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A Review on the Biological Control of Common Ragweed, Ambrosia *artemisiifolia* (Asteraceae)

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Abstract

Common ragweed (*Ambrosia artemisiifolia*) is an annual in the Asteraceae that is broadly distributed in most temperate regions of the world. Since it is both extremely competitive and has allergenic pollens, common ragweed presents problems to agricultural production and public health. Currently, over 450 species of natural enemies of ragweed have been discovered, among which the leaf beetle *Zygogramma suturalis* (Chrysomelidae) and the moth *Epiblema strenuana* (Tortricidae)have been the two most effective species for ragweed suppression. In addition, in China outstanding control has been provided by the leaf beetle *Ophraella communa*. The complementary use of *O. communa* and *E. strenuana* has also been tested in southern China to good effect on *A. artemisiifolia*. In addition, several pathogens have been considered as potential biological control agents of common ragweed. This paper mainly introduces common ragweed, considers its negative effects, and reviews the history and current achievements of common ragweed biological control.

Keywords: Common Ragweed; *Ambrosia Artemisiifolia*; Biological Control; *Zygogramma Suturalis*; *Epiblema Strenuana*; *Ophraella Communa*

Introduction

Common ragweed (*Ambrosia artemisiifolia*) is an invasive North American plant that has spread across most temperate regions of the world since the mid-19th century, especially in recent decades when it was facilitated by socio-economic factors. Currently, common ragweed can been found in Europe, Asia, Africa, South America and Oceania. In the 1930s, ragweed spread to the southeast coast of China, and the earliest ragweed specimens were collected in Hangzhou (Zhejiang, Province) in 1935 [1]. Since common ragweed has escaped from biotic factors (e.g., natural enemies) in its new range, its population has expanded rapidly and it has caused significant damage in China. In 1997, ragweed was classified in China as one of three most dangerous weeds, at which time it was widely distributed in 21 provinces in China [2].

Common ragweed is an annual herbaceous member of the Asteraceae that is extremely competitive and can quickly invade both agricultural and urban areas. In recent decades, more attention has been given to common ragweed in China because it can lower crop yields, and its pollen is a potent human allergen. While a range of physical and chemical controls have been employed against common ragweed, biological control provides a new approach for the control of common ragweed, and biological control has been found to be among the most effective and sustainable methods [3]. Biological control of common ragweed began in the 1960s [4], and in the ensuing decades many natural enemies have been discovered [5,6] and biological control of common ragweed has entered a new stage. Here, we review the biology of common ragweed, its effects on agricultural production and public health, and management tactics for control of common ragweed, especially biological control in worldwide.

Biology and Negative Impacts of Common Ragweed

Common ragweed seeds germinate in spring, grow from May to August, and flower from August to October [7,8]. Common ragweed produces thousands of seeds per plant, and these seeds can remain dormant in the soil for long periods. One common ragweed plant can produce 3,000-62,000 seeds, and some seeds (4%) can remain viable underground for 39 years [9,10]. Consequently, common ragweed can produce a large seed bank in the soil. Fumanal, et al. [11] reported that the total soil seed bank (to a depth of 20 cm) ranged from 250 to 5,000 seeds/m2 while the top 5 cm of soil held 200-2,800 seeds/m2 seeds.

In central and eastern Europe, common ragweed is a dominant weed in cultivated fields [12]. Common ragweed at densities of 5 and 10 plants m-2 reduced sunflower yields 21% and 30%, respectively, and that of maize by almost 30% at both densities [13]. Compared to a weed-free condition, common ragweed caused losses of 50-70% of sugar yield in sugar beet [14]. When the ragweed population is high, yield loss in soybean can reach 75% [12], and 80% in maize [15]. Common ragweed is also a serious risk to human health, whose pollen is one of the most potent human allergens in the world [16]. Its pollen is responsible for hay fever, asthma and hypersensitivity dermatitis. Whether in its native or introduced range, common ragweed pollen poses a threat to human health. In most areas of the USA and Canada, common ragweed pollen has become the second most common cause of asthma and rhinitis [17,18]. In Europe, the proportion of people sensitive to common ragweed pollen is 10% generally [19], and 60% in Hungary in particular [20].

Biological Control of Common Ragweed

Classical biological control is considered to be an effective method to control invasive plants by introducing phytophagous natural enemies from their native region. According to the Enemy Escape Release Hypothesis [21], introduced plants become invasive because of escape from their usual herbivores or pathogens in newly invaded areas.

Attempts to achieve biological control of common ragweed began in the 1960s, when many invaded countries began to search for effective common ragweed natural enemies in North America. In its original range, common ragweed is attacked by various invertebrate herbivores, such as *Zygogramma suturalis* F. and some polyphagous consumers including beetles, moths and bugs [22]. While most of these insects feed on common ragweed leaves, the plant is also attacked by stem-galling moths in the genus Epiblemaand seed predators such as ground beetles (*Harpalus spp*: Carabidae) and snails (*Trichia striolata*: Hygromiidae) [23]. The eriophyid gall mite *Aceria artemisiifoliae sp.nov*. (Acari: Eriophyoidea) is a potential biological control candidate of common ragweed in Serbia, due to its narrow host range and ability to prevent male flower development, thereby reducing pollen production [24]. Farr, et al. found more than 25 fungal pathogens with impacts on common ragweed [25]. While some 450 species of insects, mites, or fungi are known from species of plants in the genus *Ambrosia* [26], most are polyphagous species that cause little impact on common ragweed. For use as biocontrol agents, specialized agents are required, such as *Z. suturalis* and *E. strenuana*, and it is such specialized agents that are most likely to be successful.

