CellPress
OPEN ACCESS

Science & Society

Managing the Invasive Fall Armyworm through Biotech Crops: A Chinese Perspective

Yunhe Li [1,*]
Zhenying Wang [1] and
Jörg Romeis [1,2]

In late 2018, the highly destructive and polyphagous fall armyworm was first detected in China. It is now a major economic threat to corn production. In this article, the main control strategies that are available are reviewed and prospects to manage this pest with *Bacillus thuringiensis* (Bt) corn in China are discussed.

Invasion of the Fall Armyworm into China

Due to its wide host range, high reproductive and dispersal capacity, the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), which is native to tropical and subtropical regions of the Americas, has become a major invasive pest on corn (*Zea mays* L.). It is rapidly spreading in Africa, the Near East and Asia [1]. In December 2018, FAW was first found in Yunnan Province in China and has since spread quickly throughout the country, posing a serious economic threat to China's crop production [2,3]. Presently, FAW has been reported from all but five provinces (municipalities) in the North West and North East (Figure 1). This large area includes about 13 million hectares of corn, the favored crop of this destructive pest. FAW is expected to cause much greater harm to China's agricultural production than the cotton bollworm, *Helicoverpa armigera* (Hübner) [2]. Consequently, considerable effort is being devoted to developing strategies to minimize damage caused by this invasive pest.

Prospects to Manage FAW with Bt Corn

Various strategies have been recommended for managing FAW, including cultural controls (e.g., push-pull strategy), biological control (use of arthropods and microorganisms that attack the pest), and chemical control [4]. In general, it appears that the success of any of these strategies to provide efficient and timely control of FAW in large-scale open fields, especially under high pest pressure, is limited. In addition, the application of cultural or biological practices is challenging and requires well-trained farmers. However, the rapid urbanization in China has led to the shortage of rural labor, especially well-educated workers, and this will limit effective implementation of these measures. Chemical insecticides are widely used for FAW management worldwide but also have limitations. Their efficacy is highly dependent on timing because FAW caterpillars are usually found in corn whorls where they are largely protected from insecticide treatments [1]. Furthermore, over-reliance on chemical insecticides does not meet the strategic aim of achieving sustainable agricultural development in China, and, due to extensive application, FAW has developed resistance to multiple commonly used insecticides. Globally, FAW has been found to be resistant to over 30 active ingredients of insecticides from all major classes (https://www.pesticideresistance.org/). Moreover, genome-wide sequencing analysis revealed that FAW populations invading China already carry resistance to organophosphate and pyrethroid insecticides [5].

Another strategy is to use genetically engineered (GE) corn that is resistant to FAW. GE crop varieties producing insecticidal crystalline (Cry) proteins and/or vegetative insecticidal proteins (Vip) derived from Bt that are selectively toxic to different insect species, are planted in many parts of the world to manage caterpillar pests, often reaching more than 80% adoption levels [6]. The high adoption levels, together with high control efficacy provided by the technology, has led to area-wide population reductions in some pests [7]. In the Americas, the use of Bt corn hybrids is widely used to manage FAW [1]. There is strong evidence available from the growing of Bt crops in general that they can reduce the use of chemical insecticides and benefit natural pest control due to the narrow spectrum of activity of the deployed Cry and Vip proteins [6].

Since 1993, China has successfully used Bt cotton to manage *H. armigera*, the primary insect damaging this crop. Studies have shown that Bt cotton has provided tremendous economic benefit to Chinese farmers and dramatically decreased insecticide use [7]. Furthermore, the reduction of chemical insecticide use not only increased the yield and net profit of cotton farmers, but also contributed to a cleaner environment and improved the health of farmers [7]. Planting Bt-transgenic corn hybrids that are highly resistant to FAW would be an effective tool contributing to the management of this voracious pest in China and other developing countries.

