Published as: Azadi, H., A.Samiee, H. Mahmoudi, Z. Jouzi, P. Rafiaani Khachak, P. De Maeyer & F. Witlox (2015) "Genetically modified crops and small-scale farmers: main opportunities and challenges". *Critical Reviews in Biotechnology*, Jul 7: 1-13.

Genetically modified crops and small-scale farmers:

Main opportunities and challenges

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Abstract

Although some important features of genetically modified (GM) crops such as insect-resistance, herbicide-tolerance and drought- tolerance might seem beneficial to small-scale farmers, the adoption of GM technology by smallholders is still slight. Identifying pros and cons of using this technology is important to understand the impacts of GM crops on these farmers. This article reviews the main opportunities and challenges of GM crops for small-scale farmers in developing countries. The most significant advantages of GM crops include being independent to farm size, environment protection, improvement of occupational health issues, and the potential of bio-fortified crops to reduce malnutrition. Challenges faced by small-scale farmers for adoption of GM crops comprise availability and accessibility of GM crops seeds, seeds dissemination and price, and lack of adequate information. In addition, R&D and production costs in using GM crops make it difficult for these farmers to adopt these crops. Moreover, intellectual property rights regulations may deprive resource poor farmers from the advantages of GM technology. Finally, concerns on socio-economic and environment safety issues are also addressed in this paper.

Keywords: Biotechnology, GM technology, small-scale farming, resource-poor farmers, biosafety, developing countries.

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Introduction

In 2000, 189 nations made a promise to free people from extreme poverty and multiple deprivations. This pledge turned into the eight Millennium Development Goals (MDGs) which would reduce levels of hunger, malnutrition and poverty by half by the year 2015 (UNDP, 2013). Despite the potential applicability of biotechnology solutions for the first MDG (eradicate extreme poverty & hunger), many of these technologies are not being widely implemented in developing countries (Acharia et al., 2003). Although the use of genetically modified (GM) technology in agriculture has faced with opinions polarized between vehement opposition and enthusiastic acceptance, the backdrop to the debate is the fact that world population is increasing and this increase plus enhanced demands for meat and meat products is already intensifying pressure on existing agricultural systems. Another consideration is the context of global warming (Morse and Mannion, 2009). In the current environment of the polarized opinions, a wide-ranging dialogue is ongoing on how to arbitrate between risks and opportunities (Fresco, 2003).

Recent data from Vietnam and some African countries show that small-scale agriculture can act as an important engine for national economic growth and help generate relative affluence from the bottom up in developing countries (FAO, 2011). It is, however, important to notice that the exact line between developing and developed countries is not possible, and this could be the reason why there is no agreed criterion that generally accepted (Nielsen, 2011). For the purpose of this paper, the term developing/developed country is introduced by the World Bank.

According to the latest World Bank analytical country classification system[1], countries are divided into four main categories including low-, lower-middle-, upper-middle-, and high-income based on the 2012 Gross National Income (GNI) per capita estimates. Given the purpose of the paper, examples from countries of all these categories (except the high-income category) have been taken into consideration.

Biotechnology application provides farmers in developing countries with new opportunities and potential to increase living standards of farm household (Kathage and Qaim, 2012; Ali and Abdulai, 2010) and improve their livelihood (Bazuin et al., 2011; Cohen and Paarlberg, 2004; Huang et al., 2002; Morris and Hoisington, 2000; Thirtle et al., 2003). Genetically modified crops are those that have been genetically altered using techniques of genetic engineering to carry one or more beneficial new traits. Among African countries only Burkina Faso, Egypt, Sudan and South Africa have fully commercialized GM crops out of the total of 29 worldwide (Bhorat et al., 2014). For example, Bennett et al. (2003) estimated $51 per hectare per season direct benefit for *Bacillus thuringiensis* (Bt) cultivators of SAR416 adopted by small-scale cotton farmers in the Makhathini Flats region of South Africa. Similarly, Qaim and Kouser (2013) found a strong relationship between the adoption of Bt cotton and income gains among smallholder households in India that has positively influenced food safety and the quality of dietary. Huang et al. (2010) have also shown that the Bt cotton adoption reduces chemical pesticide use and increases yields in farmers' fields in China. Therefore, the number of farmers who apply this new technology has significantly increased considering the higher yields and higher incomes that this technology provides for them. In 2011, the total number of 16.7 million

[1]For the current 2015 fiscal year, low-income economies are defined as those with a GNI per capita, calculated using the *World Bank Atlas* method, of $1,045 or less in 2013; middle-income economies are those with a GNI per capita of more than $1,045 but less than $12,746; high-income economies are those with a GNI per capita of $12,746 ormore. Lower-middle-income and upper-middle-income economies are separated at a GNI per capita of $4,125 (World Bank's website, 2014).

farmers grew GM crops that are1.3 million farmers more than2010. Notably, from the total number, 15 million (90%) were resource-poor farmers from developing countries. Developing countries grew close to 50% of global GM crops in 2011 and for the first time are expected to exceed developed countries' hectarage in 2012 (James, 2011). The five leading developing countries in GM crops are China India, Brazil, Argentina and South Africa, which totally grew 71.4 million hectares (44% of the global GM cultivation) (James, 2011). Table 1 shows main developing countries growing GM crops in 2013 (James, 2013). Yet, it should be taken into consideration that different developing countries are at various stages with regard to GM crops. According to the African Agriculture Status Report 2013, for example, "The development and dissemination of new technologies and practices that increase yield potential for a particular area depend on a country's ability to make needed investments, and farmers' skills and willingness to adopt the technologies."

Table 1. Developing countries growing GM crops in 2013.

