Long-term and large-scale releases of Trichogramma promote pesticide decrease in maize in northeastern China

Article *in* Entomologia Generalis · December 2020

DOI: 10.1127/entomologia/2020/0994

Entomologia Generalis, Vol. 40 (2020), Issue 4, 331–335
Published online 13 November 2020

Short Note

Long-term and large-scale releases of *Trichogramma* promote pesticide decrease in maize in northeastern China

Ning-Xing Huang[1], Coline C. Jaworski[1,2], Nicolas Desneux[3], Fan Zhang[1], Pu-Yun Yang[4,*], and Su Wang[1,*]

[1] Institute of Plant and Environment Protection, Beijing Academy of Agriculture and Forestry Sciences, 100097, Beijing China
[2] University of Oxford, Department of Zoology, Oxford, UK
[3] Université Côte d'Azur, INRAE, CNRS, UMR ISA, 06000 Nice, France
[4] National Agro-technical Extension and Service Center, China
* Corresponding author: anthocoridae@163.com

With 3 figures

Abstract: The Asian corn borer, *Ostrinia furnacalis*, is one of the most important pests of corn crops in Northern China. From 2004 to 2015, a public financial support to biological control of the corn borer resulted in a significant increase in the cultivated area treated with *Trichogramma dendrolimi* parasitoid applications in corn field in the Jilin Province, in northeastern China. In the present study, we analyzed the impact of these parasitoid releases, from 2000 to 2015 in the Jilin province, on the control of the corn borer as well as on pesticide use. We demonstrated that the widespread large-scale use of *T. dendrolimi* applications against the Asian corn borer, while being effective for controlling the pest and ensuring competitive corn yields, led to a decrease in insecticide use across the province. The use of *Trichogramma* is an economically and competitive alternative to insecticide applications in northeastern China.

Keywords: corn borer, biological control, *Trichogramma dendrolimi*, *Ostrinia furnacalis*

1 Introduction

Maize is one of the most important crops in China, however an average of 6–9 million tons of grain yield is lost yearly owing to damage caused by the Asian corn borer (ACB), *Ostrinia furnacalis* (Guenée), 1854 (Lepidoptera: Crambidae) (Wang et al. 2014). To address this concern, large-scale releases of the parasitoid wasp *Trichogramma dendrolimi* Matsumura (Hymenoptera: Trichogrammatidae) were initiated in the 1970s to control the ACB (Chen et al. 2015). *Trichogramma* are egg parasitoids widely used to control lepidopteran pests in agricultural and forestry systems in many regions around the world (Smith 1996; Guo et al. 2019; Hou et al. 2018; Li et al. 2019; Thiery and Desneux 2018; Zang et al. 2021). This is now one of the most successful biological control programs in China (Zhan & Liang 1999; Xiang & Zhang 2011), with more than four million hectares of maize treated annually. The release rate varies from 225,000 to 300,000 wasps/ha depending on the pest pressure by ACB and the wasp species used, mainly *T. dendrolimi*, but also *T. chilonis* and *T. ostriniae* (Chen et al. 2015; Zang et al. 2021). Such large-scale releases have been made possible notably thanks to mass rearing technical advances, using eggs of the Chinese oak silkworm, *Antheraea pernyi* Guérin-Mèneville 1855 (Lepidoptera: Saturniidae), as the rearing medium for *T. dendrolimi* (Gou 1986; Zang et al. 2021). In the Jilin Province in northeastern China, large-scale applications started in the 1980s and an automatic production line producing 40 billion wasps per year has been used since the early 1990s (Song et al. 1994; Chen et al. 2015). In this area, the maize-cultivated area was 4.3 million ha in 2015, and the average yield was 7.38 ton/ha, representing roughly 15 % of the total maize-cultivated area and 20 % of corn yield in China (National Agro-technical Extension and Service Center, NAESC, China). The Jilin Province is therefore a major contributor to corn production from the Chinese North Spring Corn Region, the most important maize-cultivating region in China (the two other regions being the Summer Corn Region and the Southwest Hilly Corn Region, all three forming the Corn Belt of China).

A key aspect widely contributing to the large-scale deployment of parasitoid releases was the financial support

DOI: 10.1127/entomologia/2020/0994
www.schweizerbart.de
0171-8177/2020/0994 $ 2.25

by the government. *Trichogramma* applications against ACB have become one of the key components of integrated pest management in maize in northeastern China prioritized by public recommendations (Wang et al. 2003; Chen et al. 2015). From 2004 to 2015, governmental subsidies to ACB biological control resulted in a massive increase in the area treated with *T. dendrolimi* wasps in the Jilin province, from 0.6 to 2.72 million ha (Chen et al. 2015).

