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Benefits of Bt cotton counterbalanced by secondary pests? Perceptions of ecological change in China

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Abstract In the past, scientific research has predicted a decrease in the effectiveness of Bt cotton due to the rise of secondary and other sucking pests. It is suspected that once the primary pest is brought under control, secondary pests have a chance to emerge due to the lower pesticide applications in Bt cotton cultivars. Studies on this phenomenon are scarce. This article furnishes empirical evidence that farmers in China perceive a substantial increase in secondary pests after the introduction of Bt cotton. The research is based on a survey of 1,000 randomly selected farm households in five provinces in China. We found that the reduction in pesticide use in Bt cotton cultivars is significantly lower than that reported in research elsewhere. This is consistent with the hypothesis suggested by recent studies that more pesticide sprayings are needed over time to control emerging secondary pests, such as aphids, spider mites, and lygus bugs. Apart from farmers' perceptions of secondary pests, we also assessed their basic knowledge of Bt cotton and their perceptions of Bt cotton in terms of its strengths and shortcomings (e.g., effectiveness, productivity, price, and pesticide use) in comparison with non-transgenic cotton.

Keywords Pest management · GM crops · Bt cotton · Ecological change · Biosafety · Bollworm · *Helicoverpa armigera*

Introduction

Cotton is China's main cash crop and has been subject to severe damage by the cotton bollworm (*Helicoverpa armigera*). During the Mao era and the early period of economic reforms in the first half of the 1980s, the bollworm was controlled through chlorinated hydrocarbons (such as dichloro-diphenyl-trichloroethane) and later by organophosphates. As the bollworm developed resistance, these insecticides were increasingly rendered ineffective albeit used in ever-rising, polluting quantities. In reaction, scientists of the Chinese Academy of Agricultural Sciences initiated research on transgenic cotton, which resulted in the development of a Chinese variety of Bt cotton. The area planted to Bt cotton has increased sharply since its commercialization in 1996, from

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16,700 to 3.8 million hectares in 2007. This is equal to 69% of the national total of 5.5 million hectares sown to cotton. Until 2006, China was the world's number one producer of Bt cotton, after which India overtook it, as the Chinese area of Bt cotton was 3.5 million hectares, while India cultivated 3.8 million hectares. The area planted to Bt cotton of the two countries account for 8.7% of the total area of genetically modified (GM) crops in the world (ISAAA 2007).

Several studies on Bt cotton in developing countries claim that its use brings benefits to smallholders because it decreases the number of pesticide sprayings and increases yields. For instance, a study at the Makhathine Falts in South Africa stated that there had been a reduction in the average number of pesticide sprays per season for farmers who adopted Bt cotton. As a result, there were cost savings in the form of lower inputs for pesticide and labor (Bennett et al. 2003, p. 128). Studies for India, Burkina Faso, and China have reached similar conclusions (Qaim 2003; Pray et al. 2001; Vitale et al. 2008). However, the portrayal of the adoption of Bt cotton in developing countries as being entirely successful has been called into question by other studies. Apart from their claimed positive economic returns, aforementioned studies have also been contested on methodological grounds and on the effectiveness of pest control due to lowered and varying Bt gene expression (Shantharam et al. 2008; Jost et al. 2008; Xu et al. 2008). At the same time, there is scientific uncertainty concerning the long-term sustainability of Bt technology with regard to its ecological effects. The uncertainty of the environmental impact of Bt cotton lies in the fact that ecological change may take many years to manifest. Ecological effects of Bt cotton can appear in several ways: (1) the development of the bollworm's resistance against Bt cotton, (2) a negative impact of Bt cotton on the bollworm's natural predators and non-target species, (3) adverse effects on soil nutrients and biota, (4) the increase of secondary pests, such as lygus bugs, aphids, and mites.