Zygogramma Suturalis

The leaf beetle *Z. suturalis* (Coleoptera: Chrysomelidae) is a monophagous natural enemy native to North America. This leaf beetle is known only to feed on common ragweed and perennial ragweed (*Ambrosia psilostachya* Decandolle) [27]. Wan, et al. [28] conducted a host selection test in the laboratory, and found that among 72 plants species including major cash crops, grain crops, ornamental plant and species closely related to ragweed, *Z. suturalis* only fed on common ragweed. In no-choice feeding tests, both adults and larvae fed exclusively on common ragweed among 126 species [29]. Under laboratory conditions, females, males live on average 82.5 and 67.8 days, respectively, at 26°C. Female *Z. suturalis* beetles have a lifetime fecundity of 394.5 eggs, and eggs can hatch from 28 to 32°C. The optimum temperature for development of *Z. suturalis* immature stagesis 24-28°C [30]. In Ohio, *Z. suturalis* underwent two generations each year and 2-3 generations in the Soviet Union [27]. In China, the beetle undergoes three generations in Beijing and Dandong, but only two generations a year in Hunan province [4]. In addition, *Z. suturalis* adults has a strong tolerance for starvation and low temperatures. Females of *Z. suturalis* feed on undamaged ragweed plants but lay their eggs on other nearby ragweed plants [31]. Under natural conditions, ovipositing females tend to leave damaged common ragweed plants for less damaged plants [31]. If the common ragweed population suffered at an extremely high level, female *Z. suturalis* are unable to find intact common ragweed plants on which to oviposit, resulting in the females entering reproductive diapause during the summer [31].

The former Soviet Union imported *Z. suturalis* from North America in 1978 and the species was established successfully in the northern Caucasus Mountains [32]. In the Caucasus Mountains, *Z. suturalis* suppressed common ragweed populations at release sites and nearby locations between 1983 and 1985 [33]. The density of the beetle *Z. suturalis* in the Caucasus Mts. at the height of its abundance in this region reached 5,000 individuals per m2 in farmland in south USSR and destroying all ragweed completely, resulting in a two to three fold increase in crop production [26]. In addition, *Z. suturalis* also significantly reduced the density of common ragweed seeds in the soil surface, from 24,000/ m^2 in 1980 to 35/m^2 in 1985 [34]. Further investigation has shown that *Z. suturalis* population density remains at a low level in fields after this wave of near complete defoliation of the host plant. In 2005 and 2006, found to be 0.001 adults of *Z. suturalis* per m^2 in fields of rotated crops and 0.1 adult per m^2 in more stable habitats; consequently the impact on common ragweed was considered negligible [33]. Overall, the introduction of *Z. suturalis* was considered as a moderate success. The former USSR republics of Kazakhstan, Georgia, and Ukraine also released *Z. suturalis* in 1978, but *Z. suturalis* only established in Kazakhstan [32]. In the early 1980s, Croatia (then part of the former Yugoslavia) introduced Z. suturalisfrom the USA and released it near Bjelovar, Zagreb, et al. [29]. In 1988, establishment was confirmed in Zagreb and Zadar and the common ragweed population was suppressed to a certain extent. However, in autumn of 1991, the beetle population decreased drastically and lost its control of common ragweed [29]. Over the same period, Australia and Hungary also introduced this beetle but it failed to establish [32,35].

In view of the success of *Z. suturalis* in Russia, China introduced this leaf beetle from Canada and former Soviet Union in 1987 [28]. After a series of biology, ecology and host specificity studies of *Z. suturalis*, 30,000 individuals were released in Beijing and three cities in Liaoning province (Shenyang, Tieling, Dandong) from 1988 to 1991. As in Russia, the *Z. suturalis* population initially developed quickly, established, and partly suppressed the pest [36]. However, the leaf beetle proved unable to adapt to the climatic conditions in this part of China and its population disappeared [36]. The major reason for the failure of application of *Z. suturalis* may be related to its oviposition strategy, which causes *Z. suturalis* to remain at a low density in field [31,37]. In addition, its weak searching and spreading ability limits *Z. suturalis* population reproduction and its control effect [38].

Epiblema Strenuana Walker

Epiblema strenuana (Lepidoptera: Tortricidae) is an effective biological control agent against common ragweed and Parthenium hysterophorus [39]. Females scatter eggs host plant foliage and, larvae emerge in 3-5 days and feed on leaves [40]. After a few days, larvae bore into the stem at a growing point, typically at the axil and top buds. As the larvae continue to feed, forming a stem gall [40]. Larvae pupate inside the gall and then emerge through a portion of the stem that has been eaten to a thin-walled emergence window before pupation. Newly emerged adults can mate immediately [40]. *E. strenuana* adults have high dispersal ability and can fly over 20 kilometers with the wind, giving them an annual dispersal rate of as much as 160 kilometers [41]. *E. strenuana* developmental periods are egg (4 days), larvae + pupa (28-30 days), and adult (7-11 days) at 22-30°C [41]. There are six generations per year in Australia [41] and 2-3 generations in Mexico [42]. In China, 2-3 generations occurred in Beijing, two generations occurred in Dandong (Liaoning procinve) and 4-5 generations were found in Hunan province [30]. Mature larvae overwinter in the stem of the host plant in diapause.