However, the effect of *T. dendrolimi* applications at large spatial scales and in the long term on corn yield and insecticide use is poorly understood. Such knowledge is yet critical for future, sustainable improvement of integrated pest management in maize. In the present study, we used data of *T. dendrolimi* applications from 2000 to 2015 in seven counties among the biggest contributors to maize production in the Jilin Province to analyze the impact of such applications on ACB control and pesticide use in maize. We hypothesized that large-scale, long-term releases should contribute to sustainable control of ACB, by maintaining low densities of ACB but high corn yield while reducing insecticide use. This in turn should provide environmental and ecological benefits, by delaying pest resistance to insecticides, reducing negative impacts of insecticides on non-target biodiversity, and reducing potential negative health impacts (Weisenburger 1993; Desneux et al. 2007; Lu et al. 2012; Guedes et al. 2016). We investigated the following questions: (1) Did *T. dendrolimi* releases result in reduced density of ACB? (2) Did such releases result in higher corn yields? and (3) Did such releases result in a decrease in insecticide use in maize?

2 Materials and methods

We used data from seven counties of the Jilin Province, among the biggest contributors to maize production in the Province, totaling roughly 2.8 million ha of maize and representing 64 % of the total maize-cultivated area in the Jilin Province: Changchun area (973,030 ha), Gongzhuling (216,122 ha), Liaoyuan (71,438 ha), Meihekou (49,809 ha), Siping (416,923 ha), Songyuan (810,285 ha) and Yanbian (221,150 ha). Areas for each county are average maize-cultivated areas from 2000 to 2015. For each year and each county, we used the following available variables: the density of ACB (number of larvae/ha), maize yield (ton/ha), the total amount of insecticides applied over a year in each county in maize fields (kg/ha of commercial products), the total maize-cultivated area (ha) and the portion of this total treated with *T. dendrolimi* applications. Because of lacking data, sampling sizes were N = 73, N = 59 and N = 71 for ACB density, insecticide applications and maize yields, respectively. All data were provided by the National Agrotechnical Extension and Service Center, China.

To analyze the impact of long-term *T. dendrolimi* releases at a landscape scale, we used the ratio of *Trichogramma*-treated areas, calculated as the proportion of maize-cultivated areas treated with *T. dendrolimi* (ha) out of the total maize-cultivated areas (ha) in each county and year. We then performed three linear regressions on the log-transformed ACB density, the insecticides applied, and the maize yields, with the ratio of *Trichogramma*-treated areas as a fixed effect. The significance of the relationships were tested with ANOVAs weighted by the total maize-cultivated area in each county and year. All analyses were performed using R version 3.6.2 (R Core Team 2019).

3 Results

The density of ACB declined significantly with the increasing ratio of *Trichogramma*-treated areas, from roughly 11,000 to 1,400 larvae/ha at 0 and 100 % of areas treated with the egg parasitoids, respectively (Fig. 1; $F_{1,71} = 159.19$, $R^2 = 0.692$, $P < 0.001$).

The total amount of insecticides used also declined significantly with the increasing ratio of *Trichogramma*-treated areas, from roughly 0.89 to 0.71 kg/ha at the scale of a county, at 0 and 100 % of *Trichogramma*-treated areas, respectively (Fig. 2; $F_{1,57} = 12.77$,3 $R^2 = 0.183$, $P < 0.001$).

Finally, corn yield increased significantly with the increasing ratio of *Trichogramma*-treated areas, with a slight increase from roughly 8.4 to 10.5 ton/ha at 0 and 100 % of *Trichogramma*-treated areas, respectively (Fig. 3; $F_{1,69}$ = 57.655, $R^2 = 0.455$, $P < 0.001$).

4 Discussion

In the present study, we showed that widespread, large-scale use of *T. dendrolimi* applications against the Asian corn borer (ACB) helps reduce ACB densities, resulting in reduced insecticide use and increased maize yields. This demonstrates the efficiency of such biological control technique at large spatial scales.

