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Current Opinion in Insect Science

Current situation of pests targeted by Bt crops in Latin America

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Transgenic crops producing *Bacillus thuringiensis*- (*Bt*) insecticidal proteins (*Bt* crops) have provided useful pest management tools to growers for the past 20 years. Planting *Bt* crops has reduced the use of synthetic insecticides on cotton, maize and soybean fields in 11 countries throughout Latin America. One of the threats that could jeopardize the sustainability of *Bt* crops is the development of resistance by targeted pests. Governments of many countries require vigilance in measuring changes in *Bt*-susceptibility in order to proactively implement corrective measures before *Bt*-resistance is widespread, thus prolonging the usefulness of *Bt* crops.A pragmatic approach to obtain information on the effectiveness of *Bt*-crops is directly asking growers, crop consultants and academics about *Bt*-resistance problems in agricultural fields, first-hand information that not necessarily relies on susceptibility screens performed in laboratories. This type of information is presented in this report.Problematic pests of cotton and soybeans in five Latin American countries currently are effectively controlled by *Bt* crops. Growers that plant conventional (non-*Bt*) cotton or soybeans have to spray synthetic insecticides against multiple pests that otherwise are controlled by these *Bt* crops. A similar situation has been observed in six Latin American countries where *Bt* maize is planted. No synthetic insecticide applications are used to control corn pests because they are controlled by *Bt* maize, with the exception of *Spodoptera frugiperda*. While this insect in some countries is still effectively controlled by *Bt* maize, in others resistance has evolved and necessitates supplemental insecticide applications and/or the use of *Bt* maize cultivars that express multiple *Bt* proteins. Partial control of *S. frugiperda* in certain countries is due to its natural tolerance to the *Bt* bacterium. Of the 31 pests targeted and controlled by *Bt* crops in Latin America, only *S. frugiperda* has shown tolerance to certain *Bt* proteins in growers' fields, the most reliable indication of the status of *Bt*-susceptibility in most of the American continent.

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Current Opinion in Insect Science 2016, **15**:131–138

This review comes from a themed issue on **Pests and resistance**

Edited by **Blair Siegfried** and **Juan Luis Jurat-Fuentes**

For a complete overview see the Issue and the Editorial

Available online 10th May 2016

http://dx.doi.org/10.1016/j.cois.2016.04.012

Introduction

Transgenic crops expressing *Bacillus thuringiensis*- (*Bt*) insecticidal genes (*Bt* crops) express *Bt* proteins similar to those produced by the *Bt* bacterium. The *Bt* proteins produced by these plants have a very narrow spectrum of activity [1], making them nearly pest-specific. Currently *Bt* cotton, *Bt* maize, and *Bt* soybeans are planted in ten Latin American countries, with activity against some lepidopteran and coleopteran pests [2], while other nations such as Cuba, Bolivia and Ecuador are close to the commercialization of *Bt* maize cultivars [3].

A potential positive effect on growers adopting genetically-engineered *Bt* crops can be evaluated by a significant reduction in the use of synthetic insecticides while at the same time providing excellent control of the most problematic insect pests. For example, in a typical year prior to the availability of *Bt* cotton, a cotton farmer in Latin America needed to spray up to 12–25 times to obtain partial control of *Alabama argillacea*, *Heliothis virescens* (currently proposed as *Chloridea virescens*) or *Pectinophora gossypiella* [4,5]. Control of *H. virescens* necessitated multiple insecticide sprays prior to the use of *Bt* cotton, and now is no longer controlled with synthetic insecticides on *Bt* and non-*Bt* cotton in Mexico [6]. Planting *Bt* cotton across large areas may have been the most important force that decreased the overall population of *H. virescens*. Similarly, *P. gossypiella* is another example of a problematic pest nearly eradicated from a vast cotton-growing area of North America through the simultaneous use of multiple control tactics involving *Bt* cotton [7]. Large areas planted with *Bt* maize have also reduced the overall population of another serious pest in the United States, *Ostrinia nubilalis* [8]. The overall population of this pest has been reduced to levels such that growers using non-*Bt* maize have benefitted from not having to control *O. nubilalis* in their fields.

