Yield and economic performance of the use of GM cotton worldwide over time

A review and meta-analysis

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Abstract

Purpose – The purpose of this paper is to provide an overview of the current state of knowledge on the economic performance of genetically modified (GM) cotton worldwide based on a wide range of data and source from available literature, and second to assess yield gain and economic performance.
Design/methodology/approach – A systematic review was captured to provide the evidence of potential benefits of GM cotton. A country-specific analysis was conducted in order to compare economic indicators and employed meta-analysis to find out the significance of the different of GM cotton over its counterpart.
Findings – This paper depicts positive impact of commercialized GM cotton in terms of net revenue, and the benefits, especially in terms of increased yields, are greatest for the mostly farmers in developing countries who have benefitted from the spill over of technology targeted at farmers in industrialized countries.
Research limitations/implications – Due to the variability of the data which came from different methodologies, it is difficult to determine the differences of the performances each individual study.
Practical implications – This, it is believed that results from this study can be useful for operations of all sizes as the authors think about what needs to be focussed on for long-term producers survival.
Originality/value – The paper clearly indicates that China is the highest cotton yield of GM cotton, the lowest cost of GM seed and the lowest cost of chemical spray compare to any other countries.

JEL Classifications — A1, C120, C180, N55, Q18, P26

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Therefore, this is the fact that the adoption of GM cotton has been widely spread among the farmers across the regions in China.

Keywords Agriculture, Benefits, Effects, Cotton growers

Paper type General review

1. Introduction

The benefits of genetically modified (GM) cotton continue to be disputed, despite rapid and widespread adoption since their commercial introduction in the USA in 1995 and first planted in 1996 (James, 2009). Since its 1996 debut on US cotton farms, according to James (2012) biotech cotton reached 24.3 million hectares in 2012 down from the 24.7 million hectares grown in 2011. With lower global price of cotton, the area planted to biotech cotton globally in 2012 was down by half a million hectares from a record 24.7 million hectares in 2011. Based on a global hectarage of 30 million hectares, 81 percent or 24.3 million hectares, were biotech cotton and grown in 15 countries. Four countries grew more than 1.0 million hectares, in descending order of hectarage, they are: India (10.8 million hectares), USA with (4.4 million hectares), China (4.0 million) and Pakistan (2.8 million hectares).

It is now almost two decades since the first GM crops were introduced into agriculture. Since the first commercialization of GM cotton, during the decade 1995-2013, several studies on GM cotton in developing countries claimed that its use bring benefits to smallholders because it increased yields (Zhao *et al.*, 2011), and according to Kaphengst *et al.* (2011), there is substantial evidence that the adoption of Bt cotton provides economic benefits for farmers in a number of countries. In relation to socio-economic impacts, Carpenter (2010) reveals that covers 12 countries worldwide and summaries results from 49 peer-reviewed publications based on report on farmers surveys comparing yields and other indicators of economic performance for adopters and non adopters of being commercialized GM crops indicated that benefits from growing GM crops mainly derive from increases yields, which are greatest for small scale farmers in developing countries insofar as they have benefitted from the spillover of technologies originally targeted at farmers in industrialized countries. Smale *et al.* (2006) review the methods and findings of 47 peer-reviewed "Bt cotton" papers published since 1996, and conclude that the economic benefits are promising even if evidence for a sustained impact is not yet apparent. Although, lots of review papers have concentrated on the benefit from the deployment of GM cotton (Carpenter, 2010; Smale *et al.*, 2006; Kaphengst *et al.*, 2011), fewer of them focussed on the yield and economic performance of GM cotton compared with their non GM counterparts through the systematic review and meta-analysis. Therefore, at this point, more specifically, it is noteworthy to point out that the main objective of this paper is to review the wide range of meta-data from the individual studies which focussed on yield performance and economic performance in order to documented the potential benefits of using GM cotton over its counterparts. A literature review of academic articles, news articles and publicly available project documents were considered in this paper. A country specific analysis has been tested by SPSS 20.0 using one-sample *t*-test. In this study we conducted meta-analysis as statistical techniques for combining the finding from independent studies. Potential biases also were discussed as descriptive analysis based on the study findings. A potential weakness of this study is that due to the variability of the data which came from different methodologies, therefore, it is difficult to determine the differences of the performances each individual study. Nonetheless, it is believed that results from this study can be useful for operations of all sizes as we think about what we need to focus on for long-term cotton growers survival.

2. Methodology

2.1 Sampling approach and data

Collecting data and information in this study were undertaken from the country of China, India, USA and Australia as the core element and set as data base then adjusted by taking into account, in particular, the condition under which key parameters of economic performance reported in the literature. This literature was formed as the backbone of this study providing data and information associated with economic indicators on GM cotton performance. Many publications used as a data source for this study had to contain raw data on at least one of the parameters of economic performance of GM cotton and its counterparts: fiber yield, revenue, gross margin or costs (of seeds, management labor, pesticides and herbicides).

In order to collect the literature, a keyword search was carried out initially on specific literature databases such as the web of sciences, the web of knowledge, Research Paper in Economics (RePEc), Research in Agricultural and Applied Economics (AgEcon-search) and others, while further sources will search through google-scholar. The key words "GM cotton," "transgenic cotton," "Bt cotton," "economic performance," "input cost," "yield," "benefit," "income" or "revenue," etc. and combinations were used. To ensure that the data had not been repeated or even misinterpreted in the source document, the screening of the publication often led to another source to track primary data. Such an approach was considered to be necessary in order to avoid the publication of data and possible bias derived from citation and re-interpretation of data by different authors (Finger *et al.*, 2011). The literature search was focussed on publication in English which published between 1996 and 2012. Based on a comprehensive reference list a database was set up that was used for the subsequently presented meta-analyses. To guarantee comparability, data were entered in identical units and this often required the conversion of values. Values in various currencies were converted to US Dollars using the average exchange rate of the year of the study. All area values were entered in (and if necessary, converted to) hectares and weight measure were entered in Kg.

The database was designed which consists of a number of different sources which only publication that contained data on at least one of the investigate economic parameters (yield per hectare, costs of herbicide and pesticide per hectare, seed costs and gross margin per hectare) rather than qualitative statements would be considered in the database and by indicating the methodology of data collection applied in the study (field trials, surveys, reviews, etc.). This allowed for the classification of publication and a study according to its scientific reliability.

In total, we observed 129 papers which included peer-reviewed scientific articles as well as non peer-reviewed sources which include raw data on the economic parameters. However, only 53 papers were selected and were considered to analyze. An overview of those papers used in this review, including author, year of the data, year of publication and country observations, is presented in Table I. Non peer-reviewed sources in general from governmental organizations or agencies/institutes funded by governments, official international and national statistics as well as conference proceeding, and also from academic, governmental, from civil society or from a company. Following the methodology outlined above, studies of non peer-reviewed sources that were used in peer-reviewed publication to conduct comparative analysis, were entered in the database by assigning a conductor of the study, which can be academic, governmental, from civil society or from a company.

