; Tardif, F. Suspected glyphosate-resistant giant ragweed in Ontario. *Proc. North Cent. Weed Sci. Soc.* **2009**, *64*, 167.
127. Van Horn, C.R.; Moretti, M.L.; Robertson, R.R.; Segobye, K.; Weller, S.C.; Young, B.G.; Johnson, W.G.; Schulz, B.; Green, A.C.; Jeffery, T.; et al. Glyphosate resistance in *Ambrosia trifida*: Part 1. Novel rapid cell death response to glyphosate. *Pest Manag. Sci.* **2018**, *74*, 1071–1078. [CrossRef] [PubMed]
128. Moretti, M.L.; Van Horn, C.R.; Robertson, R.; Segobye, K.; Weller, S.C.; Young, B.G.; Johnson, W.G.; Sammons, R.D.; Wang, D.; Ge, X.; et al. Glyphosate resistance in *Ambrosia trifida*: Part 2. Rapid response physiology and non-target-site resistance. *Pest Manag. Sci.* **2018**, *74*, 1079–1088. [CrossRef]
129. Wilson, C.E.; Takano, H.K.; Van Horn, C.R.; Yerka, M.K.; Westra, P.; Stoltenberg, D.E. Physiological and molecular analysis of glyphosate resistance in non-rapid response *Ambrosia trifida* from Wisconsin. *Pest Manag. Sci.* **2020**, *76*, 150–160. [CrossRef]
130. Page, E.R.; Martin, S.; Meloche, S.; Thibodeau, A.; Nurse, R.E.; Sikkema, P.H.; Tardif, F.J.; Cowbrough, M.J.; Laforest, M. Revisiting the origins of glyphosate-resistant giant ragweed (*Ambrosia trifida* L.) in Canada. *Can. J. Plant Sci.* **2024**, *104*, 124–128. [CrossRef]
131. Faleco, F.A.; Machado, F.M.; Bobadilla, L.K.; Tranel, P.J.; Stoltenberg, D.; Werle, R. Resistance to protoporphyrinogen oxidase inhibitors in giant ragweed (*Ambrosia trifida*). *Pest Manag. Sci.* **2024**, *80*, 6211–6221. [CrossRef]
132. Johal, G.S. Effect of soilborne plant-pathogenic fungi on the herbicidal action of glyphosate on bean seedlings. *Phytopathology* **1984**, *74*, 950–955. [CrossRef]
133. Lévesque, A.C.; Rahe, J.E. Herbicide interaction with fungal root pathogens, with special reference to glyphosate. *Annu. Rev. Phytopathol.* **1992**, *30*, 579–602. [CrossRef] [PubMed]
134. Schafer, J.R.; Hallett, S.G.; Johnson, W.G. Response of giant ragweed (*Ambrosia trifida*), horseweed (*Conyza canadensis*), and common lambsquarters (*Chenopodium album*) biotypes to glyphosate in the presence and absence of soil microorganisms. *Weed Sci.* **2012**, *60*, 641–649. [CrossRef]
135. Schafer, J.R.; Hallett, S.G.; Johnson, W.G. Soil microbial root colonization of glyphosate-treated giant ragweed (*Ambrosia trifida*), horseweed (*Conyza canadensis*), and common lambsquarters (*Chenopodium album*) biotypes. *Weed Sci.* **2013**, *61*, 289–295. [CrossRef]
136. Schafer, J.R.; Hallett, S.G.; Johnson, W.G. Rhizosphere microbial community dynamics in glyphosate-treated susceptible and resistant biotypes of giant ragweed (*Ambrosia trifida*). *Weed Sci.* **2014**, *62*, 370–381. [CrossRef]
137. Taylor, J.B.; Loux, M.M.; Harrison, S.K.; Regnier, E. Response of ALS-resistant common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*) to ALS-inhibiting and alternative herbicides. *Weed Technol.* **2002**, *16*, 815–825. [CrossRef]
138. Marion, S.M.; Davis, V.M.; Stoltenberg, D.E. Characterization of Wisconsin giant ragweed (*Ambrosia trifida*) resistant to cloransulam. *Weed Sci.* **2017**, *65*, 41–51. [CrossRef]
139. Jordan, T.N. Weed survey of the north central weed control conference. *North Cent. Weed Control Conf. Res. Rep.* **1985**, *42*, 344–355.
