University of Groningen

Farmers' knowledge and opinions towards bollgard II (R) implementation in cotton production in western Burkina Faso

Sanou, Edouard I. R.; Gheysen, Godelieve; Koulibaly, Bazoumana; Roelofs, Caspar; Speelman, Stijn

Published in:
New Biotechnology

DOI:
[10.1016/j.nbt.2018.01.005](https://doi.org/10.1016/j.nbt.2018.01.005)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2018

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Sanou, E. I. R., Gheysen, G., Koulibaly, B., Roelofs, C., & Speelman, S. (2018). Farmers' knowledge and opinions towards bollgard II (R) implementation in cotton production in western Burkina Faso. *New Biotechnology*, 42, 33-41. <https://doi.org/10.1016/j.nbt.2018.01.005>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Full length Article

Farmers' knowledge and opinions towards bollgard II[®] implementation in cotton production in western Burkina Faso

Edouard I.R. Sanou^a, Godelieve Gheysen^b, Bazoumana Koulibaly^c, Caspar Roelofs^d,
Stijn Speelman^{a,*}

^a Department of Agricultural Economics, Gent University, Belgium

^b Department of Molecular Biotechnology, Gent University, Belgium

^c Programme Coton, Institut National de l'Environnement et de la Recherche Agricole (INERA), Burkina Faso

^d Science and Society department — Energy and Sustainability Research Institute, University Groningen, The Netherlands

ARTICLE INFO

Keywords:

Genetically modified

Bacillus thuringiensis

Biotechnology

Refuge area

Bollgard II[®]

Transgenic cotton

ABSTRACT

In 2008, the commercial cultivation of Genetically Modified (GM) cotton (Bollgard II[®]) started in Burkina Faso. The adoption rate increased rapidly in subsequent years to reach around 70% in 2014. Although some criticisms were raised concerning the suitability of the technology for the farming system in Burkina Faso, the introduction of transgenic cotton in the country was generally regarded as a great success. Despite this, during the 2016–2017 agricultural campaign, the government of Burkina Faso decided to suspend the cultivation of Bollgard II[®]. In this context, this paper investigates farmers' knowledge, perceptions, opinions and attitudes towards Bollgard II[®] as well as their views on the recent decision to suspend its cultivation. Data was collected from 324 cotton farmers, both growers of conventional and Bollgard II[®]. The results showed that the farmers surveyed had a poor knowledge concerning the core concepts of biotechnology and Bollgard II[®] in particular. Moreover, the regulatory oversight of the implementation of the technology was found insufficient, as illustrated by the lack of compliance with prescriptions concerning refuge areas and pesticide treatments. Nevertheless, overall, the farmers interviewed had a slightly positive opinion about the effects on yield, income and their wellbeing. In particular the reduction in pesticide treatments was perceived very positively by all respondents. Although the study finds that the majority of farmers disagreed with the recent suspension of Bt cotton cultivation by the government, it also makes clear that a thorough debate on the technology and its implementation is necessary.

Introduction

Cotton (*Gossypium* L.) is one of the most important cash crops in West Africa and is a vital catalyst to economic development in the region [1]. In Burkina Faso, despite the recent reduction in the share of export earnings for cotton in favor of gold [2], cotton still remains the most important agricultural crop. In fact, the cotton sector not only provides labor for more than 350,000 farmers but also indirectly contributes to the livelihood of more than 3 million people, taking into account the entire chain and that of by-products, such as local oil factories and cattle food producers.

Around the year 2000, the government of Burkina Faso became interested in Genetically Modified (GM) cotton. At that time, the cotton sector in many developing countries was facing considerable problems with pest damage [3], a problem aggravated by global warming [4]. This interest was stimulated by the deteriorating socio-economic situation in the cotton sector [5] and by the findings of Burkina Faso's

National Agricultural Research Center (INERA) concerning the decreasing effectiveness of conventional chemical spraying methods [1] and their negative environmental and health impacts.

In collaboration with Monsanto, INERA began a 5-year program of field testing of Bollgard II[®], a second generation of *Bacillus thuringiensis* (Bt) improved cotton [1]. In parallel to the field testing, biosafety legislation and protocols governing regulatory oversight and approval of biotechnology products were developed by the government. Two regional Bollgard II[®] varieties were developed in 2008 and the Burkina National Biosafety Agency authorized these two Bt varieties for seed production and commercialization by national cotton companies. This was a significant milestone for Burkina Faso, being the first commercial use of Bt cotton in the country and the third commercial release of a GM crop in Africa [1,6,7].

However, this move was not viewed positively by all stakeholders. As in many developing countries, the debate around the adoption of biotechnology in agriculture is still ongoing and lags behind the

* Corresponding author at: Address: Coupure Links 653, 9000 Gent, Belgium.

E-mail address: stijn.speelman@ugent.be (S. Speelman).

technology uptake. The opponents of GM crops have argued that the introduction of agricultural biotechnology could threaten the survival of indigenous crops and would negatively affect biodiversity [8]. Besides, in Burkina Faso, the lack of farmers' knowledge regarding the correct use of Bt-technology was one of the main concerns of the opponents of GM crops. Along the same lines, Renaudin et al. [5], questioned the appropriateness of introducing GM cotton into the peasant production systems in Burkina Faso. They point to the lack of information disseminated to the cotton farmers regarding management of secondary pests and the concept of refuge areas, which are essential aspects of this new technology. Also Vitale et al. [6] show that this concern might be valid because farmers did not perform the recommended two late-season treatments to target the secondary pests that are not controlled by the Bt-technology.

The introduction of Bt cotton in Burkina Faso is often described as a success. For example, Vitale et al. [6,7,9,10], in a series of follow-up studies, report the rapid spread (covering 70% of the cotton area), yield performance (15–20% increase), improved economic returns for smallholder farmers and the health and environmental benefits due to reduced pesticide use. Other authors, such as Renaudin et al. [5] and Dowd-Urbe [11], are more critical and state that the social and agro-ecological context of adoption is not given sufficient consideration.

Moreover, there is a growing awareness among researchers that the voice of farmers needs to be heard in the GM debate [12]. In the light of the recent decision [13] by the Government of Burkina Faso to suspend the production of Bollgard II® cotton, and given the criticism that both the spread and suspension of Bt cotton happened in a top-down way, it is interesting to focus on the farmers' perspectives concerning this technology. In this framework, three objectives were identified. The first objective was to gauge farmers' understanding and knowledge about the concept of biotechnology and, more specifically, Bt-technology. The second objective was to assess the attitudes of farmers towards Bollgard II® and the third objective was to look at their experience with the Bollgard II® crop and their views on the decision to impose a suspension on its cultivation.