In order to assess the economics performance between transgenic cotton and non transgenic cotton over time, country specific analysis have been done by

No.	Authors	Year of the data	Location
Country: China			
1.	Huang *et al.* (2002a, b)	1999	Hebei, Shandong
2.	Huang *et al.* (2002a, b)	1999	North China (not clear)
3.	Huang *et al.* (2002a, b)	1999, 2000, 2001	Hebei, Shandong, Henan, Anhui, Jiangsu
4.	Huang *et al.* (2002a, b)	1999	Hebei, Shandong
5.	Huang *et al.* (2003)	1999	Hebei, Shandong
6.	Pray *et al.*, (2002)	1999, 2000, 2001	Hebei, Shandong, Henan, Anhui, Jiangsu
7.	Fan (2005)	1999, 2000, 2001	Hebei, Shandong, Henan, Anhui, Jiangsu
8.	Xu *et al.* (2004)	2002	Jiangsu
9.	Pray *et al.* (2001)	1999	Hebei, Shandong
10.	Pemsl *et al.* (2011)	2002, 2005	West of Shandong
11.	Pemsl *et al.* (2008)	2002, 2005	Shandong province
12.	Pemsl *et al.* (2005)	2002	Shandong province
13.	Yang *et al.* (2005)	2002	Shandong
14.	Waibel *et al.* (2005)	2002	Shandong
15.	Dong *et al.* (2004)	2001, 2002	Hebei, Shandong, Jiangsu
16.	Sun *et al.* (2000)	1999	Shandong
17.	Fok and Xu (2007)	2005	Jiangsu
Country: India			
18	Stone (2011)	2003, 2007	Warangal District
19.	Kathage and Qaim(2011)	2002-2004, 2006-2008	Central and Southern India, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu
20.	Sadashivappa and Qaim (2009a, b)	2002-2003, 2004-2005, 2006-2007	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu
21.	Subramanian and Qaim (2009a, b)	2002-2003, 2004-2005	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Kanzara village
22.	Qaim (2003)	2001	Central and Southern India
23.	Morse *et al.* (2005)	2002-2003	Vidharba, Marathwada, Khandesh
24.	Pemsl *et al.* (2004)	2002	Karnataka
25.	Subramanian and Qaim (2010)	2002-2003 2004-2005, 2006-2007	Kanzara
26.	Loganathan *et al.* (2009)	2004-2005	Tamil Nadu
27.	Bennet *et al.* (2006)	2002-2003	Maharashtra
28.	Gandhi and Namboodiri (2006)	2004	Gujarat, Maharashtra, Andhra Pradesh, Tamil Nadu
29.	Narayanamoorthy and Kalamkar (2006)	2003	Maharashtra
30.	Qayum and Sakkhari (2006)	2002-2003, 2003-2004, 2004-2005	Andhra Pradesh
31.	Sadashivappa and Qaim (2009a, b)	2002-2003, 2004-2005, 2006-2007	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu
32.	Orphal (2005)	2002/2003	Karnataka
33.	Gauraf and Mishra (2012)	2009-2010	Gujarat
34.	Naik (2001)	1998-1999/2000-2001	na
35.	Bennet *et al.* (2005)	2003-2004	Gujarat
36.	Patil *et al.* (2007)	2003-2004, 2004-2005, 2005-2006	na

(*continued*)

Table I. Overview of empirical studies of meta data analysis

No.	Authors	Year of the data	Location
Country: USA			
37.	Jost *et al.* (2008)	2001-2004	Georgia
38.	Bryant *et al.* (2003)	1998-2000	Arkansas
39.	Allen *et al.* (1999)	1998	Arkansas
40.	Tingle *et al.* (2001)	2000	Arkansas
41.	Reed *et al.* (2009)	2008	Alabama
42.	Reed *et al.* (2010)	2008-2009	North Alabama
43.	Patterson *et al.* (2012)	2010-2011	Alabama
44.	Guidry *et al.* (2010)	2009	na
45.	Boman *et al.* (2005)	2004	Texas
46.	Johnson and Blackshear (2004)	1998-2000	Texas
47.	Ward *et al.*, (2006)	1999	Georgia
Country: Australia			
48.	Fitt (2003)	1996/1997-2000/2001	Northern Australia.
49.	Pyke (2000)	1998/1999	Emerald/Central Queensland
50.	Doyle *et al.* (2002)	2001/2002	Southern New South Wales
51.	Hoque *et al.* (2000)	1999	New South Wales
52.	Richards *et al.* (2007)	2005-2006	New South Wales
53.	Strickland and Annels (2005)	2002	Kununurra

Note: na, Not available

Table I.

using SPSS 20.0. with one-sample *t*-test for compare means. This analysis had rely on mean values from the literature, as most of the studies used do not provide for the raw data.

2.2 Meta-analysis

From that we selected 53 papers which considered into the database for meta-analysis, we focus on yield and net return as the economic performance. Therefore, 46 papers have been successfully considered into the yield meta-analysis, and 29 papers as net return meta-analysis). In this analysis data from individual studies may be pooled quantitatively and reanalyzed using established statistical methods. Meta-analysis if trials provide a precise estimate of treatment effect, giving due weight to the size of the different studies included. The rationale for meta-analysis is that, by combining the sample of individual studies of the treatment of GM cotton and non GM cotton, the overall sample size is increased, thereby improving the statistical power of the analysis as well as the precision of the estimates of treatment effect by using GM cotton and its conventional. In this study we applied STATA 12.1 as the statistical tool to analyze the meta-data based on the database set.

There are two statistical models in meta-analysis, namely, the Fixed Effect Model and the Mixed or Random Effect Model. A fixed effects model assumes a normal distribution, a single true effect size in the population, and variation across studies due to sampling error only. The random effects model assumes that effect size across studies and provides a method to estimate the average effect size (Borenstein *et al.*, 2009). In our study this would be assumed that factors or economic indicators vary from region to region across countries or may have changed over time. By using a mixed model (both fixed and random effects), we get the advantages of the random effects model, but also gain a method for controlling heterogeneity (Cooper and Hedges, 1994; Rosenberg *et al.*, 2000; Borenstein *et al.*, 2009). The significance of the residual heterogeneity, τ^2, was tested in each meta-analysis. The metan command, by default, will calculate the Q-test for the heterogeneity and I^2 to assess the degree of heterogeneity. Metan now displays the I^2 statistic as well as Cochran's Q to quantify heterogeneity, based on the work by Higgins and Thompson (2004) and Higgins *et al.* (2003). Briefly, I^2 is the percentage of variation attributable to heterogeneity and is easily interpretable. Cochran's Q can suffer from low power when the number of studies is low or excessive power when the number of studies is large.

The absence of heterogeneity is usually tested using Q (Cochran, 1954), which under a fixed effects *Ho* ($\tau^2 = 0$) is given as the weighted sum of squared differences between individual mixing effects and the meta-effect. For comparability reasons, Q may be better reported as the percentage of variation across effect sizes that is due to the heterogeneity rather than chance (Higgins and Thompson, 2004; Higgins *et al.*, 2003), having I^2 is calculated from the results of the meta-analysis by:

$$I^2 = 100\% \times \frac{(Q - df)}{Q} \tag{1}$$

where Q is Cochran's heterogeneity statistic and df is the degrees of freedom. Negative values of I^2 are set to zero so that I^2 lies between 0 and 100 percent. A value of 0 percent indicates no observed heterogeneity, and larger values show increasing heterogeneity. Although there can be no absolute rule for when heterogeneity becomes important, Higgins *et al.* (2003) tentatively suggest adjectives of low for I^2 values between 25 and 50 percent, moderate for 50-75 percent, and high for 75 percent. Empirical Bayes variables are estimates of effect and standard errors for each study that take into account within and between study variance.

In contrast to Q, I^2 can be directly compared between meta-analysis with different number of studies and different combinations of covariate, and it was thus used to quantity the importance of introducing a covariate or a factor to a meta-regression model. Therefore, the I^2 is effectively the percentage of variance explained by heterogeneity, and measures whether the observed variance is greater than would be expected by chance. Our general interpretation of heterogeneity is that I^2 of 50 or less is desirable. An I^2 value between 50 and 75 is interpreted as likely measuring a single latent variable, but needs to be standardized. I^2 values over 75 are addressed individually.

3. Limitations and scope of the study

The aims of this study are to provide an overview of the current state of knowledge on the economic performance of GM cotton worldwide based on a wide range of data and sources from available literature and secondly, to assess the economic performance. In order to assess the economic performance of GM cotton, economic indicators such as yield, seed costs, pesticide costs, management and labor costs were chosen. This analysis summarizes results from 53 peer-reviewed publications reporting on farmers surveys and field trials that compare yields and other indicators of economic performance for adopters and non adopters of currently commercialized GM cotton.