Challenges in Managing FAW with Bt Corn

One main challenge with Bt crops is the risk that target pests evolve resistance to specific Bt proteins produced by the plant. Thus, for a sustainable use of Bt-transgenic plants, efforts have to be taken to delay the development of resistance [8]. The primary approach for this goal is the high-dose/refuge strategy in which Bt plants producing a high dose of the insecticidal protein are combined with refuges of non-Bt that allow susceptible insects to survive. The aim is to increase the likelihood that the rare resistant, or tolerant individuals in

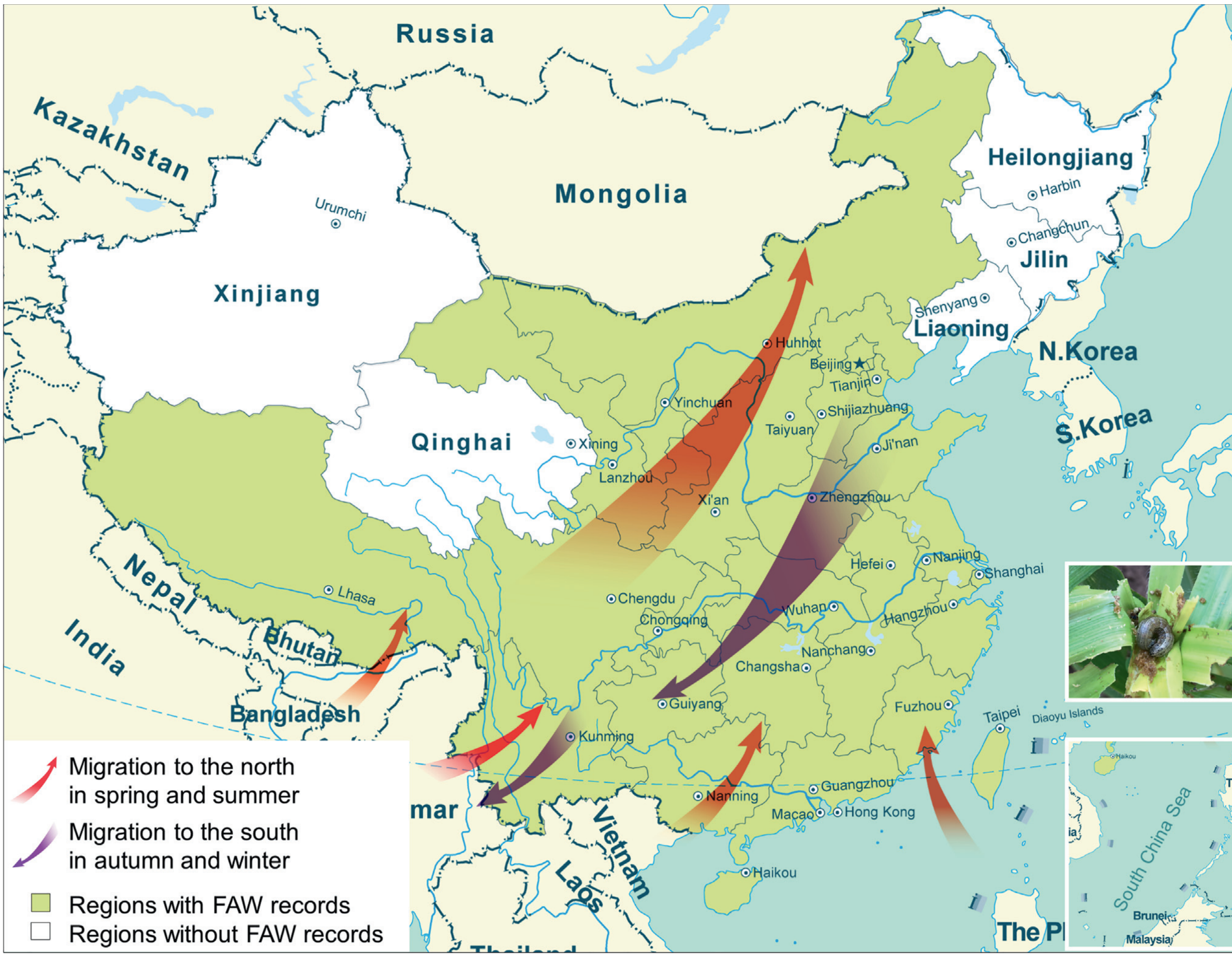

Figure 1. Occurrence and Movement of *S. frugiperda* in China. Inset: damage on corn plants.