Controlled field conditions have provided evidence for the bollworm's potential to build up resistance against Bt cotton (Downes et al. 2007; Gujar et al. 2007; Wu 2007). These results have recently been confirmed in actual field conditions (Li et al. 2007). To avoid the development of resistance against Bt cotton, it is advised to plant 20% of Bt cotton acreage with non-transgenic varieties as a refuge area to avoid resistance development. However, particularly in developing countries, of which China is not an exception, the enforcement of such refuge areas has been problematic due to weak regulatory structures and small, fragmented agricultural plots on which cotton cultivation generally takes place. To date, there have been no confirmed findings of negative effects of Bt cotton on natural predators and non-target species (e.g., parasitic wasps; Men et al. 2004; Zhang et al. 2008). However, there is evidence of a negative influence of Bt cotton on soil biology and nutrient availability (Viktorov 2008; Sarkar et al. 2008).

Lastly, there is the issue of secondary (including sucking) pests. Bt cotton is not effective against secondary pests, which in non-transgenic cotton cultivation are usually killed through heavier insecticide sprayings. However, as fewer pesticides are used, secondary pests might increase, thereby counteracting the effects of Bt cotton and gradually even evolving into primary pests themselves (Turnipseed et al. 1995). Although several studies have predicted the eventuality of secondary pests (Cannon 2000; Lang 2006; Wang et al. 2006, 2008; Xu et al. 2008), there are no solid data available from the field, except for a few, at times, contradictory studies. The first study by (Wang et al. 2009) concludes that the increase in insecticide use for the control of secondary insects is far smaller than the reduction in total insecticide use due to Bt cotton adoption. Another study contradicts these findings. Based on a 3-year experimental field study in one province in China (Henan), Men et al. (2004) concluded that there is no difference in the total pesticide application between Bt cotton and conventional varieties because of additional sprayings to control secondary pests.

Against this backdrop, we conducted a field research on farmers' perceptions of secondary pests in three Chinese cotton-producing regions. Several questions were analyzed: Are farmers aware of a shift from primary to secondary pests in Bt cotton cultivars as compared to non-Bt cultivars? If so, what types of secondary pests have been identified by farmers? Are the types of perceived secondary pests alike under the different geographical, climatic, and soil conditions of the three cotton regions? In answering these questions, the current article will be a contribution to the wider studies on the effectiveness of Bt cotton.

Methodology: pilot and full study

The research sites

This research draws on data from a pilot and full-fieldwork study. The pilot study was carried out in the provinces of Anhui and Jiangsu and the Xinjiang Uyghur Autonomous Region and consisted of 12 interviews and a survey of 50 randomly selected households. The full study that was conducted in 2005, apart from these three sites, also included the provinces of Hebei and Shandong and involved 1,000 randomly selected farm households, 5 focus group sessions, and 68 in-depth interviews using semi-structured interview lists with various stakeholders in agro-biotechnology (farmers, local and national officials, scientists, and business and NGO representatives). In each province, a total of three to five counties were visited for the fieldwork. The research sites were selected to reflect the climatic and agricultural differences between China's three main cotton regions: the Yellow River, Yangzi River, and Northwestern regions.

The Yellow River region is the largest cotton-producing area of the three. It produces close to 40% of the nation's total, while Xinjiang and the Yangzi River region account respectively for 24% and 30% (National Bureau of Statistics 2003, p. 426). The most important differences between the three regions are the climatic conditions and the scale of cultivation.

The Yellow River region encompasses the northern China plain and includes the northern provinces of Shandong, Hebei, Henan, Shanxi, and Shaanxi and the provincial-level municipalities of Beijing and Tianjin. The weather is dry during springtime, requiring irrigation for cotton production. The major portion of the precipitation falls in summer, while the weather is dry during harvest time in the fall. Because of its northern location, the Yellow River Region has approximately 180 days in the growing season and has to adopt early-maturing cotton varieties, which are double-cropped with winter wheat (Hsu and Gale 2001).

The Yangzi River region includes the Jiangsu, Anhui, Hubei, Hunan, Jiangxi, and Zhejiang provinces. In contrast with the Yellow River and Northwest regions, rainfall is relatively abundant here. The average precipitation exceeds 1,000 mm per year, the greater part of which is concentrated in the cotton-growing season. Excessive rainfall gives rise to frequent pests and diseases affecting cotton quality. With a long growing season, cotton is generally double-cropped with wheat or rapeseed.