Five plant species are most commonly used by *E. strenuana*: common ragweed, *Ambrosia trifida*, *Ambrosia psilostachya*, *Parthenium hysterop*horus, and *Xanthium sp*. In addition, *E. strenuana* occasionally feeds on *Siegesbeckia orientalis* and *Artemisia annua*. However, in the presence of common ragweed and *P. hysterophorus*, *S. orientalis* and *A. annua* are generally free from damage [39]. Under no-choice conditions, *E. strenuana* can feed and develop on *Bidens pilosa*, *Rsdbeckia hirta*, *Tagetes erecta*, *Tagetes patula* and *Parthenium confertum*, and can also oviposit and feed on *Guizotia abyssinica* [43]. In Mexico, 14 economically important species of composite plants, including species of Helianthus, were examined in host range tests. Among these plants, *E. strenuana* was only able to complete its development on *P. hysterophorus*. Only one adult was discovered on *B. pilosaand R. hirta*, and its developmental stages were prolonged significantly on these plants. But in the field, there has been no observation of *E. strenuana* feeding on *B. pilosa* [42]. Multiple-choice tests were conducted in Queensland [44], which found *E. strenuanaonly* fed on common ragweed, *P. hysterophorus* and *Xanthium strumarium*, consistent with results by Wan FH [45]. Since first being released in sunflower growing regions of Queensland, there has been no records of *E. strenuana* damaging sunflower, demonstrating the limited host-range of this moth. However, *E. strenuana* was rejected for release in India for completely developing on *Guizotia abyssinica* in laboratory testing [43]. Russia and Africa also have noted potential risks with releases of *E. strenuana* [46].

Because larvae of *E. strenuana* bore into and gall plant stems, they change the physiological status of host plant [47]. Fusiform stem galls such as those of *E. strenuana*, cause plants to change their metabolism and disrupt the tissue regeneration process, stopping the further growth and development of host plants [42]. *E. strenuana* was introduced from Mexico into Australia in 1979 as a biological control agent of *Parthenium hysterophorus* (Asteraceae) [48]. After the first release of the moth in Queensland, *E. strenuana* established and spread rapidly to most *P. hysterophorus*-infested areas within two years [49]. In 1984, field surveys found 500-800 galls per square meter and *E. strenuana* spread to an area of 120 thousand square kilometers, at least 25% of the invaded area. Observed that heavily attacked host plants were severely stunted, bearing 30 to 100 stem galls [50]. The stem-galling moth scan kill seedlings and significantly reduce plant height and flowering production, thereby reducing the production of pollen and seeds. However, being attacked by *E. strenuana* has no effect on seed fresh weight, the percentage of seeds filled or seed vitality [42]. Presently, common ragweed is under good biological control in Queensland, and New South Wales [50] as a result ragweed is no longer a serious weed in eastern Australia. China introduced *E. strenuana* from Australia and released the moth in Beijing in 1990 and in Yue yang, Hunan province in 1993 [51], where it established and spread across Hunan province, eventually covering more than 2000 hectares.

Ophraella Communa

Ophraella communa (Coleoptera: Chrysomelidae, Galercinae), originating from North America, is an oligophagous insect feeding on various species of Asteraceae, including common ragweed. The leaf beetle is multivoltine and all stages occur on ragweed. Currently, *O. communa* populations are present in the USA, Canada, Mexico, Japan, South Korea, and China. In Japan, the beetle was discovered in Chiba Prefecture in 1996, from where it quickly spread across eastern Japan within two years [52]. In 2001, *O. communa* was occasionally found in China in Nanjing in Jiangsu province, and by now is widely distributed across southern China [53]. This beetle has also been found recently attacking common ragweed in northwestern Italy [54], which is the first report of *O. communa* in Europe, presumable from natural or accidental spread. *Ophraella communa* undergoes at least three generations each year in southern California [55], four or five generations in Japan [56], and at least four generations in Nanjing, China [57]. Female beetles lay eggs on the front or back of common ragweed leaves, which turn quickly from yellow to orange. Eggs hatch in four or five days and there are three larval instars. Mature larvae spin loosely woven cocoons and pupate on common ragweed leaves or stems. Usually, *O. communa* takes one month to finish its life cycle in summer. On perennial ragweed, Goeden and Ricker found a female can oviposit 667 eggs, with an oviposition period of 66 days and a total developmental period of 25 to 29 days [58]. Welch reared the beetle on common ragweed at 26°C and a 16:8 h L:D photoperiod, and found developmental times for eggs, larvae, pupae and pre-adults to be 5.1, 8.9-11.4, 3.7-4.4 and 21.8 days, respectively [59]. Adults can also display mixed sex aggregations in the field. Mate location and recognition depend on olfactory and tactile cues, but sex pheromones absent [60]. A study showed that *O. communa* could survive and reproduce successfully at different photoperiods, which may expand its distribution to regions [61]. Subsequently, they also reported frequent mating can significantly increase male and female adult longevity, fecundity, and the hatch rates of eggs [62]. Interestingly, studies have reported that large males of *O. communa* facilitate population expansion [63].

Generally, in the presence of ragweed in the field, *O. communa* only feeds on common ragweed, but it can also foraging some other species of Asteraceae such as *A. psilostachya*, *Iva axillaris*, and *X. strumarum*. Palmer and Goedenstudied the leaf beetle host selection using small scale, no-choice tests, and found that both larvae and adults feed on *A. psilostachya*, *X. strumarum*, *Parthenium* and *H. Annuus* [55]. In addition, eggs were also laid on *H. annuus*, leading to the rejection of the use of *O. communa* as a natural enemy even though there is no record of *O. communa* as a pest of *H. annuus* in its native range in North America [55]. Yamazaki, et al. [56] studied the feeding behavior of *O. communa* and found that it preferred common ragweed and that sunflower was free of damage in the presence of *O. communa*. Dernovici, et al. [64] used both choice and no-choice tests to demonstrate that common ragweed is the main host plant of the leaf beetle. Even though sunflowers suffered some damage in the no-choice test, the beetle cannot complete its life cycle on sunflowers and beetle populations decrease on sunflowers. Hu, et al. [65] found *O. communa* feeding on *H. annuus*, *X. strumarum*, *Helianthus tuberosus*, *Eupatorium adenophorum*, *Centipeda minima* and *Carpesium abrotanoides* among a total of 52 plant species tested. However, except for common ragweed, feeding by *O. communa* on other plants was insufficient to support the development of its offspring, and reproduction was reduced on these plants.