Background

Cotton was introduced in Burkina Faso in the 20th century [14]. Over time, Burkina Faso's cotton sector has seen lots of changes, among them the liberalization of the sector [15] as well as the creation of a special research program dedicated to the improvement of cotton production. Furthermore, in 1998, the National Union of Cotton Producers (UNPCB) was established in order to give farmers a voice in decision making. To date, the sector is administered by a dominant parastatal company (Sofitex) and two private companies (Socoma and Faso Coton). The traditional vertical integration between farmers and companies, in which the cotton industries provide inputs, such as seeds, pesticides, fertilizers, and technical advice still exists [16].

In 2008, Burkina Faso became the third African country, after South Africa and Egypt, to commercialize Bt crops [17]. The 2008 approval and production of seeds paved the way for the planting of 125,000 ha of Bollgard II® cotton in Burkina Faso in 2009 – the most extensive single-year biotechnology launch in Sub-Saharan Africa (SSA) to date [6]. In addition, one year later, the adoption rate had already increased to 29% and by 2014 it had reached 70% or a total of 454,124 ha [17,18]. In 2016, Pertry et al. [19] described the Bollgard II® case in Burkina Faso as a role model for sustainable cotton production.

Bollgard II® cotton requires only two insecticide treatments to control secondary pests such as aphids and jassids. This is in contrast to conventional cotton which requires six treatments, with the initial four targeting Lepidoptera and the last two targeting secondary pests. Growing Bollgard II® cotton was expected to increase yields by up to 30% and to reduce pesticide use with positive effects on farmers' health and the environment. INERA also recommended that the cotton

companies and the farmers' union (Union Nationale des Producteurs de Coton du Burkina, UNPCB) emphasize the need for effective implementation of two late-season treatments in order to guarantee yield improvement and compliance with structured refuge areas to prevent development of resistance to Bt toxins.

Overall, the effectiveness of Bollgard II® in terms of pest control was not questioned. There were only some concerns with respect to the financial risks for smallholders due to the high cost of the Bt seeds [5] or about the lack of an integrated pest management strategy by the cotton producers [5,6]. Nevertheless, in 2012–2013, the cotton companies reported a shorter fiber length in comparison to previous years. According to INERA, this observation was reported to Monsanto and both agreed to investigate the cause. In 2014, the use of the Bollgard II® variety was determined as the main source. In order to avoid cotton companies losing money on the international market owing to reduced fiber length, the tripartite framework (Monsanto, INERA and cotton companies) initially agreed to reduce the Bt cultivated land to 50% while trying to fix the genetic issue over a period of 3–5 years. In 2015, however, the permanent consultative framework (Association Inter-professionnel du Coton au Burkina, AICB) incorporating the government, the cotton companies and the UNPCB, urged for the suspension of Bollgard II® cotton cultivation and this decision was endorsed in 2016 by the government of Burkina Faso. This means that in 2016 only conventional seeds have been distributed by the cotton companies in Burkina Faso.

Materials and methodology

Study sites and sampling design

The study was conducted during the 2015–2016 agricultural season in western Burkina Faso – an area administered by SOFITEX (Société Burkinabe des Fibres Textiles). Sofitex is the largest of three cotton companies (see Fig. 1) covering more than 85% of the cotton cultivated land and representing about 80% of the national cotton production [2]. Three districts (Dedougou-Bobo-Diebouougou) were chosen along a north-south gradient presenting different agro-climatic characteristics. These districts include 7 of the 13 Sofitex cotton ginning factories. A total of 12 villages were selected for the study (4 per district). Given that cotton farmers are organized into groups in Burkina Faso (Groupement de Producteurs de Coton, GPC) at village level, and their individual interests could differ depending on the type of farmer (Small, Medium, Large) and/or the cotton variety grown (Bt or non-Bt), the sample was designed to allow a pairwise comparison between the growers of the different varieties as well as between the types of farmer. The position occupied by farmers in their GPCs (president, active member or simple member) was also considered. In total, 324 farmers were selected. Classification of farmers was made based on the total cotton acreage grown and the number of cattle pairs used for labor.

Structure of the questionnaire

The questionnaire focused on the appraisal of farmers' knowledge, perceptions, opinions and attitudes towards GM cotton production in Burkina Faso, as well as on their experience. The structure of the questionnaire is summarized in Table 1 (see annex). For instance, to gauge farmers' understanding about the use of Bt-technology, 4 statements were developed to which the farmer could answer Yes/Not sure/No. Furthermore, 7 and 3 point Likert scales were used, respectively, to measure farmers' opinions about the advantages of Bt-technology and about the recent decision to suspend Bollgard II® cotton production. Throughout the questionnaire, statements were formulated, both in positive and negative ways, in order to test the consistency of the responses given by farmers.

Fig. 1. Cotton growing zones in Burkina Faso (Sofitex, Socoma et Faso Coton).

Source: Vognan et al. [4]

Data collection

The survey team consisted of five students recently graduated from the Rural Development Institute of the Polytechnic University of Bobo Dioulasso. The students were selected according to their previous survey experiences and their native local language (Moore, Bobo, Dioula or Dagara) to enable coverage of the predominant languages in each district. Before interviews were initiated, the enumerators were trained and exposed to the objectives of the study. Surveys were conducted using a door-to-door strategy. Individual assessment was

adopted in order to avoid all external influences. Once at the farmer's home, the farmer was first informed about the purpose of the survey; then he was assured that his opinions would be kept confidential and that he did not have to represent the view of someone else. Each interview took about 45–60 min.

Statistical analysis

Data were analyzed using IBM SPSS Statistics (version 22). The data were summarized and descriptive data analysis was conducted using

Table 1
Structure of the questionnaire.