Decreases in insecticide use as a consequence of very large-scale deployment of new pest control techniques have already been shown in cotton crops in China, with the implementation of Bt cotton (Lu et al. 2012). The decreases in insecticide use shown in the present study were expected due to the large-scale deployment of *Trichogramma* applications. Indeed, the control of ACB populations by released *T. dendrolimi* wasps should decrease pest pressure, and hence reduce the need for chemical control. Also, biological control is mostly not compatible with chemical control, or may at least require temporal asynchrony, due to lethal and sublethal impacts of pesticides to beneficial arthropods (Desneux et al. 2007), including *Trichogramma* parasitoids (e.g. Wang et al. 2018; Jiang et al. 2019). Therefore, farmers may avoid use chemical insecticides in fields treated with *T. dendrolimi*. In addition, non-insecticidal pesticides, such as herbicides may also cause sublethal effects to wasps, hence

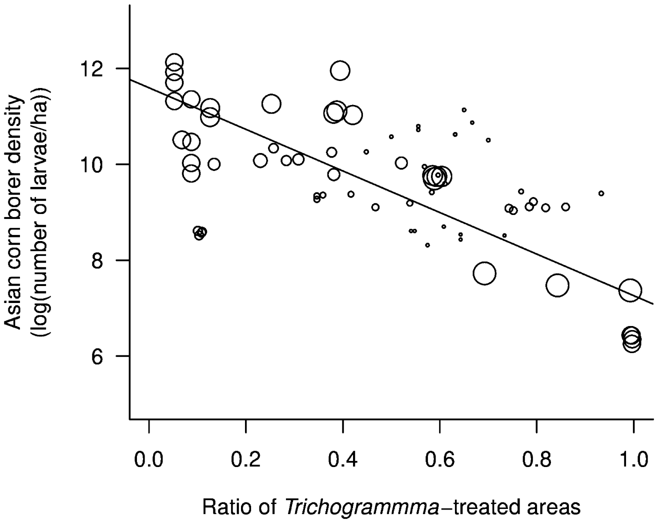

Fig. 1. Impact of the ratio of *Trichogramma*-treated areas (proportion of maize-cultivated areas treated with *T. dendrolimi* applications) on the density of the Asian corn borer in seven counties of the Jilin Province between 2000 and 2015 (N = 73). Dot size is proportional to the total maize-cultivated area. The linear relationship was defined by Y = –4.337X + 11.60.

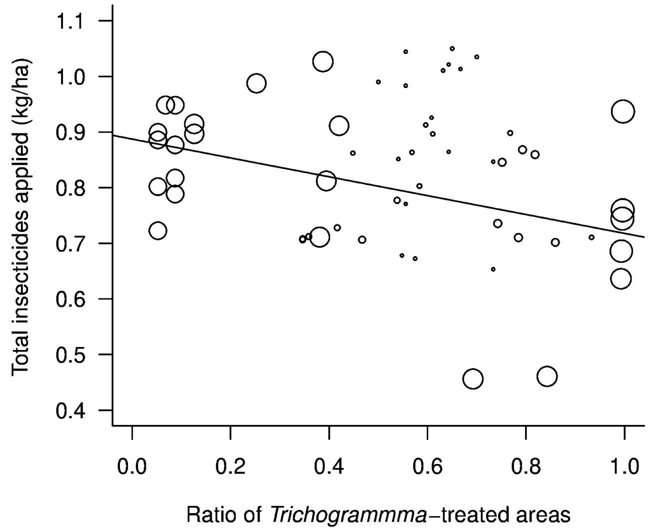

Fig. 2. Impact of the ratio of *Trichogramma*-treated areas (proportion of maize-cultivated areas treated with *T. dendrolimi* applications) on total insecticides applied in seven counties of the Jilin Province between 2000 and 2015 (N = 59). Dot size is proportional to the total maize-cultivated area. The linear relationship was defined by Y = –0.1695X + 0.8873.

biocontrol efficiency relies on reduced use of all pesticides (Desneux et al. 2007). A deeper analysis of the dataset provided by the National Agro-technical Extension and Service Center also revealed that, beyond insecticide applications, the pesticide applications also decreased with increased ratios of *Trichogramma*-treated areas ($F_{1,57} = 41.373$, $R^2 = 0.421$, $P < 0.001$, unpublished data).

The positive impact of the large-scale adoption of *Trichogramma*-based biocontrol, related to decrease in pesticide use, may go beyond ACB control in maize fields. First, *Trichogramma* species may also regulate populations of other non-target pests in maize, such as non-target butterflies (Babendreier et al. 2003; Wang et al. 2014). Second, and due to the massive wasp releases and spatial scale considered, *T. dendrolimi* may also regulate pest populations in other crops adjacent to maize fields via spillover (Li et al. 2016).