Despite the global increasing of GM crops application and potential advantages of GM technology, there are serious problems faced with the farmers and it remains doubtful whether this technology can positively affect the situation of small-scale farmers (Bazuin et al., 2011). Some policy-makers take this view that supporting smallholders with GM crops might not regularly reduce overall poverty. They even consider this technology as an additional risk to food safety (Friends of the Earth, 2014) while opponents argue that assisting smallholder for development GM cultivars can be a critical approach for food insecurity and poverty alleviation (Qaim and Kouser, 2013; Juma, 2011; Borlaug, 2007). On one hand, the economic and environmental benefits of GM technology for smallholders like increasing income due to high yield and reduction of toxic chemical inputs are not ignorable, the challenges and problems of using GM technology by small-scale farmers are serious on the other. A number of definitions has been developed to characterize smallholders such as Adams and Coward (1972); FAO/RAFE (1978); Wapenham (1979) and Steenwinkel (1979). The common recognition of these studies for these farmers emphasizes on those farmers in developing countries who do not have capabilities and necessities to meet their basic requirements or are living in lasting fear of losing their recourses. The critical elements in all definitions are livelihood, low earnings and profits, and illiteracy (Devendra, 1993). As the term ‘smallholder’ is central in this paper, our definition of this term refers specifically to farmers in the rural areas of developing countries with subsistence farming system in which the family provides the majority of labour and farm provides the principal source of income (Djurfeldt et al., 2005). In light of understanding the merits and demerits of GM technology for smallholders, the aim of this paper is to review the main opportunities and challenges of GM crops for small-scale farmers. Accordingly, the paper first portrays an overview on the opportunities that might be created by GM crops for small-scale farmers. The second part of the paper, on the contrary, will address the main challenges caused by these crops to the poor farmers. Findings from different studies which were about GM technology in different developing countries were analyzed. The main keywords used to obtain the documents were “GM crops” and “smallholders” followed by a combination of “opportunities” and “challenges” of GM technology.

Pro-GM crop arguments

Farm size

Farming plots in developing countries are small in size. Nevertheless, as many studies revealed, GM seeds are suitable for both large and small-scale farmers (Brookes and Barfoot, 2009; Qaim, 2009). Consequently, the adopters of GM crops may belong to either the subsistent small-scale or commercial large-scale farmers; although it is important to note that the adoption of GM crops by small-scale farmers might not show that GM crops are scale neutral. With an emphasis on developing countries, Pray et al. (2002) reported that the adoption of GM insect-resistant (IR) cotton in China was not influenced by the farm size as many of the adopters were small-scale farmers who held between 0.3 and 0.5 ha of cotton plots (Brookes and Barfoot, 2009). Also, studies in South Africa show that the adopters of IR cotton and maize were among both large and small-scale farmers (Brookes and Barfoot, 2009; Gouse, 2006; Ismael et al., 2002; Morse et al., 2004). Hence, there is a chance for developing countries to convert the challenge of their small farming plots to an opportunity to secure the issue of food production.

Other studies conducted in developed countries have led to the same conclusion (e.g. Brookes, 2005 on the case of herbicide-tolerant (HT) soybeans in Romania; Brookes 2005on the case of GM IR maize in Spain), although an earlier study carried out by Fernandez-Cornejo and McBride (2000) in the US reported that in the case of herbicide tolerant crops (soybeans and maize) the adoption rate increased with the size of operation up to 50 hectares and then was fairly stable. This implies that the type of GM crop and the context of production may better determine the level of influence on the rate of adoption among different groups of farmers with different sizes of land.

On-farm economic benefits

Nowadays, in comparison with developed countries, developing nations are more concerned about economic costs and benefits of GM technologies in their agricultural sector (Sonnino et al., 2009) which includes a great number of smallholders. Results of many studies suggest that farmers in these countries may economically have a lot to gain through the application of GM crops compared to their counterparts in developed countries. For example, only in 2007, 58 percent of farm incomes were earned by farmers in some developing countries, mostly by the cultivation of GM IR cotton and GM HT soybeans. These impacts have been examined in some studies. For example, since 2002 and commercial release of Bt cotton in India, it has had a positive impact on farmers' revenues. It is important to note that in this case, the real benefit is not because of reduced cost but rather due to higher yields (Bennett et al., 2005). According to Brookes and Barfoot (2009), during a period of twelve years (1996-2007), the cumulative farm income from using the GM technology gained by farmers in developing countries was estimated at $22.1 billion. The results of different studies suggest that in developing countries such as Argentina, Mexico, South Africa, India and China, the enhancement of yield is more likely to occur among marginalized and resource-poor farmers who have less access to pesticide due to technical or economic constraints (Gouse et al., 2004; Huang et al., 2005; Park et al., 2011; Qaim and de Janvry, 2005; Union of the German Academies of Science and Humanities, 2006). Gouse et al. (2005, 2006) evaluated the effect of the adoption of GM IR maize in South Africa and concluded that the most income gained by poorest farmers from the higher yields related to the adoption of GM IR maize. Gonzales (2006) also examined the relationship of the adoption of GM IR maize in the Philippines. Based on data analysis from surveys conducted at farm level over a one-year period from 2003 to 2004, he concluded that the adoption of GMIR maize substantially enhanced the subsistence level carrying capacity of smallholders. Wang et al. (2008a) assessed the influence of GM IR cotton adoption on livelihoods of farmers in the Hebei province of China during 2002-2003, and found that increases in farm income, resulting from higher yields, have led to a significant increase in household incomes. They also found that this higher level of subsistence had a major role in further investment in family education, healthcare and leisure activities. This yield increase, however, is necessary but not sufficient to estimate the overall farm-level economic benefits of growing GM crops. According to Raney (2006), costs and returns associated with the application of such technologies must be taken into account simultaneously. Furthermore, it remains questionable whether or not it is possible to generalize the economic benefits attributed to GM crops since their performance and thus profitability depends strongly on agronomic, social and institutional factors which shape the context of production (Bennett et al., 2006; Raney, 2006; Smale et al., 2006).