Clusters	Description	Method/tools	Target group
Farmers' knowledge and understanding	Knowledge about Biotechnology and Bt technology Understanding on the use of Bt technology	Yes/No (6 statements) Yes/No/Not sure (4 statements)	All farmers Type of farmers, Education level and Position in the GPC
Farmers' perception towards Bt technology effectiveness	Agricultural practices, pest control, labor times, etc.	True/False/Don't know (15 statements)	all farmers
Farmers' opinions about Bt technology advantages	yield performance, income gain, farmers wellbeing, etc.	7 points likert-type scale (from 1 = Strongly disagree,.... 4 = Neutral, ...to 7 = Strongly agree): 7 statements	Type of farmers (Small, medium and large)
Farmers' opinions regarding health and environmental effects of growing Bt cotton	Health benefit, environmental risk, etc.	True/False/Don't know (6 statements)	all farmers
Farmers' opinions about Bt seed cost?	Did farmers know how the Bt seed price was fixed? Is this price affordable for them?	Yes/No (3 statements)	all farmers
Farmers' attitudes to pest management	How many times have farmers sprayed their cotton fields this year?	Based on the declaration of farmers (1 statement)	Bt and Non Bt growers
Farmers's opinions and preferences regarding the decision to abandon Bt cotton	Do farmers know why this decision was undertaken? Do they agree with that?	Yes/No (2 statements) 3 point likert-type scale (Agree/Neutral/Disagree)	all farmers Bt and non Bt growers

Table 2
Basic demographic background of the farmers surveyed.

Parameters	No. farmers	Percentage (%)
Age		
up to 20 years	2	0.6
21–30 years	22	6.8
31–40 years	127	39.2
41–50 years	141	43.4
51–60 years	27	8.4
over 60 years	5	1.6
Education level		
Non	103	31.8
Non formal	159	49.1
Primary	37	11.4
Secondary	16	4.9
Formal agriculture background	9	2.8
Type of farmers		
up to 2 ha + 1 cattle pair (Small)	108	33.3
between 2 and 5 ha + 2 cattle pairs (Medium)	108	33.3
over 5 ha + more than 2 cattle pairs or tractor (Large)	108	33.3
Farmers Position in GPC		
President	51	15.7
Active member	90	27.8
Simple member	183	56.5
Experience		Mean (years)
Farmer overall experience in cotton	324	26.7
Average Bt-experience of Bt cotton growers	162	5.8
Average Bt-experience of conventional growers	162	2.4

Gender: 100% of farmers are males (N = 324).

means, frequencies and percentages. Chi-square and one-way analysis of variance (ANOVA) were conducted to assess differences between farmer types (small, medium, large), variety grown (Bt and Non-Bt) and education level, as well as their position in the GPC (president, active member, simple member).

Results

Basic demographic profile of farmers

All of the farmers surveyed (100%) were male and the majority were in the age groups 31–40 (39.2%) and 41–50 (43.4%) (see Table 2 in annex). Most farmers (over 80%) had not had any formal education. Only 2.8% of the selected farmers had received formal education in agriculture, 11.4% had followed primary education and 4.9% secondary. The overall experience of the selected farmers in cotton production was slightly greater than 25 years. Seven years after the introduction of Bollgard II® in Burkina Faso the farmers growing Bt had, on average, 6 years of experience with this crop, but even those not growing Bt at the time of the survey had tried it for 2 years, on average. The farmers interviewed held different positions within the GPC: President (15.7%), Active member (27.8%) and Simple member (56.5%).

Farmers' knowledge and understanding of biotechnology and bt-technology and its use

The majority of the farmers surveyed (over 90%) presented low awareness and a poor knowledge of the core concepts of biotechnology and Bt-technology (Table 3 in annex). Most terms and concepts appeared to be new for the majority of participants. In spite of the ongoing trials for two other GM crops (Bt maize and Bt cowpea) 97% of the farmers interviewed had not heard about any biotech crops other than Bt cotton. While the “No” respondents were the majority, a one way ANOVA was conducted to see whether this knowledge was influenced by education level. The test showed that there was a significant difference ($F(4, 319) = 215.22, p < 0.001$). The small group of farmers with a formal agricultural education background had significantly more

knowledge than those with Secondary, Primary, Non Formal and No education.

Farmers' understanding on the use of Bt-technology was tested using the four statements in Table 4 (see annex). More precisely, the knowledge about the two late-season insecticide treatments required and on the implementation of refuge areas was tested. Nearly 60% of the selected farmers asserted that the two late-season treatments were necessary to target secondary insects, whereas 32% of participants were “not sure” versus 8% who did not know anything about this. Regarding the required timing to apply the two late-season treatments, the “Yes” respondents presented a slightly higher percentage (42.9%) than the “Not sure” group (41.1%), while 16% of farmers surveyed did not really know. As regards compliance with refuge areas, most of the farmers (over 60%) were “Not sure” what this meant and how it worked. Moreover, nearly 30% of respondents did not know anything about refuge areas. Only 8% of participants knew what it was and only 3% were able to explain how a refuge strategy should be implemented. To explore whether or not there was a difference in understanding concerning Bt-technology implementation according to farmers' positions in the GPC, a one-way ANOVA was performed. A statistically significant difference was found ($F(2, 321) = 78.34, p < 0.001$). A post-hoc test (Scheffe test) indicated that the mean score for simple members was significantly ($p < 0.001$) lower than that of presidents and active members. Presidents and active members did not differ significantly ($p = 0.946$). The overall mean score for respondents was 0.29 (SD = 2.08, 95%CI = 0.06, 0.22).

Farmers' perceptions about bt-technology effectiveness in cotton production

To appraise farmers' perceptions about the effectiveness of Bt-technology, fifteen statements (Table 5 in annex) were designed around three keys points: agricultural practices, pest control and field management. The questions were formulated both as positive and negative statements comparing Bt and non-Bt cotton. Results show that farmers did not adjust agricultural practices when growing Bollgard II® cotton except for insecticide use. Over 95% indicated that they did not change input quantities (fertilizers, herbicides, labor etc.). Farmers agreed, however, that the quantity of insecticides used in Bollgard II® cotton production was reduced. In addition, the efficacy against lepidopteran insects is illustrated by the affirmation of the farmers that they never resort to any additional insecticide treatment to target these insects. Similarly, most farmers confirmed that Bollgard II® plants resisted lepidopteran insect attacks. Furthermore, the farmers interviewed stated that Bollgard II® cotton plants carry and retain more capsules than conventional cotton due to their resistance to lepidopteran insects. Overall, the majority of farmers expressed their satisfaction concerning the elimination of the first four pesticide treatments.