Because both larvae and adults feed extensively, have short developmental periods, high fertility, and high longevity, *O. communa* populations can completely defoliate a common ragweed stand within a few insect generations [52]. At high densities, *O. communa* can prevent flowering and seed set. In addition, *O. communa* has a strong host discrimination ability and spreads rapidly [56]. Moriya, et al. [66] reported that the average rate of beetle expansion was 100 km/year, making the leaf beetle a promising biological control agent of common ragweed in China. In Canada, *O. communa* has been widely applied augmentatively against common ragweed in various vegetable crops and organic soybean fields, achieving good control and demonstrating the potential for using *O. communa* to suppress ragweed in this way [67,68]. In addition, the leaf beetle has been successfully used to control common ragweed in the USA and Mexico [68]. Teshler, et al. [69] designed a device especially for collecting and transporting the leaf beetle for long distance use, making its augmentative use practical. In Europe interest in this species is developing. Kiss found *O. communa* to be the most suitable biological control agent of common ragweed in Europe [68]. In Japan, the leaf beetle was first discovered in Chiba-ken in 1996, from where it spread quickly and could be found in 39 ragweed infested areas in 2001, causing significant control on common ragweed [56,70]. *O. communa* has also been found in many regions of South Korea including Inchon and Busan, where it can completely kill common ragweed plants, reducing pollen and seed production. In Italy, common ragweed populations were completely defoliated by *O. communa* feeding, stopping growth, causing the plant to dessicate, and preventing flowering and pollen production [54]. Since *O. communa* was first discovered in Nanjing in 2001, it has spread across southern China [53]. In areas where this leaf beetle is present, common ragweed has been significantly suppressed. In a field-release experiment, with increasing initial release density of *O. communa* adults, plant height and number of branches was reduced and the leaf control index increased [71]. In the early stage of ragweed growth, even at a release density as low as 1adult per plant, the beetle significantly suppressed plant height and number of branches and a higher leaf control index compared with the herbicide treatment.

Pathogens

In common ragweed's native range, it is infected by many pathogens. Among these, *Puccinia xanthii* is the most promising species for biological control. *Puccinnia xanthii* is a *microcyclic autoecious* rust that has been reported to infect common ragweed in some regions of North America [25,72]. This rust as a species is comprised of several different formae speciales that have a high degree of host specialization and can complete their life cycles on just one plant species performae speciales.

Another fungal pathogen of common ragweed, *Protomyces gravidus* causes a stem gall disease on *A. trifida* in the USA, and has been evaluated as a mycoherbicide against both giant and common ragweed [73]. While the fungus causes stem gall disease and ragweed mortality if hosts are infected systemically, mycoherbicide production has a low infection rate and a general lack of virulence, limiting its control ability of common ragweed.

A third fungal pathogen, as species in the genus Phoma performed well in inundative experiments where it was tested as a potential mycoherbicide. When combined with the leaf beetle *O. communa*, Phoma and the beetle synergistically increased common ragweed mortality [74].

Another mycoherbicide under development is a strain of *Sclerotinia sclerotiorum*, which was evaluated as a potential biocontrol agent of common ragweed in Hungary [75]. In the same study, two fungal pathogens, *Phyllachora ambrosiae* and *Plasmopara halstedii*, were found to significantly suppress common ragweed and its pollen production in 1999 and 2002, but no infection of ragweed was discovered in other years [76,77].

In glasshouse trials, the bacterium *Pseudomonas syringae pv. tagetis* was found to infect a related species, Ambrosia Grayi, causing systemic chlorosis. This bacterium was found to kill the weed at low concentrations under field conditions in Texas [78]. However, none of these pathogens can be cultured *in vitro*, making them as of yet unsuitable for mass production and application as a mycoherbicide.

Joint control with Two Biological Control Agents

According to the ecological niche theory, two or more phytophagous insects that do not directly compete for resources will synergistically combine to produce greater damage to their host plant. *Ostrinia orientalis*, a local herbivore associated with *X. sibiricum* in Hunan, China, attacks ragweed. Ma, et al. [79] found that the selection and use of host resources differed significantly between *E. strenuanaand O. orientalis* and competition between them was rare in the field.

Similarly, the spatial niche resources needed by *O. communa* and *E. strenuanaare* different because all developmental stages of *O. communa* occur on common ragweed leaves and both *E. strenuana* larvae and pupae live in ragweed stems. This means *O. communa* and *E. strenuana* can survive together on the same common ragweed plant and there control effects should be synergistic. Zhou, et al. [80] demonstrated that a combination of *O. communa* and *E. strenuana* killed all common ragweed plants before seed production, while all or some plants could survive or bear seeds in the other, single species treatments and control plots. A joint biological control strategy using both *O. communa* and *E. strenuana* has been proposed in China, and it has been widely adopted in Hunan, Jiangxi, and Guangxi provinces, markedly inhibiting the development and diffusion of common ragweed [2].