The Northwest region includes primarily the Xinjiang Uyghur Autonomous Region and parts of Gansu Province. Xinjiang covers one sixth of the entire area of China and borders Tibet, Mongolia, and Central Asia. The climate here is arid, with annual precipitation below 200 mm and wide daily swings in temperature, but dryness has kept pest and disease problems to a minimum (Hsu and Gale 2001). Xinjiang mainly grows upland cotton, with a high-quality color and fiber length due to its favorable climate conditions compared with the other two cotton-producing areas. Due to the cold winters and arid climate, infestations by the bollworm are less severe in Xinjiang, as compared to the Yellow River and Yangzi River regions. Until 2000, Xinjiang was officially designated as a "GM-free zone." However, in recent years, Bt cotton has found its way to the Northwest through illicit channels (Zhao and Ho 2005, p. 371).

An important difference between the Northwest and the other two regions is the scale of cotton cultivation: Xinjiang features large-scale, mono-cultivation on military state farms, known as the *bingtuan*. In the Yangzi and Yellow River regions, cotton is produced on small, fragmented plots that are on average smaller than a half hectare. The cotton fields are interspersed with fields planted with other crops, varying from wheat, maize, potato, and vegetables. This implies that the enforcement of GM-free buffer zones to prevent the resistance development of the bollworm against Bt cotton is particularly problematic in these two regions.

Survey design

The research presented here includes several main aspects: (1) assessing the ways through which farmers learned about Bt cotton, as well as their level of understanding of it; (2) an evaluation of farmers' perceptions of Bt cotton as compared to conventional cotton in terms of its strengths and shortcomings (e.g., effectiveness, productivity, price, and pesticide use); and (3) their perceptions of ecological change in Bt cotton cultivation, with particular reference to secondary pests. The research covered 3 years from 2003 and 2004 until 2005. In the first and second parts of the full study, respondents were provided with hypotheses formulated on the basis of most common answers that we derived from the interviews and focus sessions during the pilot research. The answer categories ranged from "definitely disagree" to "fully agree" and have been designed to falsify the hypotheses by forcing respondents away from affirmative answers if they were not fully certain.

Previous studies have mainly drawn conclusions by using the number of pesticide applications as a proxy for changes in secondary pests (Men et al. 2004; Wang et al. 2006, 2008). Our study directly asked farmers whether they perceived any changes in the incidence and type of pests, in addition to enquiring about the frequency of pesticide sprayings. In the literature, there has been discussion on farmers' ability to identify agricultural production problems in relation to the environment (Trutmann et al. 1996; Heisey 1990). Bentley posited that agricultural production problems that are relatively easy to observe and have a high perceived importance (e.g., weeds or termites) have a higher probability to be reflected in farmers' knowledge (Bentley 1992). Thus, it can be posited that Chinese farmers are likely to link the incidence of secondary pests (both easily detectable and accorded with a high importance) with the cultivation shift from conventional to Bt cotton.

Initially, the environmental part of this research was focused on the perceived effectiveness of Bt cotton against the bollworm to see if there would be reason to suspect a possible buildup of bollworm resistance. However, during the pilot research, there were numerous reports from farmers and agricultural extension officials that secondary pests had increased over the past years.[1] Official reports by the provincial bureaus of agriculture also noted this phenomenon (Hebei Bureau for Agriculture 2003). Therefore, we decided to focus the assessment of environmental change entirely on farmers' perceptions of secondary pests. During the pilot, we first identified the most common secondary pests in cotton as experienced by farmers and as suggested by agricultural extension officials. This resulted in a list of eight different types of secondary pests. In the full survey, we then asked the respondents to rate changes[2] in the incidence of each of these eight pests before and after they started Bt cotton cultivation.

Results

Knowledge about Bt cotton

During the Mao period, the dominant channel of news about new seed varieties was the government represented by local cadres in the communes. The communes were responsible for the planning of agricultural production and controlled the full supply and marketing chain. After the start of the economic reforms in December 1978, the government has withdrawn many of its former functions from rural society. In 2000, the National People's Congress adopted the Seed Law, which effectively liberalized the domestic cotton seed market and resulted in the emergence of a wide variety of private traders and companies (Ho et al. 2009). Despite these changes, official rather than private channels remain important for news about seed varieties for the farmers, although there is a clear diversification in the channels to obtain news. Our survey confirms this trend.