the population, mate with susceptible insects, and that the heterozygous progeny are killed by the high dose of the insecticidal protein in the plant. A solid insect resistance management plan is particularly important in the case of FAW. The species was the first lepidopteran pest reported to develop resistance to a Bt protein (Cry1F) in the field, leading to Bt corn failures in Puerto Rico [8]. Practical resistance in FAW populations to Cry1F were subsequently also detected in Brazil and on the US mainland. Likely reasons contributing to this development included: (i) high pest pressure; (ii) limitation in alternative host plants; (iii) large numbers of generations (up to 11); (iv) multiple corn-growing seasons in tropical areas, combined with the facts that the corn event grown did not provide a very high dose of the insecticidal protein; and (v) resistance alleles do not appear to be associated with fitness costs [9]. For similar reasons, FAW also became resistant to Cry1Ab which shares binding sites with Cry1F and other Cry1 class proteins in the gut of sensitive insects [10]. What is promising however, is the fact that in the field FAW has not yet evolved resistance to Bt proteins from other classes, such as Cry2A and Vip3A, that have no shared binding sites with the Cry1 proteins, and that resistance allele frequencies to these proteins appear to be low [11,12].

In a recent study, Li and colleagues [13] demonstrated that the FAW population invading China is highly susceptible to the commonly used Cry1, Cry2, and Vip3 proteins with the highest susceptibility to Vip3A, Cry1Ab, and Cry1F. So far, a number of Bt corn events have been developed for managing lepidopteran pests in China [7] of which the event DBN9936 (producing Cry1Ab) and the pyramided events (i.e., plants modified to produce two or more Cry or Vip proteins)

DBN3608 and DBN3601 (Cry1Ab+Vip3A) exhibit high resistance to FAW [14], thus presenting prospects for commercial application. Event DBN9936 has already passed regulatory approval and received biosafety certificates in January 2020 (http://www.moa.gov.cn/ztzl/zjyqwgz/). Thus, the path forward is open to breed these lines into popular corn hybrids then release them to the farmers.

Strategies for Delaying FAW Resistance to Bt Corn

Given the fact that FAW has shown a high capability to evolve resistance to certain Cry proteins, care must be taken when introducing Bt corn hybrids in China. Based on the experience gained in the Americas and in Africa, the most durable control is provided by pyramided events that produce a minimum of two Bt proteins with different modes of action, and that do not share binding sites in the insect's gut [8]. The most promising approach appears to be a pyramid of Cry1Ab, or Cry1F with Vip3A. Pyramiding of genes would not only enhance the efficacy to manage FAW, and delay resistance evolution, but would also reduce the required refuge size. Ideally, a refuge plan would be in place that includes a structured refuge of non-Bt corn, even though other crop plants, and native areas, would serve as a natural refuge [15]. The value of such natural refuges has been demonstrated to be effective in the case of *H. armigera* and Bt (Cry1Ac) cotton in China for which no planted non-Bt cotton refuges were required [15]. Given that FAW is as polyphagous and mobile as *H. armigera*, natural refuge may be an effective strategy for delaying resistance evolution of FAW to Bt corn. Resistance evolution could be accelerated in geographical areas, where Bt corn would be planted alongside Bt cotton producing Cry1Ac, since both FAW and *H. armigera* will feed on both crops. It is believed however, that this risk is minimal, since today, cotton is mainly grown in Xinjiang Province (76% of the cotton crop in 2019), due to a change in Chinese agricultural policy affecting the structure of this sector. This province grows little corn and has a low suitability to sustain FAW populations [3,7]. In any case, planting of Bt corn should be accompanied by a resistance monitoring plan, including an early warning and prevention system, to ensure a durable and effective use of the technology.