Discussion

As global trade and travel increase every year, common ragweed has more opportunities to be accidentally spread as a crop or birdseed contaminant, in ballast soil or in other cargo. Climate changes may further cause this species to spread in to currently unsuitable areas of the world. To date, various control methods have been used in different regions of the world. In Europe (except eastern Europe), the main methods to control common ragweed are artificial extraction, physical machinery and herbicide control or combined measures. However, these methods require extensive manpower and material resources. In addition, the movement of people or machines may unintentionally spread common ragweed to new locations. Sometimes the actual terrain of ragweed habitat will limit the control implementation for mowers. Control of common ragweed with herbicides is very difficult in crops like sugar beet or soybean, and is nearly impossible in sunflowers because both common ragweed and sunflower belong to the same botanical family. Furthermore, the continuous application of herbicides results in herbicide resistant common ragweed biotypes and loss of biodiversity, which carries a risk to human health. More problematic, short-term abandonment, inadequate chemical control and mowing may stimulate the development of persistent soil seed banks and allow common ragweed to sprout quickly from the bases of stems. Some countries have passed legislation on the control of ragweed and launched large-scale ragweed eradication campaigns [81]. On the other hand, many countries have a long history of the biological control of common ragweed, including Russia, the former Yugoslavia, Georgia, Ukraine, Australia, China and Kazakhastan. Especially in Australia and China, the biological control of common ragweed is considered an outstanding success [82,83]. Significantly, in china, one study found that *O. communa* can follow host plants by adapting to new temperature environments via rapidgenetic evolution [84]. Although there is no single agent that is and effective biological control agent for common ragweed in Europe, more and more scientists are shifting their focus to biological control and many previously studied species have been reconsidered.

Unfortunately, there are several introduced enemies that have failed after release in the field. For example, *Tarachidia candefacta* was the first intentional introduction of a natural enemy for biological control of common ragweed in Europe and released in 1969 [85]. While the noctuid moth cannot play an effective role under harsh environmental conditions [86], *Euaresta bella*, *Trigonorhinus tomentosus* (Say), and *Zygogramma disrupta* Rogers have all been shown to have strict host specificity, although all failed to establish after release in Russia [32]. Wan and Dingintroduced *Z. suturalis*, *E. strenuana*, *Liothips* sp., *Euaresta* spp., and *T. candefacta* into China during 1990s, but only *E. strenuana* established successfully [45]. With more than 450 species that attack ragweed in North America, the selection of specific and effective natural enemies is still the most critical work for the biological control of common ragweed. When an organism is selected as biological control agent, its biology, ecology, and host-specificity should be studied before release. In addition, a prediction of suitable habitat and proper domestication for introduced natural enemies is also needed [87].

Compared with other methods, biological control for alien plants is safe, practical and economically feasible [87]. More and more countries are adopting this approach, even as outstanding successes in Australia and China have demonstrated that biological control is a promising method in such situations. In the future, relevant laws are needed to strengthen the control of common ragweed, and the public is still to be encouraged to increase their awareness over common ragweed control and engage more in management programs.

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References

1. Wan F H, Zheng X B, Guo JY (2005) Biology and management of invasive alien species in agriculture and forestry. Science Press, Beijing, China, pp: 774.

2. Zhou ZS, Guo JY, Wan FH (2015) Review on management of *Ambrosia artemisiifolia* using natural enemy insects. Chinese Journal of Biological Control 31: 657-665.

3. Ding J, Richard R, Wu Y, Zheng H, Fu W (2006) Biological control of invasive plants through collaboration between China and the United States of America: A perspective. Biol Invasions 8: 1439-1450.

4. Wan FH, Li BP, Guo JY (2008) Biological Invasions:

Biological Control Theory and Practice. Science Press, Beijing, China.

5. Harris P, Piper GL (1970) Ragweed (Ambrosia spp.: Compositae): its North American insects and the possibilities for its biological control. Technical Bulletin Commonwealth Institute of Biological Control 13: 117-140.

6. Stegmaier CE (1971) Lepidoptera, Diptera, and Hymenoptera associated with *Ambrosia artemisiifolia* (Compositae) in Florida. Fla Entomol 54: 259-272.

7. Brandes D, Nietzsche J (2006) Biology, introduction, dispersal, and distribution of commonragweed (*Ambrosia artemisiifolia* L.) with special regard to Germany. Nachrichtenbl Deut Pflanzenschutzd 58: 286-291.

8. Brandes D, Nitzsche J (2007) Ecology, distribution and phytosociology of *Ambrosia artemisiifolia* L. in Central Europe. Tuexenia 27: 167-194.

9. Dickerson CT, Sweet RD (1971) Common ragweed ecotypes. Weed Sci 19: 64-66.

10. Bassett IJ, Crompton CW (1975) The biology of Canadian weeds. 11. *Ambrosia artemisiifolia*L. and A. psilostachya DC. Can J Plant Sci 55: 463-476.

11. Fumanal B, Gaudot I, Meiss H, Bretagnolle F (2006) Seed demography of the invasive weed: *Ambrosia artemisiifolia* L. Neobiota. From Ecology To Conservation. European Conference on Biological Invasions pp: 127.

12. Cowbrough MJ, Brown RB (2003) Impact of common ragweed (*Ambrosia artemisiifolia*) aggregation on economic thresholds in soybean. Weed Science 51: 947-954.

13. Kazinczi G, Beres I, Novak R, Karaman J (2009) Focusing again on common ragweed (*Ambrosia artemisiifolia* L.). Novenyvedelem 45: 389-403.

14. Bosak P, Mod S (2000) Influence of different weed species on sugar beet yield. Novenyvedelem 49: 571-580.

15. Weaver SE (2001) Impact of lamb's-quarters, common ragweed and green foxtail on yield of corn and soybean in Ontario. Can J Plant Sci 81: 821-828.

16. Bousquet J, Van CP, Khaltaev N (2001) Allergic rhinitis and its impact on asthma. J Allergy Clin Immun 108: 147-334.

17. Salo PM, Calatroni A, Gergen PJ, Hoppin JA, Sever ML, et al. (2011) Allergy-related outcomes in relation to serum igE: results from the national health and nutrition examination survey 2005-2006. J Allergy Clin Immun 127: 1226.