With regard to costs, some evidence from developing countries reveals that GM crops have the potential to radically reduce expenditures at farm level particularly for small-scale farmers. Although the study by Qaim and Traxler (2005) shows that the use of Roundup Ready (RR) soybeans in Argentina provides farmers with remarkable revenues, it is important to note that due to weak intellectual property protection and the fact that RR technology is not patented in this country, soybean growers paid relatively small amount for GM seeds. Moreover, GM crops leads to cost savings associated with lower pesticide and herbicide use (Qaim and Traxler, 2005; Union of the German Academies of Science and Humanities, 2006; Brookes and Barfoot, 2008; Naranjo and Ellsworth, 2009), lower manual labor required for spraying (Qaim and Traxler, 2005; Thirtle et al., 2003), and reduced fuel requirements for machinery weed control and tillage (Qaim and Traxler, 2005). Regarding other determinants, however, cost savings tend to pay off for increased labor required for harvesting higher yields which leads to a vagueness of net labor effect (Qaim and Matuschke, 2005). Another issue that should be taken into account during economic assessments is that GM crop seeds are more expensive than the conventional ones. However, in case of Bt cotton seeds, Raney (2006) pointed out that the cost savings and yield effects outweigh additional cost in developing countries, particularly in those wherein seed costs are not high due to weak intellectual property rights (IPR) protection (e.g. in China) (Pray et al., 2001). Arguably, from advocates' viewpoint, GM crops are at least assumed to be cost neutral (Park et al., 2011). Additionally, from a broader perspective, Lemaux (2009) showed that the economic benefits of GM crops do not confine farm borders. At a larger scale, contributing to higher employment generation (Subramanian and Qaim, 2009) and higher household's income rates, the adoption of GM crops help reduce poverty among resource-poor farmers in developing countries (Qaim, 2009) that will improve their standard of living.

Environmental benefits

It has been estimated by Brookes and Barfoot (2008) that between 1996 and 2006, Bt cotton resulted in global savings of 128 million kg of pesticide active ingredients which accounted for 25 percent reduction in the environmental impact of total cotton pesticides. This 33-77 percent decrease in insecticide use, mainly detrimental chemicals belonging to international toxicity classes I (very toxic) and II (toxic) such as organophosphates and synthetic pyrethroids (Qaim and de Janvry, 2005; Qaim and Zilberman, 2003), has mainly occurred among Bt cotton farmers in developing countries particularly in China and Mexico (Qaim and Matuschke, 2005) (Fig. 1). However, results vary across studied developing countries since the degree of pest pressure and farmers' spraying patterns differ due to agro-ecological conditions. Furthermore, in some cases, Bt cotton farmers still use insecticides in fear of not achieving the desirable result by GM crop technology particularly in the early stages of adoption (Ismael et al., 2002).

Fig. 1.Average agronomic effects of Bt cotton (Adapted from Qaim and Matuschke, 2005).

In contrast with significant agronomic effects of Bt cotton, mainly on major decreases in herbicide quantities (Krishna and Qaim, 2012; Morse et al., 2005a in the case of India; Morse et al., 2005b in the case of South Africa), some researchers maintain that reductions in herbicide quantities with regard to the adoption of HT crops are not significant (Qaim and Traxler, 2005). Nevertheless, they still confirm that the replacement of herbicides with less toxic ones is an advantage for the environment (Qaim, 2009).

The environmental benefits of growing GM crops are not limited to the reduction of toxic chemical inputs. GM crops can also contribute to the expansion of min-till or no-till practices, and thereby help reduce soil erosion and increase organic matter of soil (Brookes and Barfoot 2008; Park et al., 2011). Accordingly, there is a hope that more food will be produced on less land if drought-tolerance GM crops can be created that may help manage the effects of climate change in drought prone areas. Apart from benefits to soil, GM crops may have the potential to reduce greenhouse gases through lower fuel use due to the implementation of no-till practices, biofuel production and lower level of emissions resulted from less pesticide manufacture (Edgerton, 2009; Park et al., 2011; Phipps and Park, 2002). For example, Brookes and Barfoot (2006, 2008) examined the global impacts of GM crops on reducing greenhouse gas emissions for each of the country growing GM crops for the first seventeen years (1996-2012) of their adoption. Their results showed that the crops reduced global environmental impacts resulted from pesticide utilization by 18.7%. Brookes and Barfoot (2006, 2008) also found that GM technology has also considerably decreased the release of global greenhouse gas emissions from agriculture that was equal with taking 11.9 million cars away from the roads. The International Service for the Acquisition of Agri-biotech Applications (ISAAA, 2009) also confirms savings in carbon equivalents. For instance in 2007, savings of 1.1 billion kg of CO_2 were estimated due to the less usage of sprays. Additional saving of 13.1 billion kg CO_2 was attributed to HT varieties leading to the use of min-till systems (ISAAA, 2009).

Moreover, it has been acknowledged that GM crops have some indirect effects on biodiversity conservation. Furthermore, through higher yield effects, these crops help reduce the consistent expansion of agricultural zones to non-cultivated ecosystems (Park et al., 2011). Besides, compared to the conventional breeding, the developments of GM traits through genetic engineering can be backcrossed at reasonable costs into numerous varieties which in turn, restrict the replacement of local landraces (Qaim, 2009), although there will be no varieties to backcross GM traits into if there is not simultaneously conventional breeding occurring. Furthermore, the possibility of feely backcrossing into many varieties is significantly reduced by intellectual property rights. In general terms, reduction in pesticide and herbicide use, lowering tillage operations, and reducing the rate of land use change contribute significantly to the conservation of the environment which is a key factor in livelihoods of resource-poor farmers.

Health and nutritional benefits

The advantageous effects of GM crops on small-scale farmers' healthcare can be both direct and indirect. The former includes less exposure to toxic chemicals (Qaim, 2009) during spraying due to less use of pesticide and herbicide in developing countries where farmers mostly apply these chemical toxic manually in their small farms and lack of knowledge about their unhealthy side-effects (Qaim, 2009). Results of a survey in China revealed that the introduction of Bt-cotton cultivars reduced this health risk (Union of the German Academies of Science and Humanities, 2006). The reduced incidence of pesticide poisoning has been reported in South Africa as well (Bennett et al., 2006).