Due to the strong variation in data presented in the different publication and for analytical reasons, gross margin per hectare was regarded as the most comprehensive measure to compare the economic performance of GM over conventional cotton, as it captures both costs and benefits which are often not further specified in the studies. However, it must be acknowledged that the ways in which gross margin was calculated did vary between studies which came from different geographical conditions, site specific, and climatic condition, making it difficult to directly compare values. And it is important to note that the analysis of yield differences is complicated by differences in yield potential and other characteristics of background germplasm that may differ between the varieties that are available with and without the engineered traits.

We should note that, in meta-analysis, data from the individual studies are not simply combined, as if they were from a single study. A major drawback of this model, however, is that there is no way to control for heterogeneity. Results in this study provides the information that some of the single studies either GM cotton effect or non GM cotton effect is likely to be closer to the true effect that we are trying to estimate.

4. Yield and economic performance of gm cotton: insights from China, India, USA and Australia

Vast literature has accumulated since transgenic cotton varieties were initially launched to farmers in 1996. More than six teen years after their introduction in the USA, GM cotton with transgenic resistance to insects or herbicide tolerance were supplied to farmers in countries with developing economies and non industrialized agriculture.

Bt cotton farmers in China are typically small producers and are usually resources poor and risk aversive with an average crop area of $<1\lambda$ ha per household, of which the cotton area $<0.5\lambda$ ha (Huang *et al.*, 2002b). Previous economic analysis based on comparison between Bt and non Bt cotton and farmer studies have shown that Chinese farmers decrease the application of pesticide, save labor inputs and reduce farmers exposure to highly toxic pesticide by adopting Bt cotton (Yang *et al.*, 2005). Paper by Pray *et al.* (2001) depicts that surveys of cotton growers indicated that resource-poor, small farmers obtained bigger yield gains and profits from adopting transgenic cotton than wealthier, larger farmers. The primary benefit of transgenic cotton over conventional cotton in China has been reduced insecticide use. As a result of greater protection against bollworm damage with transgenic cotton 47-75 percent less kilograms of insecticide, or 4-13 fewer insecticide applications, were needed to control these pests, reductions in insecticide use associated with transgenic cotton have varied regionally, and in regions where bollworms are not the primary cotton pests, farmers growing transgenic cotton observed a decrease in their insecticide use as low as 14 percent (Huang *et al.*, 2002c). Therefore, farmers in regions with few bollworms may not benefit as much from adopting transgenic cotton as farmers in areas where bollworm are key pest.

To assess the impact of GM cotton in China, a series of surveys has been conducted by Huang *et al.* (2002b) from 1999 to 2001 in five villages (Hebei, Shandong, Henan, Anhui and Jiangsu) which shows that Bt cotton variety yields are higher than its counterparts. For instance, in the year of 2001 when comparing yields for all surveyed farms, Bt cotton were about 10 percent higher that slightly higher compare to conventional cultivars. Meanwhile, in terms of net revenue, non Bt cotton was lower than Bt cultivars due to the number of chemical spray. Therefore, there is no doubt that the Bt cotton are becoming resistant to bollworm and suggest that farmers may be learning to better manage Bt cotton varieties, thus obtaining higher revenue. Some economic studies are highly enthusiastic about the merits of the technology for Chinese farmers, although a considerable number of studies were conducted to assess the farm level impact of Bt cotton in China, none of the studies has uses actual panel data. A panel data survey was conducted by Pemsl *et al.* (2011) which has collected data in five villages in Linqing County located in Shandong Province during the 2002 cotton season and was applied for the same set of farmers in 2005. Although, the average of Bt cotton yield in 2002 was higher than in 2005, the gross margin of Bt cotton farmers in 2005 was higher than in 2002 due to the increased cotton prices in 2005 by about 40 percent at that time the 2005 crop was harvested. Surprisingly, the Bt cotton area has decreased from 64.4 percent of total land in 2002 to 41.9 percent of total land in 2005. This indicating the potential for profitability in terms of the effectiveness of Bt cotton in China, although it is not representative for country. The promise of major merits of Bt cotton in China is still no doubt when compare with non conventional cultivars particularly in terms of yield potential and net revenue derived from planting transgenic cotton. According to Pray *et al.* (2011), it is notable that Bt cotton net revenue have fluctuated trend from 1999 to 2007, meanwhile conventional varieties have upward trend from 1999 to 2007 and the year of 2007 is the highest net revenue of Bt cotton probably due to the high yield cotton price at that time. This is reasonable because the yield Bt cotton in 2006 were higher than in 2007 but in contrast the net revenue in 2007 was higher than in 2006. The yield of conventional cotton is not stable, however, the net revenue of conventional cotton gradually increased from 1999 to 2007, this is due to the high yield cotton price of conventional cotton that is indicate improved. Moreover, the net revenue of Bt cotton and its counterpart in 2004 and 2006 was not significantly different, meanwhile the cotton yield of Bt and non Bt in 2004 and 2006 was highly different. It is also indicated that the conventional cotton more effective in terms of economic benefits at that time.

In India cotton is an important cash crop and plays a significant role in the national economy, contributing about Rs 360 biliion (US$8 billion) toward export income and 4 percent of GDP. It is estimated to support about 60 million people, including farmers who cultivate the crop and those involved in the cotton industry for processing and trading (Manjunath, 2011). India planted the largest area to biotech cotton at 10.8 million hectares due to significant gains in production, economic, environmental, health and social benefits (James, 2012). Most of Bt cotton growers in Indian, like in China, are small-scale farmers; several studies in the past of ten years Bt cotton commercialization have shown that they benefit considerably from adopting this technology in terms of reduction in pesticide use and higher effective yield (Bennet *et al.*, 2006, Kambhampati *et al.*, 2006; Pray *et al.*, 2002; Qaim *et al.*, 2006). Field trials in 2001 revealed a yield increase of 30-80 percent for transgenic hybrids over their conventional hybrid counterpart (Qaim, 2003). Surveys in 2002 and 2003 reflected that smallholder farmers growing Bt cotton in several regions had significantly higher yields (3,463 percent) than those who grew conventional cotton (Bennet *et al.*, 2006; Qaim *et al.*, 2006). Before the introduction of Bt cotton in India, many farmers were often unable to adequately control bollworm despite the use of insecticide (Qaim and Zilberman, 2003). Morse *et al.* (2005) based on the data collected for a total of 7,793 cotton plots in 2002 and 1,577 plots in 2003 stated that while the cost of cotton seed was much higher for farmers growing Bt cotton relative to those growing non Bt cotton, the cost of bollworm spray much lower. While Bt plots had greater costs (seed plus insecticide) than non Bt plots, the yields and revenue from Bt plots were much higher than those non Bt plots (some 39 and 63 percent higher in 2002 and 2003, respectively). The gross margin of Bt plots were some 43 percent (2002) and 73 percent (2003) higher than those of non Bt plots (Morse *et al.*, 2005). Bt plots had higher yields and revenues compare to non Bt, while costs were typically higher for Bt they were not so much higher as to negate a substantial advantage in gross margin. Given the yield advantage of Bt over non Bt is maintained and provided the price for the product is not much lower than non Bt, then it can be assumed that the gross margin benefits are likely to continue in the short to medium term.