18. Chan-Yeung M, Anthonisen NR, Becklake MR, Bowie D, Sonia BA, et al. (2010) Geographical variations in the prevalence of atopic sensitization in six study sites across Canada. Allergy 65: 1404-1413.

19. Burbach GJ, Heinzerling LM, Edenharter G, Bachert C, Bindslev-Jensen C, et al. (2009) GA2LEN skin test study II: clinical relevance of inhalant allergen sensitizations in Europe. Allergy 64: 1507-1515.

20. Taramarcaz P, Lambelet C, Clot B, Keimer C, Hauser C (2005) Ragweed (Ambrosia) progression and its health risks: will Switzerland resist this invasion?. Swiss Med Wkly 135: 538-548.

21. Keane RM, Crawley MJ (2002) Exotic plant invasions and the enemy release hypothesis. Trends Ecol Evol 17: 164-170.

22. MacKay J, Kotanen PM (2008) Local escape of an invasive plant, common ragweed (*Ambrosia artemisiifolia* L.), from aboveground and belowground enemies in its native area. J Ecol 96: 1152-1161.

23. Genton BJ, Kotanen PM, Cheptou PO, Adolphe C, Shykoff JA (2005) Enemy release but no evolutionary loss of defence during ragweed invasion of France: an inter-continental reciprocal transplant experiment. Oecologia 146: 404-414.

24. Vidovic B, Cvrkovic T, Rancic D, Marinkovic S, Cristofaro M, et al. (2016) Eriophyid mite Aceria artemisiifoliae sp.nov. (Acari: Eriophyoidea) potential biological control agent of invasive common ragweed, *Ambrosia artemisiifolia* L. (Asteraceae) in Serbia. Syst Appl Acarol-Uk, 21: 919.

25. Farr DF, Bills GF, Chamuris GP, Rossman AY (1989) Fungi on plants and plant products in the United States. Mycologia 42: 243-246.

26. Goeden RD, Andres LA (1999) Three recent successes outside of North America. In: Handbook of Biological Control. Academic Press, San Diego, CA, USA.

27. Kovalev OV, Reznik SY, Cherkashin VN (1983) Characteristics of methods of using leaf-beetles of the genus Zygogramma Chevr. (Coleoptera: Chrysomelidae) in the biological control of ragweeds (*Ambrosia artemisiifolia* L.; A. psilostachya D.C.). Entomologicheskoe Obozrenie 62: 402-408.

28. Wan FH, Wang R, Qiu SB (1989) Host specificity

tests of *Zygogramma suturalis* [Col: Chrysomelidae]: an important biological control agent of *Ambrosia artemisiifolia* L. Chinese Journal of Biological Control 5: 20-23.

29. Igrc J, Deloach CJ, Zlof V (1994) Release and establishment of *Zygogramma suturalis*, F. (Coleoptera: Chrysomelidae) in Croatia for control of common ragweed (*Ambrosia artemisiifolia* L.). Biol Control 5: 203-208.

30. Wan FH, Guan GQ, Wang R (1993) Ragweed and its integrated management in China. Science Press. Beijing, China.

31. Reznik SY (1991) The effects of feeding damage in ragweed Ambrosia artamisiifolia (Asteraceae) on populations of *Zygogramma suturalis* (Coleotera: Chrysomelidae). Oecologia 88: 204-210.

32. Julien MH, Griffiths MW (1998) Biological control of weeds: a world catalogue of agents and their target weeds, 4th edn. CABI Publishing, Wallingford, UK.

33. Reznik SY, Spasskaya IA, Dolgovskaya MY, Volkovitsh MG, Zaitzev VF (2007) The ragweed leaf beetle *Zygogramma suturalis* F. (Coleoptera: Chrysomelidae) in Russia: current distribution, abundance and implication for biological control of common ragweed, *Ambrosia artemisiifolia* L. In: Julien MH, Sforza R, et al. (Eds.), 7th International Symposium on Biological Control of Weeds, pp. 614–619. CAB International, Wallingford, UK.

34. Kovalev OV, Tyutyunov YV, Iljina LP, Berdnikov SV (2013) On the efficiency of introduction of American insects feeding on the common ragweed (*Ambrosia artemisiifolia*, L.) in the south of Russia. Entomological Review 93: 962-973.

35. Futuyma DJ (1990) Observations on the taxonomy and natural history of Ophraella wilcox (Coleoptera: Chrysomelidae), with a description of a new species. J New York Entomol 98: 163-186.

36. Wan FH, Wang R, Ding JQ (1995) Biological control of *Ambrosia artemisiifolia* with introduced insect agents, *Zygogramma suturalis* and Epiblema strenuana, in China. In: Delfosse ES, Scott RR (Eds.), Proceedings of the Eighth International Symposium on Biological Control of Weeds. Melbourne, Australia: DSIR/CSIRO, pp: 193-200.

37. Zhao MT, Guo JY, Zhou ZS, Wan FH (2012) Biosafety assessment of several insect natural enemies against common ragweed and their application prospects. Journal of Biological Control 28: 424-429.

38. Reznik SY, Belokobyl'Skiy SA, Lobanov AL (1994) Weed and herbivorous insect population densities at the broad spatial scale: *Ambrosia artemisiifolia* L. and *Zygogramma suturalis* F. (Col., Chrysomelidae). J Appl Entomol 118: 1-9.