Farmers' opinions concerning bt-technology

Farmers' opinions about Bt-technology across three farmers' groups (small, medium, large) are reported in Table 6 (see annex). Regarding the positive yield performance, small scale farmers are least convinced that Bt cotton increases production ($M = 4.96, SD = 0.864$) compared to medium size farmers ($M = 5.84, SD = 0.877$) and large scale farmers ($M = 6.05, SD = 0.741$). Asking whether yield performance generated an income gain or not, small scale farmers partially agreed ($M = 4.81, SD = 0.855$), whereas both medium size ($M = 5.81, SD = 0.755$) and large scale farmers ($M = 5.87, SD = 0.628$) agreed on the increase in income. In addition, small scale farmers, on average, partially agreed that Bollgard II® cotton production improved their livelihood, living conditions and allowed them to increase their acreage due to the income gain. Medium and large scale farmers were slightly more positive about these effects. Moreover, farmers were asked whether Bollgard II® cotton growing enabled them to increase their land surface cultivated with cereals and to recover their debts from the cotton companies. The

Table 3
Farmers' knowledge towards Biotechnology and Bt technology core concept.

Statements	Yes		No	
	N	%	N	%
Q1. Have you ever heard about Biotechnology concept in agriculture?	31	9.6	293	90.4
Q2. Do you know that Biotechnology is a product of molecular biology based on genemanipulation and can be applied in agriculture improving local varieties?	11	3.4	317	96.6
Q3. Do you know that Bt cotton is a biotechnology variety?	31	9.6	293	90.4
Q4. Have you ever heard about another biotechnology crop other than Bt cotton?	7	2.2	317	97.8
Q5. Do you know that Bollgard II (Bt cotton variety) has been obtained by introducing a <i>Bacillus thuringiensis</i> gene into your local varieties (FK37 and SAM 59)?	20	6.2	304	93.8
Q6. Do you know that <i>Bacillus thuringiensis</i> is a bacteria and its gene gives power to plant to naturally defend itself against lepidopteran insect group in cotton production?	9	2.8	315	97.2

The highest scores are given in boldface. Cronbach's alpha = 0.828.

Table 4
Farmers' understanding of Bt technology use.

Statements	Yes		Not sure		No	
	N	%	N	%	N	%
Q7. Before growing Bollgard II, did you know that it requires only 2 late-season sprays targeting secondary insects?	192	59.3	105	32.6	27	8.3
Q8. Do you know at what stage of the production you may apply the 2 late-season sprays?	139	42.9	133	41.1	52	16
Q9. Before growing Bollgard II, did you have any idea about refuge area management intended to prevent lepidopteran insects' resistance?	26	8	202	62.3	96	29.6
Q10. Do you know how refuge area work?	12	3.7	212	65.4	100	30.9

The highest score are given in boldface. Cronbach's alpha = 0.859.

Table 5
Farmers' perception about Bt technology effectiveness.

Statements	TRUE		FALSE		Don't Know	
	N	%	N	%	N	%
Q11. Bt cotton production requires the same inputs quantity in term of mineral and organic fertilizers like conventional cotton production.	319	98.5	2	0.6	12	3.7
^a Q12. Bt cotton production changes my current agricultural practices such as labor, sowing, weeding, etc.).	–	–	312	96.3	12	3.7
^a Q13. Bt cotton increases my manpower (internal and/or external) compared to conventional cotton production.	–	–	312	96.3	12	3.7
^a Q14. Since I grow Bt cotton, the quantity of insecticides used doesn't change.	–	–	322	99.4	12	3.7
Q15. Except the reduction of the number of sprays, Bt cotton production does not present any difference compared to conventional cotton.	312	96.3	–	–	12	3.7
^a Q16. Bt seeds present a weak rate of germination compared to conventional cotton	2	0.6	312	96.3	10	3.1
Q17. Since I grow Bt cotton, the shedding of capsules attributed to lepidopteran insects attack has utterly disappeared.	312	96.3	–	–	12	3.7
Q18. Since I grow Bt cotton, my cotton plants retain more capsules owing to the absence of lepidopteran insects attack.	312	96.3	1	0.3	11	3.4
^a Q19. Bt cotton presents a long cycle of production comparing to conventional cotton.	–	–	315	97.2	9	2.8
Q20. Since I cultivate Bt cotton, I do not observe lepidopteran insects attacking and damaging my cotton field.	312	96.3	–	–	12	3.7
^a Q21. Since I grow Bt cotton, sometimes I use more than 2 sprays because of lepidopteran insect attack.	–	–	312	96.3	12	3.7
Q22. I agree that the Bt cotton variety that I grow resists quite well lepidopteran insects attack.	312	96.3	–	–	12	3.7
Q23. By cultivating Bt cotton I save much labor time due to the reduction of the number of sprays (2).	321	99.1	–	–	3	0.9
^a Q24. Bt cotton field management is more painful compared to conventional cotton	–	–	315	97.2	9	2.8
Q25. With Bt cotton, the painfulness due to spraying machine carrying is quite reduced.	321	99.1	–	–	3	0.9

^a Questions formulated in an opposite way. The highest scores are given in boldface. Cronbach's alpha = 0.962.

small scale farmers were, on average, neutral towards this, whereas both medium and large scale farmers were more positive and partially agreed. In order to test the hypothesis that farm size (small, medium, large) could have an effect on the level of satisfaction (using a scale from 1: Strongly disagree to 7: Strongly agree), ANOVA was performed.¹ This found a statistically significant effect $F(2, 321) = 22.189$, $p < 0.0001$. To further evaluate the nature of the difference between the three farm sizes, three Scheffe post-hoc tests were conducted. The mean score for small scale farmers ($M = 5.08$, $SD = 0.41$, $95\%CI = 4.99, 5.05$) was found to be significantly ($p < 0.0001$) different from that of medium size ($M = 5.44$, $SD = 0.54$, $95\%CI = 5.34$,

5.55) and large scale farmers ($M = 5.46$, $SD = 0.47$, $95\%CI = 5.37, 5.55$). Medium and large scale farmers did not differ significantly ($p = 0.976$). The overall level of satisfaction in the sample was 5.21 ($SD = 0.57$, $95\%CI = 5.1, 5.3$) reflecting that farmers have a partially positive attitude.

Farmers' opinions regarding the health and environmental effects of growing bollgard II[®] cotton

Based on the lower use of pesticides in Bollgard II[®] cotton cultivation, six statements were developed to capture farmers' opinions about health and environmental risk management. A combination of positive and negative statements was used. Outcomes reported in Table 7 (see annex) revealed that all respondents agreed entirely with the first three statements. They agreed that the reduction in pesticides used was

¹ First the assumption of homogeneity of variances was tested and satisfied based on the Levene's F test, $F(2, 321) = 0.395$, $p = 0.674$.