Generally, Bt technology can influence cotton profits mainly through three channels, namely, alters in yields, changes in pesticide cost, and converts in seed costs. Analyzed the impacts of Bt technology on cotton yields, profits and household living standard in India by using panel data during 2002-2008 period which covers four states of India shown that Bt adoption has positive and significant net impacts. This technology has increased per acre cotton yields and profits by 24 and 50 percent, respectively, and stated clearly underline that Bt cotton has significantly increased living standard of smallholder farm household in India (Kathage and Qaim, 2011). Sadashivappa and Qaim (2009a, b) reported by analyzing the technology's performance of Bt cotton in India over the first five years of adoption, using panel data with three rounds of observations which the first round in 2002-2003, the second round in 2004-2005, and the third round in 2006-2007. Bt cotton technology has proved to be a success story in India, with farmers benefiting from pesticide reduction, higher effective yields, and significantly higher profits. In the first learning of adoption was a process for farmers, aggregate adoption has increased steadily and reached 65 percent of the country's cotton area in 2007-2008. In the first year of adoption, most of the farmers refuse this technology because they were not fully satisfied. Subramanian and Qaim (2009a,b), have shown that the indirect advantages of Bt are somewhat lower for smallholders than for larger farms in India. Nonetheless, there is clear evidence that both small and larger cotton producers benefit considerably from the technology (Qaim *et al.*, 2008). The number of insecticide sprays and insecticide amounts used were significantly lower on Bt than on conventional plots. Apart of this, a major effect of Bt cotton in India is a significant yield advantage due to lower crop losses. Over the years, average yields were 30-40 percent higher for Bt than for conventional plots, which is due to more effective pest control and thus a reduction in crop damage. Again, differences over the years are largely due to variability in pest pressure. Higher yields and crop revenue are also the main reason for the significant gains in cotton profits. Profit differences between Bt and conventional cotton even increased over time, from Rs 2,161 (US $49.23) per acre in 2002-2003 to Rs 2,940 (US $66.97) in 2006-2007 (Sadhasivappa and Qaim, 2009a, b).

Paper by Pemsl *et al.* (2004) stated that when the impact of Bt cotton is derived from a comparison between Bt and non Bt cotton there is a possibility that variety effects other than pest control properties of Bt are the cause for observed differences in productivity. Qaim *et al.* (2006) had analyzed farm level effects of Bt cotton in India in 2002-2003, using stratified random sample data collected in the states of Maharashtra, Andhra Pradesh and Tamil Nadu. These data are representative for cotton production in central and southern India. Subramanian and Qaim (2009) had surveyed the same farms in 2004-2005, and conducted a third round of data collection in 2006-2007. As a result, Bt cotton produced 37 percent higher yield than conventional cotton, while insecticide amounts were 41 percent lower. Between 2002 and 2007, per acre net revenues were on average 2,000-3,000 Indian Rupees (Rs) higher on Bt than on conventional cotton. Likewise, the results demonstrate that technology adoption entails important positive socio economic effects in the small farm sector. Bt cotton produces important merit in large parts of rural area in India. The technology is net employment generating and deliver income gains for all types of households. Bt cotton in India has contributed to poverty reduction and rural development. Studies of Bt cotton benefits can be seen in Table IV which conducted by public institutes in India from the year 1998 to 2010.

On average the yield increase of Bt cotton due to effective control of bollworms generally ranged from 31 to 63 percent, reduction in number of pesticide use from 25 to 55 percent, increase in profit over non Bt cotton from 50 to 134 percent, and average increase in profit per ha from $76 to $250. According to Naik (2001) in pre-commercialization Bt cotton had analyzed that the overall economic benefit of Bt cotton in 1998/1999 ranged from US$76 to US$236 per hectare which equivalent to an average 77 percent gain in comparison with non Bt cotton, and also reported a 38 percent yield increase and 75 percent reduction in numbers of chemical sprays on Bt cotton over non Bt counterparts. The data set of Qaim *et al.* (2006) has similar economic benefits with Naik (2001) and also Indian Council for Agricultural Research (ICAR) (2002). These pre-commercialization studies confirmed that Bt cotton resulted in a major economic advantage to cotton farmers by substantially increasing yield, reducing insecticide use and reduction in labor cost (Choudhary and Gaur, 2011).

According to Choudhary and Gaur (2011) the first on farm study by Bennet *et al.* (2006) indicated that important gain from Bt cotton in India was the significant yield gains estimated at 45 percent in 2002 and 63 percent in 2001, for an average of 54 percent over the two years. Study by Gandhi and Namboodiri (2006) confirmed a yield gain of 31 percent, a significant reduction in the numbers of chemical sprays by 39 percent and increase in profit by 88 percent or an increase per hectare (US$250) during the growing cotton season in 2004. Report from ICAR (2006) in Front Line Demonstration study on cotton for 2005-2006 reconfirm a net 30.9 percent increase in seed yield of Bt cotton hybrids over non Bt hybrids. In the demonstration plots which covered 1,200 demonstration and farmers plots in 11 cotton growing states in India reported that the Bt cotton hybrids proved to be highly productive with an average yield of 2,329 kg/ha of seed cotton in comparison with Bt cotton counterparts by 1,742 kg/ha and also varieties by 1,340 kg/ha similar with the average yield of Bt cotton hybrids was higher than in farmers' plots at 1,783 kg/ha compared to conventional cotton by 1,362 kg/ha.

Moreover, study by Ramgopal (2006) confirmed that the average Bt farmer had a 46 percent higher yield and applied 55 percent less pesticide use than non-Bt cotton farmer in Guntur District. Meanwhile, Bt cotton farmers in Warangal District applied <16 percent of pesticide application and reaped 47 percent more cotton in comparison with non Bt farmers. Dev and Rao (2007) reported a study which carried out in Warangal, Nalgonda, Guntur and also Kurnool in Andhra Pradesh representing the four agroclimatic zones in 2004-2005 and 2005-2006, concluded that yield increase by 32 percent resulting in the overall cost of cotton per quintal decreasing by 11 percent. Thus, as a result of higher yield and reduces pesticide sprays, Bt cotton farmers improved their net income by 83 percent over conventional cotton. In addition, according to Subramanian and Qaim (2009) showed that Bt technology increased yield ranged from 30 to 40 percent and reducing the numbers of chemical sprays by 50 percent consequences an generating additional farmers' income of US$156 per hectare. It is notable that the economic benefit recorded in pre-commercializing field trials are consistent with the actual experience of farmers commercializing Bt cotton during the eight year period 2002-2009.

Since the first commercialized of Bt cotton in 1996-2001, transgenic Bt cultivars in USA appeared to have increased profits in most cases for the southern regions of Arkansas but have not been profitable for the northern regions of the state (Bryant *et al.*, 2003). Since then, over a four year period, yields and costs were similar when comparing transgenic cultivars to non transgenic cultivars on farms in Mississippi

(Cooke *et al.*, 2001). Early evaluations showed that Bt cotton provided more effective control of the three major caterpillars pests of cotton in the USA and yield increased across the Cotton Belt (Edge *et al.*, 2001). An average yield increase of 90 kg/ha (approximately 10 percent) for Bollgard II as compared to Bollgard in the USA was reported by Mullins *et al.* (2005, cited in Sankula *et al.*, 2005). Brookes and Barfoot (2008a, b) report average yield increase of 9 percent for Bollgard and 11 percent for Bollgard II (2003-2006). Expenditures on insect control was reported to be marginally reduced using Bollgard II technology for the years of 2003-2005, after subtracting the cost of the new technology from the insecticide cost savings; net cost savings were US$5.78/ha (Brookes and Barfoot, 2008a, b). Between 1996 and 2002, average profitability level increased by US$53-US$115 per ha with Bollgard cotton and by US$108-US$118 per ha between 2003 and 2006 with Bollgard II cotton Brookes and Barfoot (2008a, b). Moreover, according to Sankula *et al.* (2005) reported the net economic advantage of Bollgard II compared to conventional cotton to be US$74.29λ ha and for Bollgard II, US$128.85/ha.

Field trials conducted by Bryant *et al.* (2003) trough the experiments from 1998 to 2000 in Arkansas to compare between transgenic cultivars and non transgenic cultivars, reported that in three of the five site year, yields were not statistically different for most or all of the cultivars tested. In the other two site years, the highest yielding cultivar and those not significantly different from the highest yielding cultivars included glyphosate resistant, Bt, stacked gene and conventional cultivars. Furthermore, field studied were initiated in 2001, 2002 and 2003 in Arkansas, reported by Bryant *et al.* (2003), derived from comparison between GM cotton and its counterparts, it was clear that no one cultivar had the greatest return each year and differences between cultivars did exist within years. However, over the long run, as expressed by the three year averages, differences between some cultivars were relatively small. No single cultivar or type of production system stands out as always resulting in the greatest return. The evaluation of the profitability of various transgenic cotton varieties (Roundup Ready (RR) and Liberty Link (LL)) compared to conventional cotton has been conducted by Boman *et al.* (2005) in the Texas High Plains in 2004 resulted in varying locations, indicated that some transgenic varieties were competitive with its counterparts types in terms of production economics.