The latter includes less pesticide residues in food and water. For instance, Wu (2006) reported that Bt technology decreases the contamination levels of certain mycotoxins which are one of the main contributors to cancer and other diseases. Additionally, bio-fortified GM crops (such as Golden Rice) which aim to increase micronutrient intake and thereby improve human health are assumed to be beneficial particularly for poor farmers (Bouis, 2007; Park et al., 2011). Simulations for India show that Golden Rice could reduce related health problems significantly, preventing up to 40,000 child deaths every year (Qaim, 2010). Besides the enhancement of nutritional content of food which directly benefits farmers, lower food costs due to higher yield gains indirectly provide them with a broad-spectrum of foods, thus enrich their diets (Wu and Butz, 2004). One reason is that undernourished and poor farm households will mostly select cheapest foods available from calories sources, mainly cereals within the rural India. Only when they have surpassed livelihood, farm families will begin to replace more expensive sources of calories with the previous cereals meal (Jensen and Miller, 2010). Qaim and Kouser (2013) also stated that in general, higher incomes are likely to result in increasing food consumption in poor smallholder’s households.

Con-GM crop arguments

Availability and accessibility

Availability of appropriate type of GM crop and irrelevance of the transferred GM technology to the conditions of resource-constrained farmers are important challenges of GM crops. Furthermore problems of seed supply because of higher price of GM seeds and accessibility of valid and needed information for applying GM technology is other main cons of GM crops that are explained as follows.

Research and development (R&D) efforts and flow of GM technology

The development of suitable type of GM crops that benefit small-scale farmers in developing countries has globally raised many questions so far. A great number of GM crops, currently available in developing countries, has been originally produced through pioneering research and development (R&D) efforts of private firms in the developed world accounting for 65-80percent of the research in the field (FAO, 2002). As a good example, Monsanto allocates 10 percent of its total revenues to agro-biotechnology R&D efforts conducted by the company, which amounted to more than US$550 million worth of investments in agro-biotechnology in 2006. This figure is comparable to the investments of the whole CGIAR system spending US$450 million in agricultural R&D generally, of which just a small share is allocated to agro-biotechnology R&D (Eicher et al., 2006; Virgin et al., 2007). Compared to the notable agro-biotechnology R&D efforts made by the private sector of developed countries, attempts made by public and even private sectors of developing countries were limited in number forcing them to import GM technology from elsewhere. One reason that made this flow inevitable is that developing countries are not able to take advantage of their biotechnological capacity due to limited financial resources (Herrera-Estrella, 1999) and thereby are heavily dependent on outside germplasm resources (Fowler et al., 2001). More specifically, the public sector and national agricultural research programs (NARS), as a dominant player in R&D in developing countries, lack the capability of supplying appropriate GM seeds(e.g. in Eastern and Southern African countries) because of their constraints (Virgin et al., 2007). Further to this, the considerable influence of private firms of industrialized countries on GM crop R&D has confined the progressive expansion of GM technology among other public or private bodies (i.e., Monsanto, Syngenta, Dow AgroSciences and BASF, along with various other public and private companies and research institutions, and scientists connected with them) in developing countries, and thereby benefits sharing among subsistence-oriented farmers (Qaimand de Janvry 2003). Illustrating the impediments of further development of GM crops in developing countries, Wu and Butz (2004) suggest that the intellectual property issues prevent organizations−either public or private− to make R&D efforts other than the firm initiating the technology and this can restrict farmers' accessibility in developing countries. They added that as the pioneers of advances in modern biotechnology, corporations own the rights of many GM technologies and knowledge for development and thus public researchers and other private companies are not legally permitted to take advantage of those technologies or to exploit what they already know.

However, there exist some hopes as limited efforts have been made to facilitate the cooperation among companies who are willing to work with other regional institutions and public sector of developing countries to donate substantial portion of their scientific knowledge that pertains to agricultural conditions of small-scale farmers (Herrera-Estrella, 1999; Wu and Butz, 2004). For instance, international agencies such as International Agricultural Research Centers (IARC) system, bilateral programs and organizations such as International Service for the Acquisition of Agri-biotech Applications (ISAAA) and Center for the Application of Molecular Biology in International Agriculture (CAMBIA) mainly supported by donors, have attempted to address such issues through development and distribution of enabling technologies tailored to agricultural needs of farmers in developing countries (Nuffield Council on Bioethics, 1999). Another example of these alliances is the agreement between Centro de Investigacióny Estudios