39. Ma J, Wan FH, Guo JY, You LS, Lu DY (2002) Risk analysis of host specificity for *Epiblema strenuana* (Lepidoptera: Tortricidae), a biocontrol agent against ragweed, Ambrosia artemissifolia (Compositae). Acta Ecologica Sinica 22: 1710-1717.

40. Navie SC, Adkins SW, Priest TE, Mcfadyen RE (1998) Efficacy of the stem-galling moth *Epiblema strenuana* Walk. (Lepidoptera: Tortricidae) as a biological control agent for ragweed Parthenium (Parthenium hysterophorus L.). Biol Control 13: 1-8.

41. Wan FH (1991) A literature review on Epiblema strenuana-a potential biological control agent of *Ambrosia artemisiifolia* and its feasibility of application in China. Journal of Biological Control 7: 177-180.

42. McClay AS (1987) Observations on the biology and host specificity of *Epiblema strenuana* [Lepidoptera, Tortricidae], a potential biocontrol agent for Parthenium hysterophorus [Compositae]. Entomophaga 32: 23-34.

43. Jayanth KP (1987) Investigations on the host-specificity of *Epiblema strenuana* (Walker) (Lepidoptera: Tortricidae), introduced for biological control trials against Parthenium hysterophorus in India. Journal of Biological Control1 pp: 133-137.

44. McFadyen RE (1989) Ragweed, Parthenium and Noogoora burr control in the post-Epiblema era. In: Proc. 5th Bienn. Nox. Plants Conf. Lismore, NSW 1: 5-8.

45. Wan FH, Ding JQ (1993) Determination of host specificity of Epiblema strenuana. Chinese Journal of Biological Control 9: 69-75.

46. McConnachie AJ (2015) Host range tests cast doubt on the suitability of Epiblema strenuana, as a biological control agent for Parthenium hysterophorus, in Africa. Biocontrol 60: 715-723.

47. Dhileepan K, McFadyen RE (2001) Effects of gall damage by the introduced biocontrol agent epiblema strenuana (Lep., Tortricidae) on the weed Parthenium hysterophorus (Asteraceae). Journal of Applied Entomology 125: 1-8.

48. McFadyen RE (1992) Biological control against Parthenium weed in Australia. Crop Protection 24: 400-407.

49. Dhileepan K, Mcfadyen RE (1997) Biological control

of parthenium in Australia: progress and prospects. International Conference on Parthenium Management 1: 40-44.

50. McFadyen RE, Lemerle D, Leys AR (1987) The effect of climate on the stem-galling moth, *Epiblema strenuana* in Eastern Australia. Proceedings of the Eighth Australian Weeds Conference, Sydney, New South Wales, Australia, pp: 97-99.

51. Li HK, Li YN, Deng KQ (1993) A study on biological control of Epiblema strenuana. In: Ragweed (Ed.), its integrated management in China. Chinese Science and Technology Press, Beijing, China.

52. Yamanaka T, Tanaka K, Otuka A, Bjornstad ON (2007) Detecting spatial interactions in the ragweed (Ambrosia artemissifolia L.) and the ragweed beetle (*Ophraella communa*Lesage) populations. Ecol Res 22: 185-196.

53. Meng L, Li BP (2006) Mating and oviposition behaviors of exotic leaf beetle, *Ophraella communa*. Chinese Bulletin of Entomology 43: 806-809.

54. Bosio G, Massobrio V, Chersi C, Scavarda G, Clark S (2014) Spread of the ragweed leaf beetle, *Ophraella communa* Lesage, 1986 (Coleoptera Chrysomelidae), in piedmont region (northwestern Italy). B Soc Geol Ital 146: 17-30.

55. Palmer WA, Goeden RD (1991) The host range of *Ophraella communa* Lesage (Coleoptera: Chrysomelidae). Coleopts Bull 45: 115-120.

56. Yamazaki K, Natuhara Y, Imai C (2000) Rapid population growth and food-plant exploitation pattern in an exotic leaf beetle, *Ophraella communa* Lesage (Coleoptera: Chrysomelidae), in western Japan. Appl Entomol Zool 35: 215-223.

57. Meng L, Li BP (2005) Advances on biology and host specificity of the newly introduced beetle, *Ophraella communa* Lesage (Coleoptera: Chrysomelidae), attacking *Ambrosia artemisiifolia* (Compositae) in continent of China. Chinese Journal of Biological Control 21: 65-69.

58. Goeden RD, Ricker DW (1985) The life history of Ophraella notulata (F.) on western ragweed, *Ambrosia psilostachya* De Candolle, in southern California (Coleoptera: Chrysomelidae). Pan-Pac Entomol 61: 32-37.

59. Welch KA (1978) Biology of Ophraella notulata (Coleoptera: Chrysomelidae). Ann Entomol Soc Am 71: 134-136.

60. Zhou ZS, Guo JY, Guo W, Wan FH (2015) Synergistic effects of olfactory and tactile cues in short-range mate finding of *Ophraella communa*. Entomologia Experimentalis Et Applicata 138: 48-54.

61. Zhou ZS, Luo M, Guo JY, Chen HS, Wan FH (2014) Effect of photoperiod on developmental fitness in *Ophraella communa* (Coleoptera: Chrysomelidae). Environ Entomol 43: 1435-1442.

62. Zhou ZS, Rasmann S, Zheng HY, Watson A, Guo JY, et al. (2015) Mating frequency positively associates with fitness in *Ophraella communa*. Ecol Entomol 40: 292-298.

63. Zhang Y, Zhao C, Ma W, Cui S, Chen H, et al. (2021) Larger males facilitate population expansion in *Ophraella communa*. J Anim Ecol 90: 2782-2792.