Cotton yield has been significantly influenced by the biotech revolution in the USA. The biotech cotton traits, coupled by continued cotton cultivar improvement, accelerate the rate of yield increase over the past ten years by approximately 33 percent compared with the rate of cotton yield improvement before the introduction of transgenic cultivars. The potential economic advantages offered by the three cotton biotechnologies in the USA are expected to directly influence producer adoption considerations. Accordingly, cotton growers may adopt Bollgard (BG), RR, or stacked Bollgard/Roundup Ready (BR) in order to reduce production costs, ease production risks and associated output losses and exploit potential synergies with relevant agronomic practices. Pasu and Nicholas (2009) based on the empirical data in USA from 1999 to 2006 reported that the effectiveness of Bollgard cotton to control target pests against that of conventional practices is one of the most important factors in the farmers adoption decision. This maybe as much a reflection on the limited effectiveness of some conventional pest control practices, and also stated those producers who perceive effective preservation of beneficial insects, and concomitant benefits from secondary pest control, increase their level of Bollgard adoption. Meanwhile, use of reduced tillage practice and irrigation are also found to have positive effects on the adoption of RR cotton. As in the case of bollgard, adoption of RR cotton is strongly influenced by its relative weed control effectiveness. The perceived effectiveness of RR cotton in reducing production risks plays a significant role in the producer adoption decision. Moreover, perceived cost saving become a significant driver in the decision to adopt ST cotton varieties. The combination of BG and RR traits may be resulting in a reduction in the numbers of sprays sufficient to make such cost efficiencies significant (Pasu and Nicholas, 2009). Large two year farm scale evaluation of IR (Insecticide Roundup) cotton on 81 commercial fields in Arizona demonstrated a 40 percent reduction in number of insecticide applications for IR cotton relative to its counterparts (Cattaneo *et al.*, 2006). Moreover, Herbicide Roundup cotton has expanded use of conservation tillage practice in the US approximately 60 percent of total cotton acreage (USDA National Agriculture Statistic Service, 2004).

Economic benefit is the one of the most prominent factor that can affect GM adoption technologies among the farmers worldwide including in USA where biotech cotton was first adopted, several surveys have demonstrated that growers are achieving higher yields from IR cotton and attaining higher profit. It is remarkable that the average increases in net returns from five to seven states comparing IR cotton to conventional cotton was US$8.42/ha, taking into account the technology cost. New generation of IR cotton with stacked genes may provide additional economic returns. In 2004, the net growers returns in the USA due to planting new stacked gene IR cotton was estimated at US$13.7 million. James (2010), reported based on a study by Piggot and Marra (2008) of 2005 data in North Carolina, USA assessed the additional per hectare benefits to a farmer and to the state of North Carolina resulting from a change in policy for Bollgard II cotton that would eliminate the required refuge. The annual profit at the farm level was US$56.37 per hectare and US$32,209,907 at the state of North Carolina, when non pecuniary benefits are not considered. When non pecuniary benefits are considered, the farmers gain per hectare was US$66.44 per hectare and US$37,986,449, which is an increased of US$10.07 per hectare and US$5,783,542 at the state level. Limited applied studies have addressed Bt and non Bt returns (Bryant *et al.*, 2003; Cooke *et al.*, 2001; Ward *et al.*, 2006). These studies compared returns from Bt and Non Bt cotton varieties.

Besides, in order to increase yield, farmers in the US strive to achieve high fiber quality, both to maximize their price at the gin and to respond to world market needs that are in line with state-ofthe – art spinning mills requirements. One example is the introduction of FiberMax in the USA, Texas cotton farmers have increased their annual farm income substantially because of improved fiber quality and yield. For the years 2004-2006, FiberMax varieties increased Texas farmers' income by 4.84 percent in three year average. In ten years, from 1998-2009, this varieties was able to achieve a 34.5 percent market share in the USA, mainly through its development in Texas (www.fas.usda.gov/cotton_arc_asp).

The adoption of Bt cotton varieties carrying resistance genes for *Helicoverpa punctigera* (Wallengren) and *H. armigera* (Hubner) by Australian cotton growers has been high. This has been particularly evident since 2004/2005 when varieties carrying two Bt-genes (Bollgard®II) replaced varieties carrying a single Bt-gene (Ingard®). Conventional non Bt cotton varieties have now been almost replaced by Bollgard®II varieties in Australia. Pyke (2000) reported in comparison to conventional non Bt cotton, the adoption of Ingard® and Bollgard®II has reduced the average quantities of insecticide by just over two-fifths and just over four-fifths, respectively. While Ingard® was not fully effective in controlling *Helicoverpa spp.,* Bollgard®II has been very effective and only requires chemical control for a range of sucking pest. Bollgard®II cotton requires less chemical spraying and while many cotton growers choose to plant it because of this benefit, they increasingly consider lifestyle benefits and improvements to worker safety as important reasons to plant it. In an assessment of cotton grown in Australia between 1997/1998 and 2003/2004. Knox *et al.* demonstrated that there was a 64 percent reduction in environmental impact in Bt cotton compared with conventional non Bt cotton. This study also showed that for the 2002/2003 and 2003/2004 seasons the environmental impact value for Bollgard®II was 79 percent less than conventional non Bt cotton.

Australia planted over 500,000 hectares of biotech cotton in 2012 after a peak hectarage of almost 600,000 hectares in 2011 (James, 2012). The introduction of GM cotton into Australia has had significant agronomic merits for farmers. Decreases in insecticide use and changes in the quantity have resulted in profit in terms of cost production (lower input costs) which has associated with economic benefits. According to Holtzapffel *et al.* (2008), the comparative yields of Bt and non Bt cotton varieties from 1997-1997 to 2004-2005 varies between seasons. For example, in 2004-2005 the average yield was ten bales of cotton per ha for both Bt and non Bt cotton varieties, meanwhile in 2003-2004 conventional cotton averaged 7.73 bales per ha while Bollgard II averaged 8.27 bales per ha. Moreover, this technology would have significant benefits in terms of the use of chemical spray as well as decreasing the direct cost of spraying pesticide, the cost of applying them (time, staff, machinery, etc.) is also decreased as a result of fewer applications.

In Australia, the majority of cotton farmers have realized an economic gain from growing GM cotton, although performance obviously varies due to environmental or climatic differences across locations and seasons. Comparing the economic return of Bollgard II cotton with that of conventional cotton shows that in 2004-2005 growing season, 66 percent of 50 paired comparisons showed a net profit. In the 2003-2004 growing season, 84 percent of paired comparisons showed a net profit (Doyle *et al.*, 2002). Brookes and Barfoot (2006, 2008a, b) reported that Australian growers, while not generally benefiting from higher yield gains from using GM cotton, derive farm income benefit from lower costs of production. Net income losses were reported in the first two years of adoption of the technology (Ingard, single gene Bt cotton), mainly because of the relatively high price charged for the seed. However, after the price was lowered in 1998, the net income impact was positive, with estimated cost saving between US$54/ha and US$90/ha, mostly derived from lower insecticide costs (including application) more than offsetting the cost of technology. In the few years of availability of the more effective Bollgard II cotton, Australian farmers continued to make significant net cost savings of US$ 186/ha to US$193/ha, despite the higher costs of seed.