Concluding Remarks

Finally, Bt corn should not be seen as a single tool for managing FAW but combined with other strategies including biological control, cultural controls, and judicious use of chemical insecticides (see Outstanding Questions) [2,4]. Incorporation of Bt corn in an integrated pest management (IPM) program would not only reduce the risk of resistance evolution to the deployed Bt protein(s), but also provide a more durable and sustainable pest management system.

Acknowledgments

We thank Anthony M. Shelton (Cornell University, USA) and Michael Meissle (Agroscope, Switzerland) for their critical comments on an earlier draft of the manuscript. This work was supported by the National GMO New Variety Breeding Program of China (2016ZX08011-001) and the Agricultural Science and Technology Innovation Program (CAAS-ZDRW202007).

[1]State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute for Plant Protection, Chinese Academy of Agricultural Sciences, Beijing 100193, China

[2]Agroscope, Research Division Agroecology and Environment, Reckenholzstrasse 191, 8046 Zurich, Switzerland

*Correspondence:
liyunhe@caas.cn (Y. Li).

https://doi.org/10.1016/j.tibtech.2020.07.001

References

1. Hruska, A.J. (2019) Fall armyworm (*Spodoptera frugiperda*) management by smallholders. *CAB Rev.* 14, 043
2. Wu, K. (2020) Management strategies of fall armyworm (*Spodoptera frugiperda*) in China. *Plant Protect.* 43, 1–5 (in Chinese with English abstract)
3. Wang, R. *et al.* (2020) Potential distribution of *Spodoptera frugiperda* (J.E. Smith) in China and the major factors influencing distribution. *Global Ecol. Conserv.* 21, e00865
4. Prasanna, B.M. *et al.*, eds (2018) *Fall armyworm in Africa: a guide for integrated pest management*, 1st edn CIMMYT, Mexico
5. Zhang, L. *et al.* (2020) Genetic structure and insecticide resistance characteristics of fall armyworm populations invading China. *Mol. Ecol. Resour.* https://doi.org/10.1111/1755-0998.13219
6. Romeis, J. *et al.* (2019) Genetically engineered crops help support conservation biological control. *Biol. Control* 130, 136–154
7. Li, Y. *et al.* (2020) Insect-resistant genetically engineered crops in China: development, application, and prospects for use. *Annu. Rev. Entomol.* 65, 273–292
8. Tabashnik, B.E. and Carrière, Y. (2017) Surge in insect resistance to transgenic crops and prospects for sustainability. *Nat. Biotechnol.* 35, 926–935
9. Vélez, A.M. *et al.* (2016) Cry1F resistance among lepidopteran pests: a model for improved resistance management? *Curr. Opin. Insect Sci.* 15, 116–124
10. Omoto, C. *et al.* (2016) Field-evolved resistance to Cry1Ab maize by *Spodoptera frugiperda* in Brazil. *Pest Manag. Sci.* 72, 1727–1736
11. Yang, F. *et al.* (2017) Cross-resistance to purified Bt proteins, Bt corn and Bt cotton in a Cry2Ab2-corn resistant strain of *Spodoptera frugiperda*. *Pest Manag. Sci.* 73, 2495–2503
12. Yang, F. *et al.* (2018) F_2 screen, inheritance and cross-resistance of field-derived Vip3A resistance in *Spodoptera frugiperda* (Lepidoptera: Noctuidae) collected from Louisiana, USA. *Pest Manag. Sci.* 74, 1769–1778
13. Li, G. *et al.* (2019) Susceptibility evaluation of invaded *Spodoptera frugiperda* population in Yunnan province to five Bt proteins. *Plant Protect.* 45, 15–20 (in Chinese with English abstract)
14. Zhang, D. and Wu, K. (2019) The bioassay of Chinese domestic Bt-Cry1Ab and Bt-(Cry1Ab+Vip3Aa) maize against the fall armyworm, *Spodoptera frugiperda*. *Plant Protect.* 45, 54–60 (in Chinese with English abstract)
15. Jin, L. *et al.* (2015) Large-scale test of the natural refuge strategy for delaying insect resistance to transgenic Bt crops. *Nat. Biotechnol.* 33, 169–174