Table 6
Farmers' opinions about Bt technology advantages.

Statements	Small (N = 108)		Medium (N = 108)		Large (N = 108)	
	Mean	SD	Mean	SD	Mean	SD
Q26. Since I grow Bt cotton, yield increases in comparison to conventional cotton growing.	4.96	0.864	5.84	0.877	6.05	0.741
*Q27. Since I grow Bt cotton, my income gain is increasingly getting lower.	4.81	0.855	5.81	0.755	5.87	0.628
Q28. Since I cultivate Bt cotton, my livelihood has been improved owing to the high income.	5.20	0.707	5.36	0.779	5.40	0.896
*Q29. Bt cotton growing doesn't allow me improving my living conditions.	4.93	0.680	5.34	0.699	5.33	0.684
Q30. With Bt cotton, my income gain helps me increasing my cereals cultivated surfaces.	4.31	1.073	5.19	0.990	5.20	0.925
*Q31. With Bt cotton, my GPC use to face difficulties to cover debts of cotton companies.	4.04	0.669	5.10	0.785	5.02	0.736
Q32. The income generated in Bt cotton production allows me to gradually increase my land.	4.81	1.104	5.49	0.791	5.48	0.742

Statements marked with an asterisk were coded in the opposite direction because disagreement with such statement means a positive opinion towards Bt-technology. Cronbach's alpha = 0.752. On a scale from 1 = Strongly disagree to 7 = Strongly agree. SD: Standard Deviation. N: number of farmers.

Table 7
Farmers' opinions regarding health and environmental saving by growing Bt cotton.

Statements	TRUE		FALSE		Don't Know	
	N	%	N	%	N	%
*Q33. Reduction of number of sprays does not present any effect on my health.	–	–	324	100	–	–
Q34. Since I grow Bt cotton, my pains after sprayings are abated because of less sprays.	324	100	–	–	–	–
*Q35. Less use of insecticides doesn't protect our water sources.	–	–	324	100	–	–
Q36. By cultivating Bt cotton, we reject less pesticide containers in the environment.	322	99.4	–	–	2	0.6
*Q37. Bt cotton fields present a threat for my livestock feed.	2	0.6	321	99.1	1	0.3
Q38. Since I grow Bt cotton, I use to observe in my field bees, termites and ants.	320	98.8	2	0.6	2	0.6

^a Questions formulated with negative affect. The highest scores are given in boldface. Cronbach's alpha = 0.762.

beneficial for health; that it greatly reduced the burden of spraying and that, at the same time, it protected water sources. A large majority of the farmers also agreed that growing Bollgard II[®] did not constitute a threat to their livestock and that the presence of bees, termites and ants increased in their fields.

Farmers' attitudes to pest control management

The introduction of Bt cotton in Burkina Faso has eliminated the first four treatments targeting lepidopteran insects. However, the two late-season treatments against secondary insect attacks are still required. Table 8 (see annex) outlines farmers' pest management practices. Based on farmers' declarations regarding how many times they sprayed during the ongoing agricultural season, more than 80% of the growers (Bt and Non-Bt) confessed that they sprayed their cotton fields less than the number of times recommended by INERA. The majority (71%) of Bt growers sprayed once, whereas 75% of conventional farmers sprayed three times. The proportion of farmers who applied the recommended number of treatments was respectively 19% for Bt and 6% for Non-Bt growers.

Farmers' opinions about bt seed cost and the decision to forsake bollgard II[®] cotton

During the surveys, the Bt seed price (\$45/ha) was mentioned by the majority of the farmers as the main constraint for the adoption of Bt cotton. To collect farmers' opinions about the current price, three statements were developed. The first was to see whether they knew how the price was fixed; then they were asked to respond whether or not the Bt seed cost was affordable. The last statement sought to understand whether the current Bt seed cost enabled their GPC to cover the debts from cotton companies at the end of the agricultural campaign. According to the cotton companies, the Bt seed price is fixed with the agreement of UNPCB based on the following formula: (Non-Bt seeds + 6 sprays) cost = (Bt seeds + 2 sprays) cost. In this way, the higher price of Bt is offset by the elimination of four treatments. The results in Table 9 (see annex) showed that 91% of the farmers had no

Table 8
Farmers' attitudes in pest control management implementation.

Farmer type	Variety	Number of Sprays						
N = 324	N = 324	0	1	2	3	4	5	6
Small	Bt (n = 54)	16	32	6				
N = 108	Non-Bt (N = 54)		1	9	44			
Medium	Bt (n = 54)		42	12				
N = 108	Non-Bt (N = 54)			4	41	6	2	1
Large	Bt (n = 54)		41	13				
N = 108	Non-Bt (N = 54)				37	4	4	9
Total	Bt (%)	9,9	71	19,1				
(%)	Non-Bt (%)		0,6	8	75,3	6,2	3,7	6,2

*Chi square small (3) = 89.7, $p < 0.001$ *Chi square medium (5) = 96, $p < 0.001$ *Chi square large (5) = 108, $p < 0.001$ *Chi square total (6) = 283, $p < 0.001$. The highest scores are given in boldface.

Table 9
Farmers' opinions about the decision to forsake Bt cotton.

		1*	2*	3*
Bt Growers	N	3	15	144
	%	1.85	9.3	88.9
Non-Bt Growers	N	2	17	143
	%	1.2	10.5	88.3
Total	N	5	32	287
	%	1.5	9.9	88.6

The highest scores are given in boldface. 1* = agree, 2* = Neutral, 3* = disagree; *Chi square (2) = 0.328, $p = 0.849$.

idea about this formula. Furthermore, 90% of the participants judged that the current price is unaffordable. As to the last statement, a contradictory view emerged, with 56% of respondents agreeing and 44% disagreeing.

As described above, cotton companies first began reducing Bt cultivated land to 50% in the 2015–2016 rainfall season, followed by its complete suspension in 2016–2017. To assess farmers' opinions regarding those decisions, participants were first asked whether they

knew why the Government envisaged abandoning Bt cotton. A 3 point Likert-type scale (Agree/Neutral/Disagree) was used to collect farmers' views about the decision to suspend Bollgard II® cotton. The majority of the farmers interviewed (90.7%) stated that they were surprised at the beginning of the 2015–2016 agricultural campaign when the cotton companies decided which GPCs had to stop Bollgard II® cultivation. Similarly, slightly more than 90% of the participants indicated that they had no idea about the reasons that led to the decision to abandon Bt cotton. Subsequent to the limited knowledge about the reasons behind the decision to suspend Bollgard II® cotton, shown in our surveys, 88% of respondents disagreed with the decision to suspend Bt cotton, whereas 10% remained neutral versus less than 2% who agreed.