With significant reductions in pesticide applications, INGARD cotton could be expected to provide greater returns for growers. According to Fitt (2003), reported that in the first year (1996/1997), INGARD cotton was $43 per ha more expensive to produce than conventional cotton. In addition average yields for INGARD crops were 0.53 bale per ha lower yielding than the its counterparts comparison in that year. In the first two years (1996/1997-1997/1998), net income benefit was slightly positive due to the reduced licence fee (to$155/ha net) and insect control costs being $70-$90 lower on INGARD crop. Overall, the data suggest that there is no consistent significant variation in yield that would contribute substantially to differences in economic outcomes associated with Bollgard varieties. According to Doyle *et al.* (2002) data conducted from the survey respondent were responsible for 56,087 ha of cotton in growing season of 2005/2006, representing 18.8 percent of the total cotton area for the season. Survey responses have been aggregated into four growing regions in Australian, namely, Northern : includes the Darling Downs, regions further north, including Emerald and the Dawson Valley, Border rivers/Gwydir/St. George : includes St. George/Dirranbandi, Mungundi, Moore, and the Macintyre valley, Namoi : includes Gunnedah, Narrabi and Wee Waa and surrounding districts, and Southern : includes the Darling River and Macquarie valleys; Bourke, Warren, Hilston, and Hay and surrounds (Doyle *et al.,* 2002).

5. Results and discussion

5.1 Country Specific analysis

Within the database which data majority came from China, India, USA and Australia meta-data present the economic indicators the use of transgenic cotton and its counterpart that can be seen in Table II. This shows the results of meta-data search from the year of 1996-2012 for country specific analysis over time by traits. Those collected from the peer-reviewed and non peer-reviewed articles which contained the economic indicator both transgenic and non transgenic cotton. Study findings the highest cotton yield due to the adoption of transgenic cotton is only indicated in China (3,080 kg/ha) compare to any other countries, this is consistent with (Huang and Wang (2002a), Huang *et al.* (2002b), Yang *et al.* (2005) and Pray *et al.* (2011) and also by Kaphengst *et al.* (2011) who studied in the assessment of the economic performance of

		Economic performance indicator (Average)					
Country	Trait	Yield (Kg/ha) (A)	Seed costs (US$/ha) (B)	Pesticide costs (US$/ha) (C)	Management and labor costs (US$/ha) (D)	Total Cost (US$/Ha) (B + C + D)	Net Revenue (US$/ha)
China	Transgenic	3,080***	58.65	61.3***	949.79	1,069.74	672.56
		(1.0182)	(11.8293)	(28.9172)	(308.7673)		(601.8637)
	Non Transgenic	2600	38.59	191.5	1,094.9	1,279.99	−41.28
		(0.8608)	(21.7072)	(162.2929)	(292.9018)		(408.2033)
	% Change	18.4	51.9	−67.9	−13.25		1,720.9
India	Transgenic	1,920**	76.83	76.9***	365.21**	518.94	402.43***
		(0.57920)	(13.2792)	(37.5295)	(207.6711)		(288.1860)
	Non Transgenic	1,440	27.0	111.87	293.99	432.86	270.64
		(0.4468)	(6.3946)	(51.3595)	(105.0056)		(151.1514)
	% Change	33.0	184.5	−31.25	24.22		48.69
USA	Transgenic	1,250**	108.52	102.18**	192.06	402.76	1212.0*
		(0.42599)	(52.89003)	(109.260)	(212.2875)		(570.9904)
	Non Transgenic	1,183.3	34.05	113.61	194.68	342.34	1,055.1
		(0.4369)	(17.7358)	(135.6949)	(198.9211)		(435.56654)
	% Change	5.6	218.7	10.0	1.34		14.87
Australia[a]	Transgenic	1,680**	na	503.73***	na	na	na
		(0.2573)		(110.8874)			
	Non Transgenic	1,590	na	643.26	na	na	na
		(0.4748)		(144.6791)			
	% Change	5.66	na	−21.69	na	na	na

Notes: Standard deviation in parentheses. [a]Due to the low number of observations, transgenic cotton in Australia are not statistically analyzed. *,**,***Significant at the 10, 5 and 1 percent level, respectively (comparison are made by *t*-test)

Table II. Farm level agronomics and economics effect of transgenic cotton and its conventional

GM cotton based on the meta-data in five countries (China, India, South Africa, Australia and USA) indicated that China is the highest cotton yield of GM cotton compare any other countries at that time. In terms of production cost, this study found that China is the lowest cost of GM seed and and the lowest cost of chemical spray. Therefore, this is the fact that the adoption of GM cotton has been widely spread among the farmers across the regions in China. The estimated yield increase due to the GM cotton ranges from 5.6 percent in Australia and USA to China (18.4 percent) and 33 percent in India. The differences of percent change in USA and Australian as the impact of using transgenic cotton is not significantly higher, and the yield advantage of using transgenic cotton in developing countries (China and India) is higher compare to USA and Australia.

A cross-country analysis proof the evidence that seed cost, as the consequences of using transgenic cotton is much higher than its conventional, this is consistent with the Kaphengst *et al.* (2011). That is the seed cost is actually greater worldwide over time as the first launched of GM cotton in 1995. There were significantly higher seed cost for transgenic cotton than its counterpart in the cases of China, India, and USA. The estimated of mark-up of seed cost for GM cotton ranges from 51.9 percent (China) to more than 100 percent in India and more than 200 percent in USA. China is the country for which Bt cotton adoption shows the strongest effect on pesticide cost, followed by India, Australia and USA. Reductions in pesticide costs range from 20 percent in Australia to about 60 percent in China, while in USA the cost differences between the use of transgenic cotton and conventional is slightly different. This case shows that the chemical spraying depends on the pest infestation on that condition at that time. Comparison of the management and labor expenditure as the consequences of the use both transgenic and non transgenic cotton resulting in vary range. In China, the reduction of this cost is about 13 percent due to the adoption of transgenic seed while in India and USA the estimated of mark up for GM cotton in terms of management and labor cost range from 1 percent (USA) to more than 20 percent (India).

The adoption of transgenic cotton mostly derived from the high economic value. Table II demonstrated that China is the country which has highest impact of returns due to the use of transgenic seed. India has the positive impact of net returns by growing it which range almost 50 percent while in USA indicated that transgenic cotton growers has the higher income than its counterpart which estimated range about 15 percent. In terms of production costs, Table II indicated that the production costs of growing transgenic cotton is higher than its counterpart in India, and USA. Surprisingly, we found that China is the one of the country specific analysis with lower expenditure costs of growing transgenic cotton compare to non transgenic cotton than any other country.

So far, the peer reviewed, country specific analysis based on the published literature indicates that China is the most successful case for Bt cotton in terms of seed costs and pesticide costs (see Table II.). The lowest seed costs reflect that China is the great country to control the seed price. This is due to the government control of production, seed supply and marketing system. Smale *et al.* (2006) argued that in China, the public research program had the capacity to develop and disseminate transgenic insect-resistant cotton varieties (Pray *et al.*, 2002), so that technology fees were not imposed by Mosanto, dependence on external supplies was lessened, and seed price were more competitive. This analysis is consistent with Smale *et al.* (2006) that in China, seed price (including the technology fee) is lower than in other countries due to the competition from public sector breeding programs, an inability to protect intellectual property, and limited capacity to enforce contracts. Moreover, even though Huang *et al.* (2002c) estimated damage control function demonstrate that Chinese farmers tends to over use pesticide; Yang *et al.* concluded that in Liqing County, Shandong Province, farmers grew more than six varieties of Bt cotton, but were still over-using pesticide, and also Pemsl *et al.* employed damage control frame work in Shandong province for the 2002 cropping season only estimated simultaneously with an insecticide use function, we found that China is the lowest cost of chemical spray compare to any other countries (India, USA and Australia). The highlights of the important factors behind the successful case for Bt cotton in China particularly in reducing seed cost and pesticide cost are following: first, the original transgenic lines were sub licensed to provincial seed companies and transgenes were backcrossed into more than 22 locally adapted varieties (Toenniessen *et al.*, 2003); second, the Beijing-based Biotechnology Research Institute of the Chinese Academy of Agricultural Sciences (CAAS) obtained patent, plant variety, and trademark protection in China for its Bt cotton; third, the decentralization of breeding efforts in China, leading to the "enviable wealth of cotton varieties" and fourth, despite the elimination of support prices and subsidies, an effective price premium due to import controls in the domestic cotton industry (Smale *et al.*, 2006).