We showed that the large-scale adoption of *Trichogramma*-based biocontrol along with insecticide use reduction resulted in increased yields (Fig. 3). While other factors may contribute in increasing yields (e.g., variety development and use through time), the positive relationship between maize yields and the ratio of *Trichogramma*-treated areas highlights the economic sustainability of this biocontrol method, safeguarding long-term and large-scale use by farmers (Gagnon et al. 2017, Razinger et al. 2016, Bzowska-Bakalarz et al. 2020).

Finally, the reduced ACB densities with increased ratios of *Trichogramma*-treated areas show that *T. dendrolimi* applications are efficient to control ACB. Applications of *Trichogramma* species have been shown to be very efficient at controlling various pests in many crops in many regions (Li et al. 2016; Li et al. 2018; Babendreier et al. 2019; Zang et al. 2021). Our study brings new evidence that *Trichogramma*-based biocontrol remains efficient at very large spatial scales and in the long-term.

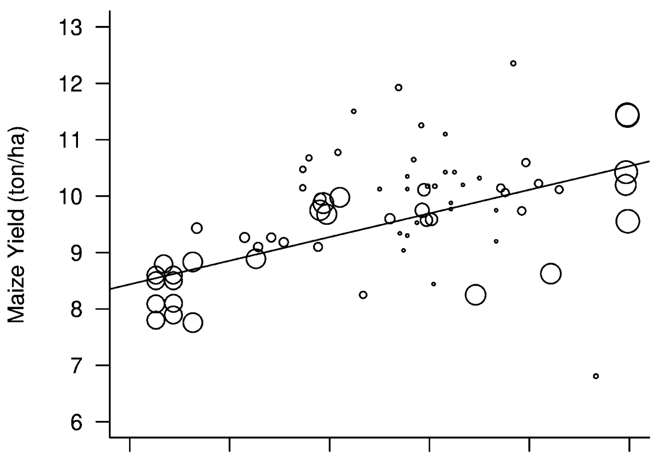

Fig. 3. Impact of the ratio of *Trichogramma*-treated areas (proportion of maize-cultivated areas treated with *T. dendrolimi* applications) on corn yield in seven counties of the Jilin Province between 2000 and 2015 (N = 71). Dot size is proportional to the total maize-cultivated area. The linear relationship was defined by Y = 2.096X + 8.436).

Unfortunately, few data is available on natural populations of *Trichogramma* species and on other biocontrol agent populations in the areas considered. Several studies yet found that inundative releases may largely exceed natural abundances in China, at least immediately after the releases (Shen et al. 1986; Shen 1987; Liu et al. 1990). They reported that natural parasitism rates in non-treated areas was much lower than that in *Trichogramma*-treated areas. In our data, we considered all releases to be inundative based on very high densities reported. Still the impact of releases on natural populations remains unknown, although there is evidence that large-scale releases of *T. dendrolimi* since the 1970s did not suppress other *Trichogramma* species. For example, *T. dendrolimi* only comprised 28.9% of the total samples of *Trichogramma* found in corn fields in the Jilin Province in 1986–1987 while *T. ostriniae* was the dominant species in the neighboring regions in the 1970–1980s (Zhang, 1988; Zhang et al. 1990). However, no recent study has performed wasp sampling at the scale of the Jilin province.

Our analysis based on long-term data at the scale of the Jilin Province provided a valuable panoramic view of the impact of *T. dendrolimi* applications on ACB control, corn yields and pesticide applications. However, the absence of data on ACB densities before the release, nor of parasitism rates are limiting our analysis. Also, introducing areas where *Trichogramma*-based control of ACB is absent would provide a control to directly compare the effect of releases on ACB densities.

The data analyzed represented one province only from those producing corn in northeastern China; the other provinces include: Heilongjiang, Liaoning, Inner Mongolia most part of Shanxi, part of Hebei, Shaanxi and Gansu, and altogether form the North Spring Corn Region. Other corn-cultivated areas in China are the Summer Corn Region and the Southwest Hilly Corn Region. Incorporating data from all these regions would extend the impact of our analysis.

Acknowledgments: This research was supported by Beijing Key Laboratory of Environment-Friendly Management on Fruit Disease and Pests in North China, Grant/Award Number:BZ0432; National Key Research and Development Program of China, Grant/Award Number: 2017YFD0201000.