Discussion

The farmers in this study showed poor knowledge concerning the core concepts of biotechnology and Bt-technology. A similar observation of a very poor understanding, awareness and knowledge among farmers was also made by Lewis et al. [20] in Tanzania concerning GM technology and terminology. Despite the involvement of UNPCB throughout the Bt cotton introduction process and 7 years of experience with Bt cotton, many farmers were still unaware of the need to install refuge areas. However, the study found that farmers' understanding towards Bt-technology implementation in cotton production was strongly affected by the position they occupied in their GPC. Indeed, results revealed that presidents and active members of the GPC had an average knowledge while a large majority of the simple members were ignorant about the use of Bt-technology. This observation could be related to the cotton production system and service extension system in Burkina Faso. Due to the high number of GPCs (over 12,000), the training for farmers in field management is organized at departmental (or provincial) level and covers at least five villages, thus including more than 200 GPCs. Therefore, only the presidents and/or some active members attend this awareness training. In theory, the participants should update farmers who did not get the chance to participate. The same operating mode was used with the implementation of Bollgard II® cotton, with no changes, in spite of the recommendation by INERA urging emphasis on the two late treatments to target secondary insects and on compliance with the refuge strategy.

During the field visits, cotton companies' fieldworkers, commonly known as ATC (Agent Technique Coton) were also interviewed. They are elected to assist and monitor producers' field management. It was striking that most of them could not explain how the implementation of refuge areas works. Some who gave a correct explanation confessed that it was quite difficult to implement the refuge strategy without first changing farmers' behavior based on their current agricultural practices. Stone [21] warned that, in Warangal in India, the overall income gains from Bt cotton could be undermined by the widespread lack of understanding and practical implementation of refuges by farmers. The same was reported by Kruger et al. [22] in the context of Bt maize introduction in South Africa.

Our data also seem to suggest that the cotton companies in Burkina Faso gave insufficient support to the farmers with respect to Integrated Pest Management (IPM) strategies. As a consequence, the majority of the farmers surveyed, over 80% of both Bt and conventional cotton growers, do not respect the guidelines put forward by INERA in terms of spraying. In his research looking at the 2009–2010 season, Renaudin et al. [5] also found relatively low compliance with the recommendations among Bt growers, with 40% following the recommendations and an average spraying frequency of 1.1. Such low compliance was reported by Vitale et al. [6] as a threat for both yield and economic performance in Bollgard II® cultivation. In his study, conventional farmers, however, sprayed 5.7 times, on average, with 81% applying the six recommended treatments [5]. This has changed drastically in our study, where less than 10% of the conventional farmers comply. There might be several reasons for this. One reason might be the

existence of spillover effects due to a change in pest dynamics and pressure caused by the high coverage of Bt. Such effects have also been reported in other studies [23,24]. Another reason could be that farmers are reluctant to revert to spraying six times.² Discussion with farmers on the decision to suspend cultivation of Bt seems to confirm this, as many farmers claim that they will no longer apply the six recommended sprayings. Moreover, they feel that the spraying calendar, which recommends spraying every two weeks from the beginning of the seedling stage, is not sufficiently flexible.

Even after eight years of experience with Bollgard II® cotton, the majority of farmers claim that the right timing for the two late-season sprays is unclear and a large majority are unaware of the importance of the refuge areas. These observations support the claim made by Renaudin et al. [5] concerning the appropriateness of the introduction of Bt-technology into the farming system of Burkina Faso given the lack of information dissemination to the cotton farmers. In the long term, this will certainly have adverse effects and will negatively influence Bollgard II® cotton yield performance. Similarly, the importance of pest management practices was shown in a study by Berlin's Ecologic Institute [25]. Reviewing 721 case studies and comparing the yield performance of GM crops with conventional crops, they show that the highly different results in different countries can mostly be attributed to this. Recent studies in Benin [26], Kenya [27] and Pakistan [28] show that efficient integrated pest management remains a challenge, both in Bt and conventional cotton production. All these studies attribute this to the insufficient knowledge of farmers concerning the implementation of integrated pest control strategies.

The farmer's point of view on the social impacts of Bollgard II® cotton has also been tackled in this study, looking at aspects such as social wellbeing, economic resilience and environmental integrity. The opportunity to reduce pesticide quantities by two-thirds was cited as the main reason by the majority of farmers to explain the rapid adoption of Bt-technology. The technology not only improved their own wellbeing in terms of health, but also reduced the pesticide burden upon the environment. Furthermore, yield gains were also reported. This is in line with studies by Vitale et al. [6,7,10]. The same conclusion was reached by Renaudin et al. [5], who also highlighted the increased financial risks for smallholders due to the high cost of the Bollgard II® seeds. This study showed that the level of satisfaction of farmers regarding Bt-technology depends on the type of farmer (small, medium, large). While large and medium sized farmers tended to be largely positive, small scale farmers were more neutral. This finding of differential effects is in line with past studies in other countries. For instance, Subramanian and Qaim [29] in India also indicated that greater benefit is generated by larger farms and Arza et al. [30] demonstrated that, in Argentina, smallholders become increasingly reliant on middlemen with the introduction of Bollgard II® cotton, reducing the benefit. In contrast, Bennet et al. [31,32], in South Africa, found that smallholders obtain greater economic benefits from growing Bt cotton than farmers with more land. In Australia, Sanchez [33] showed that, due to successful pest management, benefits are shared by the different groups of farmers. Fischer et al. [34] reviewed 99 case studies and showed how the economic impacts of GM cotton adoption for different groups of farmers were very mixed and that the political and regulatory context had a significant impact on the ability of different groups of farmers in different locations to benefit. Specifically in Burkina Faso, the results from the previous studies did not specify differences between farmer groups [6,7,9,10].