5.2 Meta-analysis

5.2.1 Yield performance. In this study, we provided the meta-analysis of yield gain from 46 studies of systematic review. We noted that there is a strong evidence of the heterogeneity studies by analyzing fixed effect and random effect estimation. Table III reflects fixed and random effects pooled estimates, lower and upper 95 percent confidence limits, and asymptotic z-test for null hypothesis that true effect (unbiased effects) = 0. Test for heterogeneity: $Q = 1{,}611.913$ on 45 degrees of freedom ($p = 0.000$). Randomeffect Der Simonian and Laird estimate of between studies variance = 0.038 (τ^2). $I^2 = 97.2$ percent. $Q >$ df indicated that the observed variation greater than we would expect based on within-study error (Borenstein *et al.*, 2009).

Figure 1 shows, at a glance, information from the individual studies that went into the meta-analysis, and an estimate of the overall results. It is also allows a visual assessment of the amount of variation between the results of the studies. This is (Figure 1) adapted from systematic review and meta-analysis which examined the yield gain of GM cotton compared with non GM cotton. All results on the left hand side are in favor of the GM cotton implementation, those on the right hand side in favor of the use of non GM cotton. Figure shows that most of the studies are favor the implementation of GM cotton and it is notable that if the 95 percent confidence interval does not overlap the y-axis, that is the result is statistically significant, as 95 percent of the result are expected to lie one side. In this case there are 15 studies which are not statistically significant.

The shape of the diamond in the last row of the graph illustrates the overall result of the meta-analysis (Figure 1). The middle of the diamond sits on the value for the overall

Table III. Mixed effect of meta-analysis of yield gain

Methods	Pooled estimation	95% CI		Asymptotic		Number of studies
		Lower	Upper	Z-Value	p-value	
Fixed	0.857	0.848	0.865	−31.769	0.000	46
Random	0.838	0.792	0.888	−6.009	0.000	

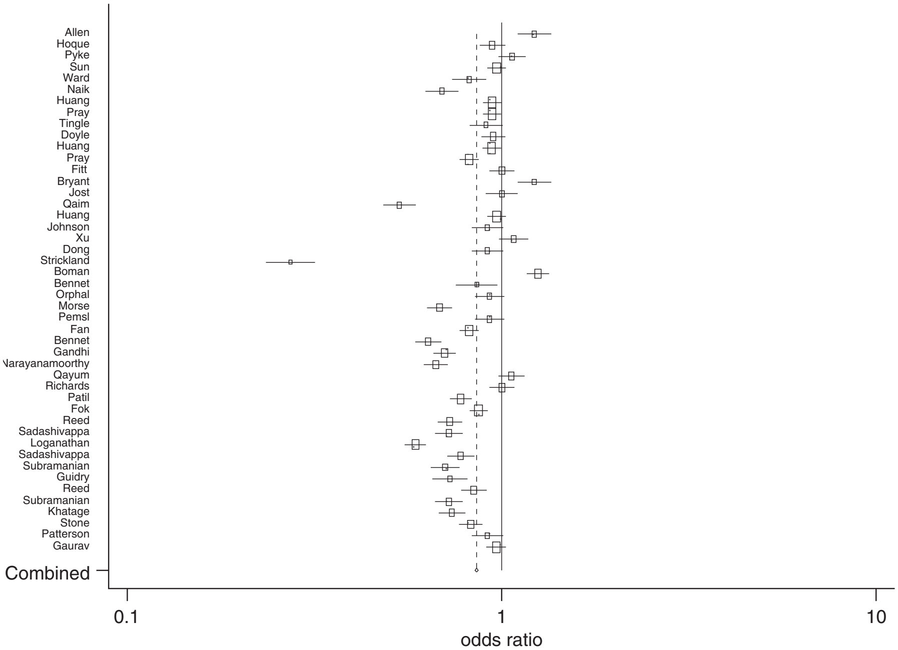

Figure 1.
Random-effect forest plots of meta-analysis of yield of GM and non GM cotton

effect of estimate and the width of the diamond depicts the width of the overall confidence interval. If the diamond does not cross the "line of no effect," the calculated difference between the yield gain of the use of GM cotton and its conventional can be considered as statistically significant. In this case, Figure 1 noted that overall of those studies are statistically significant even are not highly significant. Statistical significance of the overall result in this study is also expressed with the probability value (p-value) in the "test for overall effect." Commonly, the result is regarded as statistically significant if $p < 0.05$ (Ried, 2006). In this case p-value can be seen at Table III that indicated statistically significant for the overall of the studies. I^2 value of 97.2 percent indicates that the higher the value the more the heterogeneity increased.

The black squares symbol represent the odds ratio of the individual studies and the area of the black squares reflects the weight each trial contributes in the meta-analysis. The bigger the box, the more influence the study has on the overall results. The influence or "weight" of study on the overall results is determined by the study's sample size and the precision of the study results provided as a confidence interval. In general, the bigger the sample size and the narrower the confidence interval, the greater the weight of the study.

5.2.2 Economic performance (net return). There were 25 studies which have been analyzed by fixed effect size and random effect size. Overall studies show that p-value lower than 0.05 (0.000), this means those studies is statistically significant both in fixed effect size and random effect size. Fixed and random effects pooled estimates, lower and upper 95 percent confidence limits, and asymptotic z-test for null hypothesis that true effect $= 0$. Test for heterogeneity: $Q = 1{,}828.069$ on 24 degrees of freedom ($p = 0.000$).

Random-effect Der Simonian and Laird estimate of between studies variance $= 0.219$ (τ^2).

$I^2 = 98.28$ percent (Table IV) This indicates the higher the value the more heterogeneity increased.

Figure 2 express the forest plot based on the meta-data analysis. We can see that most of the studies favor the GM cotton in terms of net revenue. A little favor the non GM cotton. The plot shows, at glance, the information for each individual studies about net revenue which is statistically significant in 95 percent confidence interval. A typical forest plot in Figure 2. shows that the shape of diamond is the left hand of the line no effect, this means that the difference found between the two groups (GM cotton and non GM cotton) in terms of net revenue was statistically significant. The significance of the 95 percent confidence interval would contain the true underlying effect in 95 percent of the occasion if the study repeated again and again. The overall heterogeneity of effect sizes was large, that is indicating that the individual effect sizes in our data did not estimate a common population mean and that other experimental treatments or moderators may have influenced results.

Methods	Pooled estimation	95% CI Lower	Upper	Asymptotic *Z*-Value	*p*-value	Number of studies
Fixed	0.789	0.772	0.805	−22.271	0.000	25
Random	0.714	0.593	0.860	−3.552	0.000	