As we wanted to test farmers' basic knowledge about GM crops, we intentionally avoided the terms "Bt cotton," "genetically modified cotton," and "transgenic cotton." Instead, during the first

[1] Interview with official of the Agricultural Service Centre of Zougou Town, Anhui Province, 27 April 2004.

[2] The rating could be given on a five-point scale from "strong," "slight decrease," and "no change" to "slight" and "strong increase."

Table 1 Valid percentages of farmers' perceived incidence of bollworm

Region/province	Decreased	Unchanged	Increased
Yellow River region			
Hebei (n = 139)	99.3	0	0.7
Shandong (n = 126)	97.6	1.6	0.8
Yangzi River region			
Anhui (n = 180)	94.4	4.4	1.2
Jiangsu (n = 194)	97.4	2.6	0
Northwestern region			
Xinjiang (n = 124)	95.2	2.4	2.4

set of questions, we used "pest-resistant cotton" (*kangchong mian* in Mandarin), the popular term for Bt cotton used by Chinese farmers. A substantive proportion of the respondents (43.0%) stated that they had first learned about pest-resistant cotton through village and township officials (based at the agricultural technology and extension stations), while 39.9% had heard it through neighbors, family, and friends. The seed companies (which are not only newly established private enterprises but, in fact, also include the former state and collective seed companies) accounted for 11.4%; the media (TV, radio, and newspapers), for 4.5%; and other ways, for 1.2%. When we subsequently asked whether farmers had heard about "transgenic cotton" and the "Bt gene," the overall majority declared they had not heard of the former (85.1%) or about the latter (94.5%). It is interesting to note that most of the respondents who did know had learned about it via the media—63.4% for transgenic cotton and 82.0% for the Bt gene. The results indicate a clear knowledge gap about Bt cotton among Chinese farmers. In fact, 20.0% of them said they would like to have more information and practical training about the use of pest-resistant cotton varieties.

Perceived benefits

The next part of the survey contained detailed questions about farmers' perceptions on the benefits and drawbacks of Bt cotton. We first asked farmers their main motive why they opted for Bt cotton (only one answer possible). To this question, 79.1% responded because Bt cotton can control the bollworm. This answer is confirmed by the interviewees' responses to the perceived incidence of the bollworm. As Table 1 shows, in all of the three cotton-producing regions (Yellow, Yangzi, and Northwest), farmers maintain that the bollworm incidence has decreased. Farmers also say that they can save on labor input because they spray less pesticides than for conventional cotton (67.4% of the respondents, see Table 2).

Farmers do not perceive a significant difference in the seed quality of Bt cotton (expressed in terms of germination rate) versus that of non-transgenic cotton. Of the respondents, only 7.1% agree that Bt cotton seed is lower in quality than conventional cotton seed. We also tried to assess which types of Bt cotton seed varieties were preferred and which ones not. This question is severely complicated by the enormous variety of Bt cotton seed on the market (Xu et al. 2008, p. 1270). Officially there are only two types that have passed the national biosafety screening (one produced by Monsanto/Delta Pine Land and the other by the Chinese Biocentury Company of the Chinese Academy of Agricultural Sciences). In

Table 2 Farmers' views on Bt cotton use

Hypotheses	Definitely agree	Do not fully agree	Do not know	Definitely disagree
Pest-resistant cotton has lower productivity than conventional cotton	22.5	32.4	7.1	38.0
Pest-resistant cotton seed lower in quality than conventional seed	7.1	7.3	31.4	54.2
I save on labor, because pest-resistant cotton requires less pesticides	67.4	15.8	3.9	12.9
Production costs have not decreased, because pest-resistant cotton seed is more expensive	58.3	14.3	8.0	19.4
Pest-resistant cotton is only effective against bollworm, while other pests have increased	58.9	8.2	5.7	27.2

Source: Authors' survey (valid percentages; n = 88) reality, however, there is a large supply of illegal seed:

1. seed with the stolen Bt gene inserted into conventional varieties and sold without a biosafety approval;
2. official Bt Monsanto or Biocentury seed produced illicitly outside of stipulated quota agreed between the company and the seed production bases;
3. hybridized (and generally unapproved, thus illegal) seed of the F1 progeny derived by crossing transgenic cotton of the F0 generation with non-transgenic varieties, which has a higher productivity due to the heterosis effect; and
4. fake seed sold to cheat farmers, that is, either hybridized seed of the F2 generation with uncertain pest resistance and productivity or low-quality, non-transgenic seed sold as Bt seed (Ho et al. 2009).