64. Dernovici S, Teshler M, Watson A (2006) Is sunflower (Helianthus annuus) at risk to damage from *Ophraella communa*, a natural enemy of common ragweed (*Ambrosia artemisiifolia*)?. Biocontrol Sci Techn 16: 669-686.

65. Hu Y P, Meng L (2007) Potential impacts of alien herbivorous insect *Ophraella communa*(Coleoptera: Chrysomelidae) on non-target plants in mainland China. Chinese Journal of Ecology 26: 56-50.

66. Moriya S, Shiyake S (2001) Spreading the distribution of an exotic ragweed beetle, *Ophraella communa* Lesage (Coleoptera: Chrysomelidae), in Japan. Japanese Journal of Entomology 4: 99-102.

67. Teshler MP, DiTommaso A, Gagnon JA, Watson AK (2002) *Ambrosia artemisiifolia* L., common ragweed (Asteraceae). In: Mason PG, Huber JT (Eds.), Biological Control Programmes in Canada, 1981–2000. CAB International, Wallingford, UK, pp: 290-294.

68. Kiss L (2007) Why is biocontrol of common ragweed, the most allergenic weed in Eastern Europe, still only a hope?. In: Vincent C, Goettel MS, et al. (Eds.), Biological Control: a Global Perspective. Oxfordshire, UK: CAB International pp: 80-91.

69. Teshler MP, Dernovici SA, Ditommaso A, Coderre D, Watson AK (2004) A novel device for the collection, storage, transport, and delivery of beneficial insects, and its application to *Ophraella communa* (Coleoptera: Chrysomelidae). Biocontrol Sci Techn14: 347-357.

70. Moriya S (1999) Successive rearing of ragweed beetle, *Ophraella communa* Lesage (Coleoptera: Chrysomelidae) in Japan. Annual Report of the Kanto-Tosan Plant Protection Society 46: 115-171.

71. Guo JY, Zhou ZS, Zheng XW, Chen HS, Wan FH, et al. (2011)

Control efficiency of leaf beetle, *Ophraella communa*, on the invasive common ragweed, *Ambrosia artemisiifolia*, at different growing stages. Biocontrol Sci Techn 21: 1049-1063.

72. Kiss L (2007a) Is Puccinia xanthii a suitable biological control agent of *Ambrosia artemisiifolia*?. Biocontrol Sci Techn 17: 535-539.

73. Cartwright RD, Templeton GE (1988) Biological limitations of *Protomyces gravidusas* a mycoherbicide for giant ragweed, Ambrosia trifida. Plant Dis 72: 580-582.

74. Teshler MP, Briere SC, Stewart RK, Watson AK, Hallett SG (1996) Life table and feeding ability of *Ophraella communa* (Coleoptera: Chrysomelidae) a potential biocontrol agent for *Ambrosia artemisiifolia*. In: Moran VC, Hoffmann JH (Eds.), IX International Symposium on Biological Control of Weeds, Stellenbosch, South Africa, 420. University of Cape Town, Cape Town, South Africa.

75. Coutinot D, Starfinger U, Mcfadyen R, Volkovtsh M, Kiss L, et al. (2008) Feasibility of biological control of common ragweed (*Ambrosia artemisiifolia*) a noxious and highly allergic weed in Europe. XII International Symposium on Biological Control of Weeds, pp: 717-719.

76. Vajna L, Bohar G, Kiss L (2000) First report of Phyllachora ambrosiae in Europe causing epidemics on common ragweed. Plant Dis 84: 489-489.

77. Vajna L (2010) Downy mildew epidemic on common ragweed in Hungary caused by Plasmopara halstedii. Plant Pathol 51: 809-809.

78. Wheeler TA, Zak JC (2001) Biological control of Woollyleaf bursage (Ambrosia grayi) with Pseudomonas syringae pv. tagetis. Weed Technol 15: 375-381.

79. Ma J, Wan FH, Guo JY, You LS (2003) Resource use overlap between *Epiblema strenuana* and Ostrinia orientalis: two biocontrol agents against *Ambrosia artemisiifolia* and Xanthium sibiricum.Acta Ecologica Sinica 23: 2232-2238.

80. Zhou ZS, Chen HS, Zheng XW, Guo JY, Guo W, Li M (2014) Control of the invasive weed *Ambrosia artemisiifolia* with *Ophraella communa* and Epiblema strenuana. Biocontrol Sci Techn 24: 950-964.

81. Bohren C, Mermillod G, Delabays N (2006) Common ragweed (*Ambrosia artemisiifolia* L.) in Switzerland: development of a nationwide concerted action. J Plant Dis Protect 20: 497-503.

82. Zhou ZS, Zheng XW, Guo JY, Wan FH (2018) Relationship between host searching and wind direction in *Ophraella communa* (Coleoptera: Chrysomelidae). Fla Entomol 101: 536-539.

83. Ma C, Cui S, Bai Q, Tian Z, Zhang Y, et al. (2020) Olfactory co-receptor is involved in host recognition and oviposition in *Ophraella communa* (Coleoptera: Chrysomelidae). Insect Mol Biol 29: 381-390.

84. Tian Z, Chen G, Zhang Y, Ma C, Tian Z, et al. (2022) Rapid evolution of *Ophraella communa* cold tolerance in new low-temperature environments. J Pest Sci 95: 1233-1244.

85. Kovalev OV (1981) Introduction and acclimatization of Phytophages of ragweeds (Ambrosia L. Asteraceae) in North America and their application in biological control in the USSR. Zool Zh 50: 199-209.

86. Poltavsky AN, Artokhin KS (2006) *Trachidia candefacta* (Lepidoptera: Noctuidae) in the south of European Russia. Phegea 34: 41-44.

87. McFadyen RE (1998) Biological control of weeds. Annu Rev Entomol 43: 369-393.