Avanzados in Mexico and Monsanto to provide virus-resistant potatoes for the Mexican market (Herrera-Estrella, 1999). For a farmer who cannot buy seed potatoes due to the high prices, Herrera-Estrella suggests that GM virus-resistant potatoes would provide a good solution for the problem. However, "the Mexican researchers could apply the technique only to traditional varieties of potatoes grown by small-scale subsistence farmers" (Charles, 2001; p. 266). Qaim (1998) in his quantitative analysis showed that the advantages of GM technology should not be limited to producers in larger scale. In contrast, the benefits of the GM virus-resistant potato technology could be very significant for small-scale farmers. He also confirmed that the participation of Mexican public and private institutes in development and adaption of the technology to local potato varieties contributed to "human-capacity building, increased self-confidence and directed R&D" (Qaim, 1998: iv). Moreover, contribution of Mexican research institutes promoted international corporations among engaged stakeholders and researchers. However, such efforts are not an easy task because there still remain some obstacles which restrict the practical use of GM crops among small- scale farmers. First, some opponents argue that donors mainly prescribe programs that are basically rooted in the experiences of developed countries which can result in imperfect or disappointing outcomes (WHO, 2005). One potential problem with this approach is their relevance of the transferred GM technology to the unique conditions of resource-constrained farmers. Since, safeguarding the interests of private sector, the institutional context of developed-world companies has several implications for them which, to a large extent, determine the direction of their R&D efforts (Kvakkestad, 2009). Most of GM crop technologies are developed within these companies long before public awareness and funding (Pinstrup-Andersen and Schioler, 2001), and thereby are focused on the traits that are of value to wealthier farmers who are willing to pay (Wu, 2004). Hence, these companies are hesitant to invest in crops which seem to be convenient to fragile small-scale farming systems of developing world because of farmers' inability to pay for GM seed price premiums and also unwanted replanting of seeds by them. The companies that produce GM crops have IP Rover (IPR) the crops, generally in patents form (Adcock, 2007). They can, and have the right to take legal actions against those farmers growing the GM crops without the permission of the companies. However, according to Omanya et al. (2007), developing IPR with high level of protection significantly restricts delivery as well as availability of GM technologies to smallholder, for example, in Sub-Saharan Africa. Indeed, the degree of the IPR protection in a country affects the adoption of GM crop and profitable distribution (Qaim, 2009). For instance, Raney (2006) compared Argentine and China's experience with IR cotton. Monsanto in Argentine has strict regulations in terms of the IPR on IR cotton. Consequently, farmers paid more for GM seeds compared to the conventional ones and ultimately they had relatively small returns. On the other hand, thanks to the developed public agricultural research system in China, 7.5 million small-scale farmers had higher returns. Public research sector in China provides farmers with low price seeds in the country. Pray et al. (2002) also examined the issues relating to the adoption of GM IR cotton in China. They concluded that because of weak IPR, a significant amount of benefits was maintained by farmers, with small accruing to the technology producers (public and private sector). Traxler et al. (2001) and Traxler and Godoy-Avila (2004) similarly found in Mexico (adoption of GM IR cotton) that 85% of the total benefits from adoption received by farmers with only 15% gained by the suppliers of seeds and technology providers. As a result, despite their remarkable investments in agro-biotechnology, as Byerlee and Fischer (2002) suggest, only a small share is directed at developing countries which appear in form of direct investments by companies, acquisition of local seed companies, and through alliances of global and local companies. But it should be noted that although the share in investments is not eye-catching because of assuming that market may be small and sometimes a failure, there should be some large companies that are still interested in developing world markets to encourage knowledge transfer and adaptation of technologies to achieve profit interests for their companies as well as benefit local smallholder farmers. Recognizing the clear evidence of the involvement of multinational seed companies in improving biotech research in Africa, Brazil, and India (Fukuda-Parr and Orr, 2012) can be a good example for successful development of GM crops in future.

Second, in developed countries, R&D is focused on major crops which are insensitive to local agro-ecological conditions while limited efforts have been made on culturally valued orphan crops (such as cassava) which are of importance to risk-averse small-scale farmers as a livelihood strategy. Orphan crops can generally be described as those crops or species which have great contributions towards food production and development, but whose potential have been under-exploited (Naluwairo, 2011). Progress has been achieved in transforming tropical (Swennen, 2002) and orphan crops (noncereal food staples and indigenous crops, including mung beans, beans, chickpeas, cowpeas, lupin, cacao and coffee) (Cohen, 2005) mainly by the public sector of developing countries. Yet, Naylor et al. (2004) claim that even in developing countries such as China, India, and Brazil with strong National agricultural research programs (NARs), there is a huge difference between financial investments that orphan crops receive for research and development and their contribution towards food security and livelihoods in comparison to other major food crops. Then, the greatest numbers of transformation events so far are for rice, potatoes, maize and papaya (Cohen, 2005). Yet, he continues, most of these GM crops are in preliminary testing stage and only few of them have been released into open testing or into commercial stage. This is because GM crop R&D process in developing countries is both costly and time consuming. Reviewing seven case studies undertaken in Africa, Eicher et al. (2006) indicate that in reality, it takes 10-15 years for developing countries to develop GM crops and reach smallholders. This is much longer than the expected time frame (3-5 years) considered by these countries in their research agendas. Consequently, there is still much to doon directing applications toward smallholders in developing countries (Serageldin, 1999; Qaim and Matuschke, 2005).

Seed supply and delivery

One of the most important impediments to GM technology adoption by small-scale farmers is the higher price of GM seeds. The price will exclude resource-poor farming communities with little capacity to pay from benefit sharing and thereby prevent them from the application of the technology despite the fact that agro-biotechnology companies have offered price premiums (e.g., GM seed price premiums) as an opportunity to R&D efforts (Conway, 1998). Furthermore, companies apply other legal (e.g. patents, plant variety protection, and contract growing) and biological ways to make GM seeds excludable (Srinivasan and Thirtle, 2003). For example, with respect to biological methods of exclusion, companies prevent farmers from saving GM seed for future use. Multinational companies tend to broaden their activities by developing linkages among the biotechnology, seed, and agri-chemical sectors (Wu and Butz, 2004). The companies have developed partnerships with or even purchased seed companies (e.g. Monsanto) which has also helped them gain access to germplasm since seed companies owned the rights to the elite plant varieties that agro-biotechnology companies fundamentally need for their GM products (Chataway et al., 2004). As a result, to secure returns on their investments, companies needed to enforce terms such as genetic use restriction technologies (GURTs) or 'terminator technology' which inhibits farmers from replanting the previously saved seeds (Kvakkestad, 2009; Tait, 2009). However, promotion of such terms has raised serious issues such as endangered market access and restricted the flow of public benefits from GM crops to small-scale and poor farmers in developing countries (CIIR, 2004). For example, a serious drawback of GURTs is that farmers growing conventional or traditional crops of the same species as the GURTs variety in adjacent fields will find their crops polluted by cross contaminants**.** This may intensively influence food safety while also considered as a problem for market and for food security, especially if the transgenic crops were pharmaceutical ones or other kinds of plants were not predestinated for human consumption. Farmers who supply their conventional or traditional seeds for replanting may face an adverse result as it may be possible that significant amount of their seeds is not germinated. This would result in substantial yield loss (Ricarda and Steinbrecher, 2006). Considering the potential impacts of GURTs on indigenous, smallholder farmers and local communities, however, GURTs have been not approved by any companies to date for field-testing and commercial use in order to make seeds sterile. In an opposite direction, Qaim and Matuschke (2005) stated that developing such terms cannot be considered as a big deal since farmers in developing countries still retain the choice to grow either GM or conventional seeds. Moreover, they are allowed to re-plant their own GM seeds (The Green Revolution varieties were of this kind, even were so successful) while seed sales among farmers are prevalent through informal seed systems as their own mechanism of distribution (Commission on Intellectual Property Rights, 2002).