During interviews with farmers in the Anhui province, we discovered that interviewees were dissatisfied with the 32B variety produced by Monsanto. They stated that its quality was worse in comparison with conventional cotton in terms of (1) smaller buds, (2) buds and bolls that fell off during warm weather (particularly in th eWuwei County), (3) a lack of pollen, and (4) a higher need for fertilizer (specifically potassium).[3] According to them, the only reason for choosing 32B was its pest resistance. A possible explanation for this might be that 32B is an older seed variety (and thus less adapted to local conditions). In fact, 32B is only used in Anhui; the other provinces make use of newer varieties such as 33B, 99B, or Zhongmian-29 of the Chinese Cotton Research Institute (see also Table 3). Broken down per province, we discovered that the dissatisfaction of farmers with official Bt cotton seed is limited to Anhui.[4]

[3]Interviews with farmers and officials of the Agricultural Committee of Chaohu Municipality, Wuwei and Wangjiang counties, Anhui Province, April 2004 and September 2004.

[4]The percentages of those agreeing with this statement in the other four provinces are low: 7.0% (Hebei), 12.7% (Shandong), 0% (Jiangsu), and 16.2% (Xinjiang).

Table 3 Overview of farmers' views on GM cotton seed varieties

Province	Seed variety									
	33B (Monsanto)	32B (Monsanto)	99B (Monsanto)	Jidai-22 (Monsanto)	Zhongmian-29 (China Cotton Research Institute)	Gaokang-9 (Biocentury)	Junmian-1 (Military company)	Lumian-22 (Anhui, Fengle Company)	Lumian-15 (Anhui, Fengle Company)	Nankang-36 (Nanjing, Hong Taiyang Company)
Hebei	Satisfactory		Satisfactory				X			
Shandong	X		Satisfactory	Satisfactory	X	X		Satisfactory	X	
Anhui		Unsatisfactory			Satisfactory				Satisfactory	
Jiangsu					Satisfactory				Satisfactory	Unsatisfactory
Xinjiang	Satisfactory		X			Satisfactory	Unsatisfactory			

Source: Authors' survey

There is an overwhelming variety of different GM cotton seeds in China, probably over 100 legitimate and illegal varieties. During a survey, we already discovered 19 types of GM cotton seed on sale in a single township in Anhui. To keep the table readable, we have only included seed varieties if a minimum of 20% of the respondents had rated it "satisfactory" or "unsatisfactory." If rated seed varieties are used in other provinces, but have not been rated by at least 25% of the respondents, it is marked with an "X". Seeds produced by joint ventures of Monsanto (such as Andai in Anhui or Jidai in Hebei) are listed as Monsanto seeds

Table 4 Average sprayings for Bt cotton and conventional cotton per region/province

Cotton type	Yellow River region		Yangzi River region		Northwest
	Hebei	Shandong	Jiangsu	Anhui	Xinjiang
Bt cotton	23	22	17	16	–
Conventional cotton	17	13	12	11	–
Average difference in sprays	6	9	5	5	–

Source: Authors' survey
Figures for Xinjiang could not be obtained due to logistical problems during the survey

Perceived drawbacks

Notwithstanding the clear benefits of Bt cotton in the combat against the bollworm, farmers also mentioned certain drawbacks. The first drawback is a lower productivity of Bt cotton versus conventional varieties, expressed by approximately a quarter (22.5%) of the farmers. This finding is a bit surprising. Hybridized Bt cotton seed (of the F1 generation), which is widely used in China, has a confirmed heterosis effect in the field and thus also a higher productivity than F0 Bt cotton. A second drawback farmers experienced is the higher price of Bt cotton seed as a result of which there were no savings on the overall production costs. From Table 2, we can see that this problem was noted by close to two thirds of the interviewees (58.3%). Our survey did not further investigate the two noted problems to draw firm conclusions from these results. The main problem that we explored in depth is the issue of secondary pests.