The high seed cost was perceived by the majority of the farmers as the main constraint affecting the economic benefit of Bt cotton. While Renaudin et al. [5] demonstrated how economic benefit for small scale

² It is important to note that most of the farmers growing conventional cotton in our sample also have experience with growing Bt. This is related to the top down distribution of seeds by the cotton companies in Burkina Faso, which decide annually which type of seeds are distributed to each GPC.

farmers was impacted because of the extra seed cost in producing Bt cotton, Vitale et al. [6,7,10], in contrast, estimated that the higher seed costs for Bt were offset by the elimination of four treatments. As a consequence, they found no significant difference between production costs for Bt and conventional cotton. Subject to an in-depth investigation, our study notes that the higher seed cost for Bt will affect profitability. This is because nearly all farmers surveyed recognized that the recommended 12 kg of seeds per hectare for Bollgard II®, and even the 30 kg for conventional cotton, are insufficient. Therefore, they always use extra seed to overcome the lack of germination due to rainfall irregularity at the beginning of the sowing period. As a result, farmers used at least 1.5 bags of seeds (bag of 12 kg or 30 kg) instead of one bag (as advised) to sow one hectare.

Finally, the decision to suspend Bollgard II® cotton production in Burkina Faso was evaluated. It was shown that farmers and the government did not share the same point of view. As described above, in 2016, the issue of shorter fiber length for Bollgard II® cotton had already been known for some years, and the cotton companies and the Burkina Faso government were losing money on the international market. It should be noted that this did not translate into financial problems for farmers, as the Bollgard II® cotton farmer were rewarded according to the harvested yield. A breeding plan developed by INERA to maintain Bollgard II® whilst trying to resolve the issue together with Monsanto, in order not to disorient farmers in their current practices because of the familiarity created with Bollgard II® cotton, failed to convince the other stakeholders (cotton companies, AICB and the government). Therefore, the short term proposition by INERA to progressively reduce Bollgard II® cultivated land was only followed for one year (2015–2016). After that, the decision was taken to abandon Bollgard II® cotton. During our surveys, some farmers claimed that, due to the decision to reduce the area cultivated with Bollgard II®, they were obliged by cotton companies to grow conventional cotton against their will. As a consequence, certain farmers obtained Bollgard II® cotton seed from their friends in neighboring villages and mixed Bt and conventional cotton on the same plots. This shows that such a ban, opposed by the farmers, might result in situations such as that described by Fischer et al. [34] in Argentina and India where uncertified Bollgard II® cotton seeds of dubious quality circulated on the market. There is a risk of the proliferation of a black market for seeds, as has happened for mineral fertilizers and herbicides.

Conclusion and recommendations

This study focused on the perceptions and opinions of farmers in Burkina Faso concerning the cultivation of Bollgard II® cotton. Five main results can be highlighted:

- i) Knowledge of farmers concerning biotechnology and Bt-technology is limited and depends on their education level and their role within the GPC. The differences in knowledge are furthermore consolidated by the operating mode of the cotton companies, which does not involve simple members of GPCs in the awareness training provided by the fieldworkers from the cotton companies. As a result, not all information seems to trickle down.
- ii) The regulatory oversight of the implementation of Bt-technology is inadequate. This is illustrated by the lack of compliance with prescriptions concerning structured refuge areas. The risk of the non-implementation of the refuge strategy was ignored by both farmers and fieldworkers.
- iii) Farmers' compliance with recommended pest management strategies is low. Several farmers, for example, stated that Bollgard II® cotton does not require any treatment: "the main problem in cotton production is lepidopteran insects. So, with Bollgard II® cotton we don't need any insecticide treatments because the damage from secondary insects is not important". The specific recommendation for two late insecticide applications to control aphids and jassids

was only implemented by 19% of Bollgard II® cultivators. In contrast to earlier studies, the compliance of farmers growing conventional cotton with the recommended six sprayings was extremely low. Further research needs to be conducted to explain this trend.

- iv) Even though different appreciation levels for the income gain generated by Bollgard II® cotton adoption were observed between farmer groups, the study found that the majority of farmers were satisfied. However, the main constraint underlined by the farmers was the perceived seed cost. Most farmers do not realize that production costs are kept the same for conventional and Bollgard II® cotton, as some of the insecticide cost (in terms of the four early applications that are not needed) is included in the seed price for Bollgard II®. Investigation into the Bt seed pricing policy revealed that there was a greater divergence between the farmers' organizations and their base membership. While cotton companies stated that farmers are involved in the pricing strategy through their national union, farmers on the ground were unaware of what was decided and where the decision came from. This observation highlights the need to reinforce a mode of communication which would enable farmers to be regularly updated.
- v) Finally the decision to suspend Bollgard II® cotton in Burkina Faso was perceived to be bad by the majority of the farmers. Cotton producers are being paid for the cotton produced and they dislike the fact that four extra insecticide treatments will be needed once more and that the result will be a reduction in yield, and thus reduced income. There is a high risk that the majority of farmers will not respect the treatment guidelines for the production of conventional cotton and this is in the context of cotton production already characterized by a lack of integrated pest management.

To conclude, while the experience of Burkina Faso was perceived as a sustainable agricultural model, the adoption of Bt cotton in Sub-Saharan African (SSA) countries is now being hampered due to the ongoing debate around the quality of Bollgard II® fibers. However, to guarantee the success of Bt cotton in the farming system of Burkina Faso, after having fixed the fiber length issue, dissemination of knowledge needs to be improved, as highlighted by Renaudin et al. [5]. This extends to the general role of the government to create public awareness about biotechnology. Furthermore, to understand the gap between, for example, knowledge about pest management and compliance, adoption of a new multidisciplinary assessment approach will be required, taking into account parameters such as farmers' behavior. As Dowd-Urbe (2014) writes [11], throughout its evaluation it is crucial to focus on how this technology is embedded within a social and agro-ecological context. This will allow greater understanding of the impacts.

Acknowledgments

This work was supported by the ERAfrica FWO-project GA.013.14N. We are also very grateful to SOFITEX and INERA for their support during the surveys in Burkina Faso.

References

- [1] Vitale JD, Boyer T, Uaiene R, Sanders JH. The economic impacts of introducing Bt technology in smallholder cotton production systems of West Africa: a case study from Mali. *AgBioForum* 2007;10:71–84.
- [2] Food and Agriculture Organization Country Fact Sheet on Food and Agriculture Policy Trends. Country situation and Role of Agriculture. 2014. p. 6–9. Burkina Faso. September, 25.
- [3] Fitt GP. An Australian approach to IPM in cotton: integrating new technologies to minimise insecticide dependence. *Crop Prot* 2000;19:793–800.
- [4] Abate T, Van Huis A, Ampofo JKO. Pest management strategies in traditional agriculture: an african perspective. *Annu Rev Entomol* 2000;45:631–59.
- [5] Renaudin C, Pelc H, Opois J. Cotonnier genetiquement modifié: l'Experience d'une campagne agricole au Burkina Faso. *Cah Agric* 2012;21:1–6.