Another problematic issue is the functionality of the delivery system which facilitates the dissemination of GM technology among poor farmers. The shortages of the delivery system can be traced back to the gap between R&D efforts, even if it develops products well-suited to the condition of small-scale farmers and GM seed distribution and also the reluctance of the private sector to take part in seed dissemination activities because of the unattractiveness of this market (Virgin et al., 2007). According to Potrykus (2010) who evaluated the Humanitarian Golden Rice' project, one of the major problem responsible for the lack of spreading of public GM crops was the fact that public sector is inefficient and impartial for acting beyond ‘proof-of-concept’, and has neither potential nor investment to create GM crops and deliver them to consumers and farmers. He concluded that public-private-partnerships are the best solution to date, to promote utilization of GM technology to the benefit of the smallholders and poor. Cohen (2005), however, found that public-private partnerships rarely exist in developing countries in terms of seed dissemination, and those in place overlook issues such as 'time needed for acceptance, farmers involvement from the onset to the final stages, and meeting appropriate seed suppliers'.

In sum, in order to reduce the influence of large companies, Herrera-Estrella (1999) and Raney (2006) suggest that national authorities should strengthen the institutional capacity through a system which produces and distributes GM crop seeds among small-scale farmers while charging less or even no costs. South Africa can be a good example here as this country has an integrated farm sector with major commercial farms performed through an advance input supply system functioning along with smallholder semi-livelihood farms. White IR maize varieties (intended for food) were released at market in 2001/02, and free seed was delivered by Monsanto to smallholders on a trial basis (Raney, 2006). In this sense, public sector and commercial R&D efforts must be aligned toward farmers needs. Cost reduction programs coupled with strong loan systems may help achieve this objective (Chopra and Kamma, 2005).

Information

Safe uptake of GM technology requires that farmers have up-to-date timely information about their application. To what extent farmers have control on the technology and its performance is also determined by their access to valid information. As pointed out by Tripp (2001), GM technology requires that farmers gain accurate information about names and traits of different varieties to decrease the potential for confusion and thereby inefficiency with these crops. Glover (2009) indicated that farmers are in need for information about specific issues such as variation in the production of Bt toxin in the plant during the growing season. Indeed, lack of reliable information about kinds of pests that Bt toxin would kill, led Chinese and Indian farmers into misunderstanding of the function of the crop (Bennett et al., 2004; Yang et al., 2005a; Yang et al., 2005b). Besides lack of knowledge among farmers, about the differences among GM crop varieties for instance, Stones (2007) in his empirical study showed that the replacement of advice by the influence of seed dealers further exacerbates the situation. This trend may open space for propaganda instead of information. This is because, in some cases, even the trustworthy sources of information, i.e. extension services and education system, lack the capacity and trained personnel to inform farmers about GM crops.

In sum, the complex nature of GM technology calls for more attention about the overriding need for information on application, especially in developing small-scale farming communities. Thomson (2003) claims that although educational services are important to address farmers' requirements but it is more imperative to involve farmers in the development process which includes development, testing and commercialization of GM crops. Obviously, farmers' engagement in all these phases will help them make better decisions.

Forces pushing forward and pulling backward

Companies and IPR regulations

Around the world, opponents have highlighted the dominance of multinational and large companies from GM crop R&D to marketing. They believe that following their market interests, these companies exert full control over the value chain of GM crop production mainly targeted towards commercial farmers for export matters (e.g. maize, soybean, cotton etc.). With regard to seed supply, concerns are expressed from different aspects ranging from farmers limited choices of high-quality non-GM seeds (Friends of the Earth, 2008)to marketing of the same GM seeds in some developing countries such as Argentina, Brazil, China, India and South Africa without considering resource-poor farmers status quo (Virgin et al., 2007). Opponents stated that even donor organizations which aim to donate GM technology to the public good such as ISAAA are supported mainly by biotech companies and agribusinesses (such as Monsanto and others), thus are promoting the same crops around the world particularly among subsistence oriented farmers of developing countries (Friends of the Earth, 2008). In contrast, advocates of GM crops argue that resource-poor farmers benefit substantially from such proprietary GM crops.

Also, many believe that current IPR and patent regulations which are in place to protect companies against competitors and encourage them to disclose their inventions, are extremely in favor of large companies and corporations and thereby should be considered as a tool for increasing control over R&D and market. One reason is that the patent owners charge higher prices for GM seeds. Accordingly, WHO (2002) claims that patents on genes have led to monopolies rather than encouraging scientific and economic progress and thus are not within the public interest.

In an opposite direction, advocates of GM crops assert that although more than 75 percent of all patents in agricultural biotechnology is held by large multinational corporations as the main producers of GM crops (Graff et al., 2003), their gains were remarkably lower in developing countries. Paarlberg (2001) maintains that existing IPR protections in developing countries are weak and should not be considered as a challenging issue. So far, from his viewpoint, developing countries in fear of losing export markets have taken the hold-back approach which is more an obstacle than IPR. Under this approach, governments hold back on the field-testing or commercial introducing of GM crops, not only to prevent risks that are known and have been highlighted, but also to keep away from potential risks that have not yet been illustrated (Paarlberg, 2001).