Bt cotton is often promoted with the argument that it reduces the number and quantity of pesticide applications. In this regard, we found it remarkable that during the pilot research, few farmers mentioned that the decrease in pesticide applications was their motivation to adopt Bt cotton.

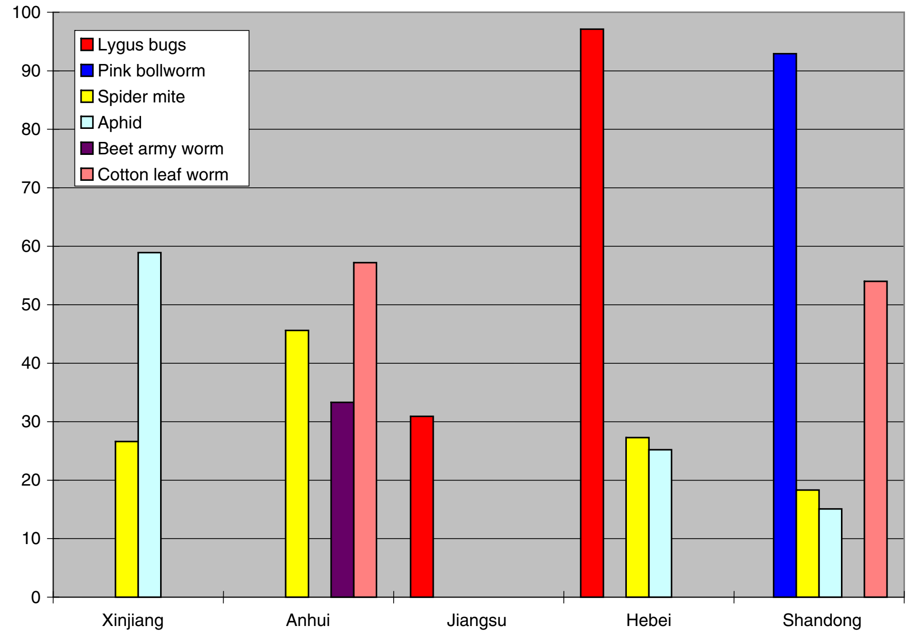

Fig. 1 Farmers perceiving "strong increase" of secondary pests (only percentages higher that 15% included). The eight tested secondary pests are cotton aphid (*Aphis gossypii*), cotton spider mite (*Tetranychus cinnabarinus*), cotton pink bollworm (*Pectinophora gossypiella*), beet armyworm (*Spodoptera exigua Hubner*), cotton leafworm (*Prodenia litura Fabricius*), sweet potato whitefly (*Bemisia tabaci*), greenhouse whitefly (*Trialeurodes vaporariorum Westwood*), lygus bug (*Adelphocoris saturalis*, *A. fasciaticolls*,*Lygus lucorum*, etc.)

This finding was confirmed during the full survey, with merely 0.9% of the respondents stating that the reduction in pesticide was the prime reason for adoption. The issue was further explored by probing into the frequency of pesticide applications prior to and after the introduction of Bt cotton. On average, the reported pesticide sprayings had decreased five to six times (see Table 4). These figures are substantially lower than the figures found through other surveys conducted elsewhere (e.g., Bennett et al. 2003; Thirtle et al. 2003; Pray et al. 2001). We suspect that these outcomes might result from the rise of secondary (including sucking) pests.