Table IV. Mixed effect of meta-analysis of net revenue

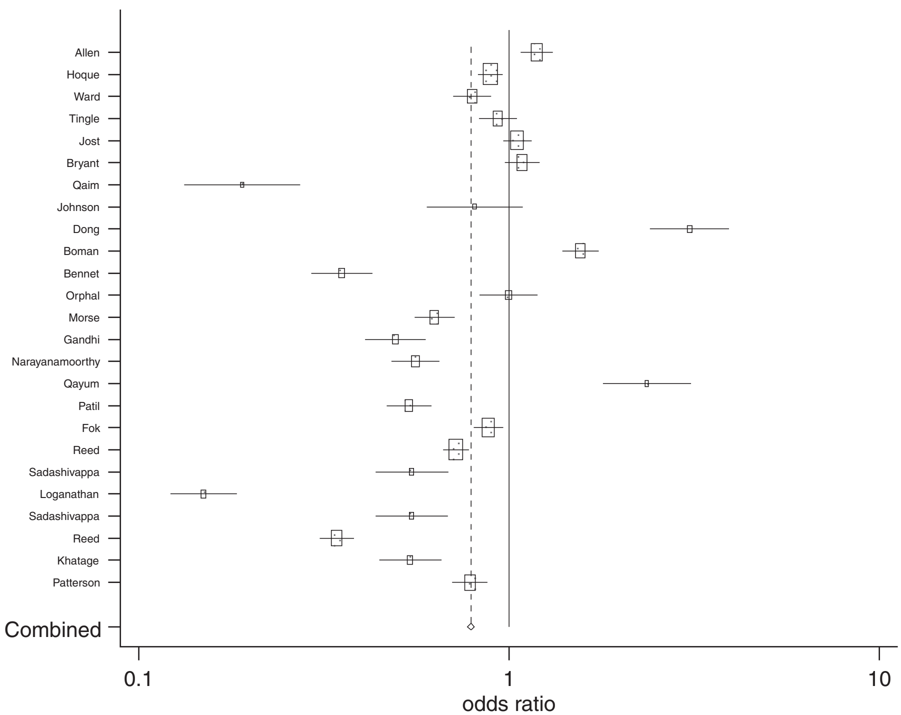

Figure 2. Forest plot random-effect of net revenue of GM cotton and its counterpart

5.3 Potential biases

Most published evidence to date indicates that GM cotton has had a positive economic impact for small-scale farmers in developing countries such as China and India and also in developed countries. Broadly they indicate an increase in yield, reduced insecticide use (insecticide product per hectare), reduced expenditure (as less pesticide is used) and an overall increase in the gross margin for GM cotton varieties compared to non GM cotton varieties. Study findings that gross margin or net revenue of GM cotton is substantially higher over its counterpart. However, we found that some of the individual studies did not measure the economic analysis appropriately. These included in "all costs" is pesticide, labor, fertilizer, planting material, running costs of machinery, etc. These are variable costs and yield tends to increase as variable costs increase, albeit within the limits of diminishing returns. In contrast, while revenue is relatively straightforward to identify, the problem lies in calculating costs.

Several early studies relied heavily on data derived from experimental plots which researchers established and managed on farmers' land, but critics were quick to label such work as unrepresentative and potentially biased. Other studies avoided this problem by focussing on plots owned and managed by farmers. Such methodological variations make comparison between studies difficult, even if the work has been carried out in the same country. Data analysis from such studies has typically employed multiple regression, with yield as the dependent variable and the various inputs as independent variables. However, even if data are available the studies are typically focussed on gross margin assessed over a short time period, possibly a single or a few growing seasons. They provide snapshots rather than a long-term picture, and fail to answer key questions about the sustainability of an increase in gross margin.

This study based on the meta-data which relied on the individual studies and those came from the field trials, plots experiments and farm survey. According to Kaphengst *et al.* (2011) the experimental setup of field trials may bias the derived economic performance results in several ways that side-by-side varietal trial, bias can occur through the so called "halo effect" that comes in when insect repellent used for GM cotton spill over onto the conventional treatment. Papers by Demont and Tollens (2001) and Marra *et al.* (2002) this "halo effect" might have impact of source of pest control, which may increase the yield of the conventional tested. Subsequently, yield increase due to GM cotton adoption might be underestimated in such field trial.

A common method to assess the economic performance on farm level, usually we used to farm surveys to compare new variety over its counterpart. According to Scatasta *et al.* (2005) and also Marra *et al.* (2002) found that a major drawback of several survey-based studies is that they often lack basic information about the sampling procedures. Kaphengst *et al.* (2011) stated that selection biases also occur if participating farmers are chosen on the basis of their willingness to cooperate and a minimum endowment with productive sources such as described by Qaim (2003) we found that the trial sites were monitored by Mahyco scientist; and used data collected by Monsanto's partners (Bennet *et al.*, 2006; Qaim and Zilberman, 2003). Another shortcoming within the survey is the answer farmers when they asked about past input allocation decisions that we doubt they can remember precisely during the interview through the questionnaire. This is consistent with Morse *et al.* (2005) stated that most of the data survey were based on records kept by the farmers and in the absence of receipt farmers were asked to recall their input use and expenditure. As a results there were some missing data where farmers either did not have the record for a particular input, could not remember or where a mistake was made in recording by the enumerators. Therefore, it should be noted that potential weakness of the survey was the lack of the data collected on other inputs to production such as labor. Such data are difficult and expensive to collect, and quality can be debatable given that there is a reliance on memory. Study findings that most of the individual studies were used to survey method to assess the economic performance in comparing between GM cotton over its conventional such as Pray *et al.* (2001, 2002); Waibel *et al.* (2005); Huang *et al.* (2002b, c, 2003); Pemsl *et al.* (2011); Yang *et al.* (2005); Fan (2005); Sun *et al.* (2000); Fok and Xu (2007); Wu *et al.* (2008); Morse *et al.* (2005); Loganathan *et al.* (2009); Bennet *et al.* (2006); Gandhi and Namboodiri (2006), Narayanamoorthy and Kalamkar (2006); Qayum and Sakkhari (2006); Orphal (2005); Gauraf and Mishra (2012); Bennet *et al.* (2005) and Patil *et al.* (2007). Thus, using meta-analysis we found some individual studies are not statistically significant or even the results are different in comparison between GM cotton and non GM cotton but actually are not greater or not highly significant.

6. Conclusions

It is clear from the above that the impact of the GM cotton on different parameters is diverse. Apart from varying results from different studies, most of the studies one way or the other appear to have the following methodological deficiencies may have potential biases. First, selection bias. For instance, selection of farmers through a company extension program, and/or self-selection of certain types of farmers into the adopting group may lead potential bias associated with study placement. Though it is a known fact that variety of the crop determines its productivity to a considerable extent, most of the studies have not specified the varieties of the cotton while carrying out the study. For instance, papers by Huang *et al.* (2002b, c); Pemsl *et al.* (2011); Sun *et al.* (2000), Fan (2005); Subramanian and Qaim (2009); Stone (2011); Pemsl *et al.* (2004); Matin Qaim (2003); Bennet *et al.* (2005, 2006). Second, measurement bias. Some of the existing studies were either carried out without following any sample design or with no specification of the method used for selecting sample farmers. For example, papers by Ward *et al.* (2006); Gauraf and Mishra (2012); and Gandhi and Namboodiri (2006). Third, estimation bias. Economic benefit is the high expectations of farmers growing GM cotton. This can be measured by gross margin include the costs of intermediate inputs but ignore the use of labor and land. Net margins include these costs. In a number of the studies examined here, only gross margins are reported as partial budgets which are deceptively simple. The way in which use of transgenic crops affects budget categories depends on the particular crop-trait combination and cannot be generalized. So far, this review found some methodological problems in terms of research design and potential biases, although it is important to recognize that no method is perfect, and typically, multiple methods will be needed to generate a fuller analysis of impact. Improved methods will enhance the quality of information about the economic impact of biotech cotton especially in developing countries.

Peer-reviewed surveys and field trials indicate positive impacts of commercialized GM cotton in terms of net revenue with few exceptions, that GM cotton have benefitted farmers in developing countries. The benefits, especially in terms of increased yields, are greatest for the mostly farmers in developing countries who have benefitted from the spillover of technology targeted at farmers in industrialized countries. The results of yield indicates that farmers in developing countries are achieving greater yield increases than farmers in developed countries. The largest yield increase found in this review (country-specific analysis) are reported for GM cotton in China. Authors generally concur that Chinese consumers are more accepting of biotech cotton than are consumers in other countries.

For this review, and for the methodological reasons, the accumulated evidence from individual studies based on the farmers survey, field trials and plot experiments on the performance of GM cotton helps to explain the widespread popularity of this technology in several regions across the world. Moreover, the wide spread of GM cotton among the farmers worldwide over time indicate a strong evidence that this technology has been adopted.

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