As an example, based on the figures on the costs paid by farmers to access four main GM cops in 2007, as illustrated in Table 2, it can be interpreted that this cost was equal to 24 percent of the technology gains which accounts for 14 percent of the total technology gains in developing countries while accounting for about 34 percent of the gains within developed countries. Notably, as the table reflects, the higher technology gains in developing countries can be attributed to the weaknesses in the implementation of IPR protections in comparison to the developed countries. In addition to the discussions around IPR, other control mechanisms such as “terminator gene” are assumed to increase reliance of farmers from developing countries on some big agribusiness in developed countries that is already patenting seeds traditionally owned by indigenous people (UNEP, 2007).

Table 2.The costs paid by farmers to access four main GM cops in 2007.

Global market

With less focus on external markets, some developing countries prefer to produce GM crops for their domestic use. They carry on with the production of conventional agricultural products mainly for export purposes as they find this more beneficial due to their reasoning to stay GM-free. For Sub-Saharan Africa, for example, running exports of GM-potential crops do not comprise a significant proportion of the whole production, and so it is expected to be highly profitable to adopting GM crop varieties there since consumers at the local market are not concerned while this is the key market to be fed (Nielsen et al., 2001). As Cohen and Paarlberg (2004) mentioned, growing skepticism toward GM foods and feeds in international commodity markets, made China as a substantial exporter to hold onto its GM-free status for major field crops (all except cotton). This, however, can be traced back to the fact that others such as European countries, despite EU regulations (2003), are skeptical about GM crops health and environmental externalities and thereby have restricted GM crops import (Zarrilli, 2005). At the international level, however, there are some industrial countries which have taken a moderate approach and are not concerned about the risks as much as their European counterparts.

Not internationally harmonized, specific regulations such as biosafety and food safety regulations have been put in place requiring that GM products should be approved prior to planting, consumption, or import into a country (Herdt, 2006). Paarlberg (2002) has recognized these regulations as the main reason for keeping GM crops out of the developing world. He asserts that although nearly all of the major developing countries have established genetically modified organisms (GMO) biosafety regulations and guidelines, only a few of them approved commercial GM crop planting. Hence, farmers are not legally allowed to plant any GM food or feed crops. For instance, in Africa there are four countries, South Africa, Burkina Faso, Egypt and Sudan that have successfully commercialized biotech crops (cotton in Burkina Faso and Sudan, Mize, Soybean and Cotton in South Africa, and Cotton and Canola in Egypt) (Bhorat et al., 2014). In Asia, however, the only significant commercial GM crop planting approval has been for cotton (in China, Indonesia, and India).

Notably, biosafety and food safety testing processes are time consuming and expensive. For example, estimations provided by Kalaitzandonakes et al. (2007) show that the private compliance costs for regulatory approval of a new Bt or HT maize technology in one country at \$6–15 million (Qaim, 2009). Separately, the commercialization of the same technology in other countries would entail additional costs. As pointed out by Qaim (2009), these costly initiatives prevent public organizations and small private companies from playing a proactive role and thereby lead to monopoly of large corporations.

Besides biosafety screening processes, to meet consumers' expectations in developed countries particularly in the European Union, labeling regulations have been put in place. This implies that GM crops must be separated from non-GM crops at all stages; i.e., from 'field to fork' which can be quite costly. This exerts more pressures on developing countries wherein labeling capacities are weak leaving them no other option than to remain GM-free or just carry on with production of industrial GM crops such as cotton rather than GM food and feed crops (e.g. China, Indonesia, India) (Paarlberg, 2002).

Socio-economic concerns

While proponents of GM crops hold the optimistic approach that GM crops such as Bt can help smallholders manage risk because of the reduction in the fluctuation of yields and prediction of the performance, opponents claim that this is true when during the year of application, a serious infection of the pests occurs. Thereby, in years when the pests do not invade, those farmers who did not pay the high price for their seeds are winners (Wang et al., 2008b). Results of studies (Raney, 2006; WHO, 2005) indicate the belief that the application of GM crops reduces the fluctuations and variability in performance is not always true and this can cause a serious risk for poor farmers. This is because other institutional factors such as national agricultural research capacity, environmental and food safety regulation, intellectual property rights and agricultural input markets exert influence at least as much as the technology itself in determining the level and distribution of economic benefits (Raney, 2006).Similarly, others maintain that with the introduction of GM crops in developing countries, small–scale farmers livelihoods will be destabilized, and poor people’s ability to feed themselves will diminish (CIIR, 2004).They believe that this can be attributed to the dominance of large companies, higher prices of GM seed, intellectual property rights, and enforcing contractual agreements around the use, storage and sale of GM seed and products which eventually lead to inequalities and high indebtedness of resource-poor farmers (GRAIN, 2004; UNEP, 2007) and thereby make the technology inappropriate for them and disruptive for traditional cultivation systems (Shiva and Jafri, 2003). Although it should be noted that in some instances while GM crop technology per se may be successful, the application of this technology can fail due to the lack of underlying institutional support systems (Fukuda-Parr, 2012). For example, Gouse (2007) highlights that the negative results caused by the implementation of Bt cotton in the Makhatini Flats of South Africa in 1998-1999 were not the fault of the GM crop technology itself, but the absence of a safety net for farmers, notably, the provision of credit and extension services to make the cost of GM seeds affordable and accessible to farmers. Moreover, as Wu and Butz (2004) stated, GM crops may have indirect impacts that change the culture of a region more slowly. Shifts in socioeconomic status due to increased food production and new agricultural methods can benefit certain groups in society but may cause other groups to suffer.

Table 3 summarizes some of the main characteristics of the opportunities and challenges of GM crops in developing countries.