Control of *Spodoptera frugiperda* (fall armyworm) in maize presents a different situation. This pest causes sporadic damage to cotton, where is satisfactorily controlled with *Bt* cultivars or with synthetic insecticides. Maize growers in Argentina, Brazil, Puerto Rico and Uruguay initially controlled this pest with *Bt* maize that expressed one *Bt* protein (Cry1Ab of Cry1F); now it is necessary to plant maize cultivars that produce two *Bt* proteins and/or spray synthetic insecticides on *Bt* maize to achieve satisfactory control [9,10••,11]. In Mexico, where *Bt* maize has not yet been authorized for commercial planting, up to 12 synthetic insecticide applications target this pest alone (Mota-Sánchez, unpublished), while in Puerto Rico the number of synthetic insecticide sprays can reach 28 applications in a single growing season (Terán-Santofimio, unpublished). In some regions of Latin America, *Bt* maize that produces one or two toxins is sprayed 0-4 times with synthetic insecticides to achieve adequate control of *S. frugiperda*.

Due to the clear advantages for the environment and growers (e.g., less use and exposure to synthetic insecticides), and the ease of control of the majority of the problematic pests (e.g., reduced need to scout for pests while having an effective and consistent control), growers, consumers and the scientific community have expressed interest in preserving the benefits of planting *Bt* crops [12,13]. It is believed that on-time detection of incipient *Bt*-resistance in fields and implementing mitigation strategies to ameliorate its development will keep *Bt* crops effective for a long time. For nearly two decades, the goal of *Bt*-resistance monitoring programs worldwide has been to detect the areas where *Bt*-resistance is developing in a selected number of insect pests. In Latin America, screening of *Bt*-susceptibility has been done on an annual basis for some of the most problematic pests [14], and as far as we know, with the exception of Brazil [15••], there have been no *a priori* confirmed reports of *Bt*-resistance 'hotspots' in the field before actual crop damage was reported by growers. The problem of not accurately detecting *Bt*-resistance prior to field failures may be the case for *S. frugiperda* and *Diatraea saccharalis*. *Bt*-resistance monitoring efforts initially targeted other pests (e.g., *Helicoverpa zea*, *H. virescens*, *P. gossypiella*), and other problematic pests were not envisioned as potential candidates for *Bt*-resistance development until the first field reports attracted the attention of growers, regulators and the scientific community [16–18] (Figure 1).

The constrains of early detection of resistance hotspots is likely the result of a number of factors, such as (1) the variability of the methodology performing pre and post-*Bt* crop deployment screening tests; (2) ecological and evolutionary factors that tend to eliminate resistant alleles from its populations primarily due to fitness costs [19,20••]; but also see [21••,22••], (3) *Bt*-susceptibility screens are commonly performed under contract between industry and researchers, and their results seldom are included in scientific reports available to the public; and more importantly (4) the large areas in Latin America ($\geq$130 million hectares [23]) planted with cotton, maize and soybeans makes *Bt*-resistance monitoring efforts extremely challenging. The laborious and expensive screening for *Bt*-resistance in areas where random samples are taken has not generally yielded useful information before resistance has been observed in the fields. As far as we know, well-planned and carefully executed *Bt*-resistance monitoring programs [24–26] have failed to yield pertinent information to predict the development of resistance in the monitored areas (e.g., *Helicoverpa* spp.). Therefore, in this report we decided to focus our discussion using field-gathered information on the current effectiveness of *Bt* crops and relate those results when possible, to laboratory-generated *Bt*-susceptibility data.

Methodology

The information in this report represents the compiled current opinion of researchers, regulators and crop advisors of six Latin American countries on the effectiveness of *Bt* crops against key insect pests. Due to (1) the variability in the susceptibility of insect pests from different regions to *B. thuringiensis* proteins, (2) the discrepancies in methodology among laboratories, and (3) the lack of published reports of routine *Bt*-susceptibility screening from different Latin American countries, this report presents a consensus on the current effectiveness of field-planted *Bt* crops to control specific pests. This is a pragmatic approach of what can be found among scarce published reports of laboratory screenings.

A questionnaire similar to what appears in Tables 1–3 was distributed among researchers and crop advisors directly involved with *Bt* crops in the six countries appearing in