We then asked farmers to validate the hypothesis that "Bt cotton is only effective against the bollworm, while secondary pests have increased." Those who "definitely agreed" with this statement outnumbered those who "definitely disagreed" by a factor two (58.9% against 27.2%, see Table 2). Subsequently, farmers in the five different provinces were asked to specify the changes in secondary pests in terms of the insect type and the extent of the decrease/increase (strong, slight, or no change). As farmers generally started to cultivate Bt cotton in the time from 1996 until 2000, it implied that they assessed a period of 8 to 9 years. This question yielded three critical findings (see Fig. 1). First, all farmers across the three cotton-producing regions perceived a rise in secondary pests. Second, in all the provinces but one, there was an increase in two to four different pests. Third, the situation appears to be the worst in the Yellow River region with 97.1% of the Hebei farmers seeing a "strong" rise in lygus bugs (*Adelphocoris saturalis*, *A. fasciaticolls*, *Lygus lucorum*, etc.) and 92.9% of the Shandong farmers perceiving a sharp rise in pink bollworm (*Pectinophora gossypiella*).

Discussion and conclusion

Through a comprehensive set of interrelated survey questions, we have provided empirical evidence of farmers' perceptions on changes in sucking and other secondary pests. In the scientific literature, it is posited that secondary pests are likely to increase over time because of two factors: (1) the general ineffectiveness of Bt cotton against pests other than the bollworm and (2) a lowered dosage of pesticides in Bt cotton. As a result of this, secondary pests that would otherwise not have survived have a chance to emerge and, without additional pest control, could potentially evolve into primary pests (Xu et al. 2008, p. 1272; Men et al. 2004). Our study has found indications that support the possibility of such a scenario.

Farmers stated that the main reason for adopting Bt cotton is its pest resistance and not the reduction in pesticide applications (the latter reason mentioned by less than 1%). This is a minute but critical difference as demonstrated below. There is no doubt that farmers are satisfied with Bt cotton, as it has effectively brought the bollworm under control (in the sample provinces, over 90% of the respondents indicated a decrease in bollworm incidence). On the other hand, farmers are also faced with rising secondary pests. The overall majority of the farmers answered affirmative to the question whether secondary pests had increased since the start of Bt cotton cultivation. The type and level of secondary pests perceived shows regional variation, but in all of the three cotton-producing regions, a substantive proportion of the farmers (ranging from 30.9% to 97.1%) have perceived a "strong" increase of one or more secondary pests.

As secondary pests increase, farmers will need additional sprayings over time. Rural surveys conducted shortly after China's introduction of Bt cotton in 1996 reported reductions in pesticide applications. For instance, in 1999,[5] the research group led by Huang and Pray found a reduction in pesticide sprayings ranging from 12 to 3 times (Pray et al. 2001, p. 814; Huang et al. 2001, 2003; Pray et al. 2002). However, posing the same question 5 years later, we found that the average decrease in pesticide sprayings was significantly lower (five to six times).

Our survey results also indicated two other potential problems of Bt cultivation. First, we found that farmers have virtually no knowledge about

[5]Note that the data reported in this article were collected in 1999 and not in 2000 as is wrongly stated in the abstract of the article. See also p. 59 and Tables 3–6 in the same article (Huang et al. 2001).

Bt cotton and genetic engineering. A low level of understanding implies that farmers have no means to interpret possible agricultural production problems that they might encounter in the field. In particular, in the case of GM crops of which ecological effects are still insufficiently understood, it is important to raise farmers' knowledge by stepping up agricultural extension and practical training. Second, approximately a quarter of the farmers perceive a lower productivity of Bt cotton versus conventional varieties. In addition, close to 60% of the respondents finds that overall production costs have not decreased due to higher prices of Bt cotton seed. This result is in contradiction with that found in other research (Pray et al. 2001; Huang et al. 2001). As the bulk of our survey questions did not concern the economic profitability and productivity of Bt cotton, these two findings therefore deserve further investigation.

Various researchers have pointed to the potential environmental risks of Bt cotton (Qiu 2008; Wang et al. 2008; Qaim 2003, p. 2126). Due to the lack of scientific understanding of Bt cotton's ecological impact and the fact that ecological changes can only be monitored and evaluated on a long term, it is vital to adhere to the precautionary principle when biosafety issues are at stake. Bt cotton has a good potential in improving worldwide cotton production due to its effective resistance against the bollworm. At the same time, because of an evident rise of secondary pests, it is critically important to closely follow and assess its commercial production in the field.

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