- [6] Vitale JD, Vognan G, Ouattarra M, Traoré O. The commercial application of GMO crops in Africa: Burkina Faso's decade of experience with Bt cotton. *AgBioForum* 2010;13:320–32.
- [7] Vitale JD, Greenplate J. The Role of Biotechnology in Sustainable Agriculture of the Twenty-First Century: The Commercial Introduction of Bollgard II in Burkina Faso. Sripada et al. *Convergence of Food Security, Energy Security and Sustainable Agriculture*. Heidelberg: Springer-Verlag Berlin; 2014. p. 67 chapter 11.
- [8] Ezezika OC, Daar AS, Barber K, Mabeya J, Thomas F, et al. Factors influencing agbiotech adoption and development in sub-Saharan Africa. *Nat Biotechnol* 2012;30:38.
- [9] Vitale JD, Glick H, Greenplate J, Abdennadher M, Traoré O. Second-generation Bt cotton field trials in Burkina Faso: analyzing the potential benefits to West African farmers. *Crop Sci* 2008;48:1958–66.
- [10] Vitale JD, Ouattarra M, Vognan G. Enhancing sustainability of cotton production systems in West Africa: a summary of empirical evidence from Burkina Faso. *Sustainability* 2011;3:1136–69.
- [11] Dowd-Urbe B. Engineering yields and inequality? How institutions and agro-ecology shape Bt cotton outcomes in Burkina Faso. *Geoforum* 2014;53:161–71.
- [12] James Jr. HS, Sulemana I. Case studies on smallholder farmer voice: an introduction to a special symposium. *Agric Human Values* 2014;31:637–41.
- [13] James C. Brief 52 global status of commercialized biotech/GM crops 2016. *Int Serv Acquis Agri-biotech Appl* 2016;52:11.
- [14] Perret C. Cotton. In: Brossard L, editor. *Regional Atlas on West Africa, West African studies*. Paris: OECD; 2009. p. 191–209.
- [15] Tumusiime E, Brorsen BW, Vitale JD. Vertical integration in West Africa's cotton industry: are parastatals a second best solution? *Agric Econ (United Kingdom)* 2014;45:129–43.
- [16] Theriault V, Serra R. Institutional environment and technical efficiency: a stochastic frontier analysis of cotton producers in West Africa. *J Agric Econ* 2014;65:383–405.
- [17] James C. ISAAA briefs brief 39 global status of commercialized biotech/GM crops: 2008. *ISAAA Briefs* 2009;317. no. Brief 46.
- [18] James C. Brief 49 global status of commercialized biotech/GM crops: 2014. *Int Serv Acquis Agri-biotech Appl* 2014;49:11.
- [19] I. Pertry, E.I.R. Sanou, S. Speelman, I. Ingelbrecht, The success story of Bt cotton in Burkina Faso: a role model for sustainable cotton production in other cotton-growing countries? In De Buck et al. *Innovative farming and forestry across the emerging world: the role of genetically modified crops and trees*. International Industrial Biotechnology Network (IIBN) e-book, 2016, pp. 81–93.
- [20] Lewis CP, Newell JN, Herron CM, Nawabu Tanzanian H. farmers' knowledge and attitudes to GM biotechnology and the potential use of GM crops to provide improved levels of food security. A Qualitative Study. *BMC Public Health* 2010;10:407.
- [21] Stone GD. Field versus farm in warangal: bt cotton, higher yields, and larger questions. *World Dev* 2011;39:387–98.
- [22] Kruger M, Van Rensburg JBJ, Van den Berg J. Transgenic Bt maize: farmers' perceptions, refuge compliance and reports of stem borer resistance in South Africa. *J Appl Entomol* 2012;136:38–50.
- [23] Wu K, Lu Y, Feng H, Jiang Y, Zhao J. Suppression of cotton bollworm in multiple crops in China in areas with Bt toxin-containing cotton. *Science* 2008;321:1676–8.
- [24] Hutchinson WD, Burkness EC, Mitchell PD, Moon RD, Leslie TW, et al. Area wide suppression of European Corn Borer with Bt maize reaps savings to non-Bt maize growers. *Science* 2010;330:222–5.
- [25] Kaphengst T, El Benni N, Evans C, Finger R, Herbert S, et al. Assessment of the economic performance of GM crops worldwide. Final report. Berlin: Ecologic Institute; 2011. p. 1–149.
- [26] Sinzogan AAC, Van Huis A, Kossou DK, Jiggins J, Vodouhè S. Farmers' knowledge and perception of cotton pests and pest control practices in Benin: results of a diagnostic study. *NJAS – Wageningen J Life Sci* 2004;52:285–303.
- [27] Midega CAO, Nyang'au IM, Pittchar J, Brikett MA, Pickett JA, et al. Farmers' perceptions of cotton pests and their management in western Kenya. *Crop Prot* 2012;42:193–201.
- [28] Khan M, Damalas CA. Farmers' knowledge about common pests and pesticide safety in conventional cotton production in Pakistan. *Crop Prot* 2015;77:45–51.
- [29] Subramanian A, Qaim M. Village-wide effects of agricultural biotechnology: the case of bt cotton in India. *World Dev* 2009;37:256–67.
- [30] Arza V, Goldberg V, Vazquez C. Argentina: dissemination of genetically modified cotton and its impact on the profitability of small-scale farmers in the Chaco province. *Cepal Rev* 2013;107:127–43.
- [31] Bennett R, Ismael Y, Morse S, Shankar B. Reductions in insecticide use from adoption of Bt cotton in South Africa: impacts on economic performance and toxic load to the environment. *J Agric Sci* 2004;142:665–74.
- [32] Bennett R, Morse S, Ismael Y. The economic impact of genetically modified cotton on South African smallholders: yield, profit and health effects. *J Dev Stud* 2006;42:662–77.
- [33] Sanchez D. Genetically modified crops: how attitudes to new technology influence adoption. Rreport. Securing Australia's Future (SAF) project 05. 2015. March.
- [34] Fischer K, Ekener-Petersen E, Rydhmer L, Björnberg K. Social impacts of GM crops in agriculture: a systematic literature review. *Sustainability* 2015;7:8598–620.