References

Babendreier, D., Kuske, S., & Bigler, F. (2003). Parasitism of non-target butterflies by *Trichogramma brassicae* Bezdenko (Hymenoptera: Trichogrammatidae) under field cage and field conditions. *Biological Control, 26*(2), 139–145. https://doi.org/10.1016/S1049-9644(02)00120-2

Babendreier, D., Wan, M., Tang, R., Gu, R., Tambo, J., Liu, Z., … Romney, D. (2019). Impact Assessment of Biological Control-Based Integrated Pest Management in Rice and Maize in the Greater Mekong Subregion. *Insects, 10*(8), 226. https://doi.org/10.3390/insects10080226

Bzowska-Bakalarz, M., Bulak, P., Beres, P. K., Czarnigowska, A., Czarnigowski, J., Karamon, B., … Bieganowski, A. (2020). Using gyroplane for application of *Trichogramma* spp. against the European corn borer in maize. *Pest Management Science, 76*(6), 2243–2250. https://doi.org/10.1002/ps.5762

Chen, L. L., Zhang, Q. H., Xue, Z., Bai, H. Y., Zhang, Z. D., Lu, Y. X., & Lu, X. (2015). Current situation and prospect of biological control of corn borer in Jilin province. *Zhongguo Shengwu Fangzhi Xuebao, 31*, 561–567.

Desneux, N., Decourtye, A., & Delpuech, J.-M. (2007). The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology, 52*(1), 81–106. https://doi.org/10.1146/annurev.ento.52.110405.091440

Gagnon, A. E., Audette, C., Duval, B., & Boisclair, J. (2017). Can the use of *Trichogramma ostriniae* (Hymenoptera: Trichogrammatidae) to control *Ostrinia nubilalis* (Lepidoptera: Crambidae) be economically sustainable for processing sweetcorn? *Journal of Economic Entomology, 110*, 59–66.

Gou, X. Q. (1986). Research and application of *Trichogramma* in China. *Natural Enemies of Insects, 8*, 113–120.

Guedes, R. N. C., Smagghe, G., Stark, J. D., & Desneux, N. (2016). Pesticide-induced stress in Arthropod Pests for Optimized Integrated Pest Management Programs. *Annual Review of Entomology, 61*(1), 43–62. https://doi.org/10.1146/annurev-ento-010715-023646

Guo, X. J., Di, N., Chen, X., Zhu, Z., Zhang, F., Tang, B., … Wang, S. (2019). Performance of *Trichogramma pintoi* when parasitizing eggs of the oriental fruit moth *Grapholita molesta. Entomologia Generalis, 39*(3-4), 239–249. https://doi.org/10.1127/entomologia/2019/0853

Hou, Y. Y., Yang, X., Zang, L. S., Zhang, C., Monticelli, L. S., & Desneux, N. (2018). Effect of oriental armyworm *Mythimna separata* egg age on the parasitism and host suitability for five *Trichogramma* species. *Journal of Pest Science, 91*(4), 1181–1189. https://doi.org/10.1007/s10340-018-0980-2

Jiang, J. G., Liu, X., Zhang, Z. Q., Liu, F., & Mu, W. (2019). Lethal and sublethal impact of sulfoxaflor on three species of *Trichogramma* parasitoid wasps (Hymenoptera: Trichogrammatidae). *Biological Control, 134*, 32–37. https://doi.org/10.1016/j.biocontrol.2019.04.001

Li, J., Zhao, L. L., Li, Y., Zhao, Z. G., & Ma, R. Y. (2016). Inoculative releases of *Trichogramma dendrolimi* for suppressing the oriental fruit moth (*Grapholita molesta*) in peach orchard in China. *Fruits, 71*(2), 123–128. https://doi.org/10.1051/fruits/2015054

Li, S., Zheng, H., Chen, L., Chen, F., Guo, R., Wang, B., & Zhang, F. (2018). Comparisons of Three *Trichogramma* Species for Controlling *Chilo suppressalis* in Paddy Field. *Zhongguo Shengwu Fangzhi Xuebao, 34*, 336–341.

Li, X. Y., Lei, Q., Hua, H. Q., Song, H. F., Wang, S., Ramirez-Romero, R., … Li, Y.-X. (2019). Impact of host suitability on oviposition preference toward fertilized and unfertilized host eggs in two *Trichogramma* parasitoid species. *Entomologia Generalis, 39*(3-4), 313–323. https://doi.org/10.1127/entomologia/2019/0857

Liu, Z. C., Liu, J. F., Zhang, F., Li, D. S., & Feng, X. X. (2000). *Production and Field Application Techniques of Trichogramma*. Beijing: Golden Shield Press.