140. Loux, M.M.; Berry, M.A. Use of a grower survey for estimating weed problems. *Weed Technol.* **1991**, *5*, 460–466. [CrossRef]
141. Fickett, N.D.; Boerboom, C.M.; Stoltenberg, D.E. Predicted corn yield loss due to weed competition prior to postemergence herbicide application on Wisconsin farms. *Weed Technol.* **2013**, *27*, 54–62. [CrossRef]
142. Fickett, N.D.; Boerboom, C.M.; Stoltenberg, D. E Soybean yield loss potential associated with early-season weed competition across 64 site-years. *Weed Sci.* **2013**, *61*, 500–507. [CrossRef]
143. Esposito, M.; Crimaldi, M.; Cirillo, V.; Sarghini, F.; Maggio, A. Drone and sensor technology for sustainable weed management: A review. *Chem. Biol. Technol. Agric.* **2021**, *8*, 18. [CrossRef]
144. Gerhards, R.; Sanchez, D.A.; Hamouz, P.; Peteinatos, G.G.; Christensen, S.; Fernandez-Quintanilla, C. Advances in site-specific weed management in agriculture: A review. *Weed Res.* **2022**, *62*, 123–133. [CrossRef]

145. Korres, N.E.; Burgos, N.R.; Travlos, I.; Vurro, M.; Gitsopoulos, T.K.; Varanasi, V.K.; Duke, S.O.; Kudsk, P.; Brabham, C.; Rouse, C.E.; et al. Chapter six—New directions for integrated weed management: Modern technologies, tools, and knowledge discovery. *Adv. Agron.* **2019**, *155*, 243–319.
146. Monteiro, A.; Santos, S. Sustainable approach to weed management: The role of precision weed management. *Agronomy* **2022**, *12*, 118. [\[CrossRef\]](#)
147. 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.P.; Burgos, N.R.; et al. Reducing the risks of herbicide resistance: Best management practices and recommendations. *Weed Sci.* **2012**, *60*, 31–62. [\[CrossRef\]](#)
148. Sharma, G.; Shrestha, S.; Kunwar, S.; Tseng, T. Crop diversification for improved weed management: A review. *Agriculture* **2021**, *11*, 461. [\[CrossRef\]](#)
149. Westwood, J.H.; Charudattan, R.; Duke, S.O.; Fennimore, S.A.; Marrone, P.; Slaughter, D.C.; Swanton, C.; Zollinger, R. Weed management in 2050: Perspectives on the future of weed science. *Weed Sci.* **2018**, *66*, 275–285. [\[CrossRef\]](#)
150. Zhang, W.; Miao, Z.; Li, N.; He, C.; Sun, T. Review of current robotic approaches for precision weed management. *Curr. Robot. Rep.* **2022**, *3*, 139–151. [\[CrossRef\]](#)
151. Wang, D.; Feng, Y.L.; Liu, M.C.; Qu, B. Effects of *Ambrosia trifida* invasion on vegetation succession and soil nutrients in the enclosed riparian ecosystems—a case study of Liaohe River main stream. *J. Shenyang Agric. Univ.* **2022**, *53*, 520–531.
152. Washitani, I. Plant conservation ecology for management and restoration of riparian habitats of lowland Japan. *Popul. Ecol.* **2001**, *433*, 189–195. [\[CrossRef\]](#)
153. Wang, H.; Liu, T.; Dong, H.; Zhao, W.; Liu, X.; Wang, R.; Xu, W. Changes in the composition of the soil seed bank of grassland after giant ragweed (*Ambrosia trifida* L.) invasion. *J. Environ. Manag.* **2022**, *317*, 115468. [\[CrossRef\]](#) [\[PubMed\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.