Liu, Z. Z., Cui, Y. Y., Wan, B. Y., Wang, C. L., Cui, D. J., Liu, H., & Wang, G. X. (1990). An evaluation of the efficacy of large scale release of *Trichogramma dendrolimi* against Asian corn borer in Yunshu country. *Chinese Journal of Biological Control, 6*, 148–150.

Lu, Y., Wu, K., Jiang, Y., Guo, Y., & Desneux, N. (2012). Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services. *Nature, 487*(7407), 362–365. https://doi.org/10.1038/nature11153

Razinger, J., Vasileiadis, V. P., Giraud, M., van Dijk, W., Modic, S., Sattin, M., & Urek, G. (2016). On-farm evaluation of inundative biological control of *Ostrinia nubilalis* (Lepidoptera: Crambidae) by *Trichogramma brassicae* (Hymenoptera: Trichogrammatidae) in three European maize-producing regions. *Pest Management Science, 72*(2), 246–254. https://doi.org/10.1002/ps.4054

R Core Team (2019). R: A Language and Environment for Statistical Computing. https://www.R-project.org

Thiéry, D., & Desneux, N. (2018). Host plants of the polyphagous grapevine moth *Lobesia botrana* during larval stage modulate moth egg quality and subsequent parasitism by the parasitoid *Trichogramma cacoeciae. Entomologia Generalis, 38*(1), 47–59. https://doi.org/10.1127/entomologia/2018/0675

Shen, X. C. (1987). The ecological effect of biological control based on variation of population of corn borer. *Acta Agriculturae Universitatis Henanensis, 21*, 485–489.

Shen, X. C., Wang, K. Z., & Meng, G. (1986). Field experiment of inoculative releases of *Trichogramma* spp. in the early season in Henan province. *Chinese Journal of Biological Control, 2*, 152–154.

Smith, S. M. (1996). Biological control with *Trichogramma*: Advances, successes, and potential of their use. *Annual Review of Entomology, 41*(1), 375–406. https://doi.org/10.1146/annurev.en.41.010196.002111

Song, R. C., Chi, Y. M., Wang, H. P., Lu, G. Y., Wang, Q. X., & Zhang, Q. B. (1994). A study on setting equipment of manufactured reproduction of *Trichogramma. Transactions of the Chinese Society of Agricultural Engineering, 10*, 48–52.

Wang, Z. Y., He, K. L., Zhang, F., Lu, X., & Babendreier, D. (2014). Mass rearing and release of *Trichogramma* for biological control of insect pests of corn in China. *Biological Control, 68*, 136–144. https://doi.org/10.1016/j.biocontrol.2013.06.015

Wang, D. S., Lu, L. H., & He, Y. R. (2018). Effects of insecticides on sex pheromone communication and mating behavior in *Trichogramma chilonis*. *Journal of Pest Science, 91*(1), 65–78. https://doi.org/10.1007/s10340-017-0864-x

Weisenburger, D. D. (1993). Human health-effects of agrichemicals use. *Human Pathology, 24*(6), 571–576. https://doi.org/10.1016/0046-8177(93)90234-8

Xiang, Y. Y., & Zhang, F. (2011). Review of application research on *Trichogramma westwood* in biological control in China. *Henan Nongye Kexue, 40*(12), 20–24.

Zhan, G. X., & Liang, G. W. (1999). Research and application of *Trichogramma* in China. *Acta Agriculturae Jiangxi, 11*(2), 39–46.

Zhang, J., Wang, J. L., Cong, B., & Yang, C. C. (1990). A faunal study of *Trichogramma* species on *Ostrinia furnacalis* in China. *Chinese Journal of Biological Control, 6*, 49–53.

Zhang, Z. L. (1988). *Trichogramma* spp. parasitizing the eggs of Asian corn borer *Ostrinia furnacalis* and its efficacy in Beijing suburbs, In J. Voegele, J. Waage, & J. van Lenteren (Eds.), *Trichogramma* and Other Egg Parasitoids. 2nd International Symposium. Colloques-de-l'INRA *43*, 629–632.

Zang, L. S., Wang, S., Zhang, F., & Desneux, N. (2021). Biological control with *Trichogramma* in China: History, present status and perspectives. *Annual Review of Entomology*. https://doi.org/10.1146/annurev-ento-060120-091620

Manuscript received: 7 January 2020
Revisions requested: 28 February 2020
Modified version received: 21 June 2020
Accepted: 16 September 2020