Table 3

This paper showed that GM plants may contribute to developing crop varieties that deliver more to farmers, but from the opponents' point of view, a big challenge needs to be addressed that is whether or not GM crops are the best choice available to deal with increasing food demand and world population growth. Opponents believe that alternative solutions for improvement of plant as well as agriculture systems – especially agroecology – represent similar advantages such as herbicide control and insect resistance, while preventing the potential damages that GM technology may produce (Uphoff, 2007). Discussion has been particularly intense when organic farming was identified to be an alternative method for GM technology. On the one hand, farmers are encouraged to adopt GM crops due to their higher yields and income generations, while on the others, some believe that organic farming in developing countries is highly profitable considering its considerations as well as socio-economic advantages (Azadi and Ho, 2010; Azadi et al., 2011). However, opponents argue that despite its advantages such as reduced water and soil pollution, as well as reduced use of chemical inputs, it is unlikely that organic farming alone can secure food supply and provide the basis for sustainable agriculture due to the challenges like financial constraints, lack of organic matter, increased cost, labor intensive, then low productivity (Nuffield Council on Bioethics, 2004; Azadi and Ho, 2010, Schoonbeek et al., 2013). The significant funding devoted to the private sector is good evidence that confirms research on GM forms of critical crops is likely to further develop, while organic farming and other agroecological techniques are not expected to receive the same amount of investments (Jacobsen et al., 2013). This rapid improvement in developing production systems has resulted in more biodiversity (flora and fauna) loss, increasing erosion and more genetic vulnerability (FAO, 2007; Gepts, 2006). It is therefore expected that the 2010 biodiversity purposes are not achieved (Larigauderie and Mooney, 2010). Jacobsen et al. (2013), in their review study, concluded that in order to provide enough food to meet the growing demands of the global increasing population in a sustainable manner, it would result better if the majority of the existing research funding, that devoted to the GM crops development, allocated to other research topics related to plant science including nutrition, governance, policy research and solutions appropriate for regional market situations. However, according to Conway (2003), agriculture can be developed in a sustainable way when the suitable approaches and implementations are integrated and utilized. As Azadi and Ho (2010) stated, this could be achieved when the public information as well as the information of private and public sector authorities considerably enhanced with regards to both GM and other alternative methods. Such enhancements would consequently result in developing proper strategies for food security.

Conclusion

There is a general agreement to achieve sustainable development. We need to find a solution to increase standards of living of farmers and consumers especially in developing countries in which many of producers are small-scale and resource-constrained. Reducing hunger and malnutrition, increasing economic benefits along with environment conservation are priorities of development program in developing world. Although there is no definite solution that can totally address all the necessities of sustainable development, using advance mechanisms like biotechnology may be helpful to achieve this goal. Each technology has its advantages and disadvantages and biotechnology in agriculture is not an exception.

The problems faced with GM crops in developing countries can be divided into three main categories- political, technical and socio-economic. To deal with these problems, the crops must be field-tested due to fitness to agro-ecological features and suitability for small-scale farmers' conditions before introducing them to farmers. Then, if the suitability of the crop is confirmed for smallholders, it is reasonable to expand the borders of its application and commercialization. In this sense, a careful assessment of small farmers needs should be carried out prior to any interventions. Many studies have identified the appropriateness of GM traits such as insect resistance, virus resistance, fungal resistance, drought tolerance, herbicide tolerance, bacterial resistance and agronomic properties which are assumed to affect local economies positively through generation of direct and indirect employment and increase in personal income and food security (Cohen, 2005; Defra, 2009). Additionally, the risks/benefits associated with GM crops should carefully be assessed with respect to the conditions of small-scale farmers who lose and suffer the most in case of failure (Bazuin et al., 2011). Because it is impossible to withdraw the technology if detrimental effects are discovered after its introduction. The risk/benefit assessment must be inclusive and based not only on scientific principles but also on social and ethical inferences. Also, evaluations must be made in the context of available, equivalent technologies. This would possibly pave the way for comparison of GM crops with conventional crops leading to a more realistic assessment of risks and benefits. This study demonstrated that adopting GM technology differs from adopting other innovations in that, its adoption is a very sensitive decision. Therefore, there is a need to conduct a series of risk assessment and risk perception studies. Accordingly, the followings seem necessary before taking any decision to accept or reject GM crops for application in small-scale farming:

- Establishment of a legal framework for biosafety control and field trials in developing countries (Biosafety Regulations)
- Development of necessary policies, mechanisms and agendas within the national innovation system to foster the need-driven development of GM crops (development of GM crops appropriate for small-scale farmers conditions e.g. minor crops; to achieve this, it is firstly needed to identify the potential barriers for GM orphan crops that are mainly the institutional and research capacity for GM research as well as applying GM methods to plant breeding)
- Development of agreements between developed countries and developing countries on the type of GM crops imported
- Planning for capacity building initiatives (development of human resources e.g. extension agents to inform small-scale farmers)
- Increasing the level of small-scale farmers awareness
- Fostering the partnership between public and private sectors (joint ventures) in terms of technology development and seed delivery, especially in developing countries
- Agreements between companies and developing countries which allow dissemination of low cost GM seed and re-planting and distribution by small-scale farmers.

Declaration of interest

The authors confirm no declarations of interest.

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Table1. Developing countries growing GM crops in 2013

Country	Area (Million hectares)	GM crops
Brazil	40.3	Soybean, maize, cotton
Argentina	24.4	Soybean, maize, cotton
India	11.0	Cotton
China	4.2	Cotton, papaya, poplar, tomato, sweet pepper
Paraguay	3.6	Soybean, maize, cotton
South Africa	2.9	Maize, soybean, cotton
Pakistan	2.8	Cotton
Uruguay	1.5	Soybean, maize
Bolivia	1.0	Soybean
Philippines	0.8	Maize
Burkina Faso	0.5	Cotton
Myanmar	0.3	Cotton
Mexico	0.1	Cotton, soybean
Colombia	0.1	Cotton, maize
Sudan	0.1	Cotton
Chile	<0.1	Maize, soybean, canola
Honduras	<0.1	Maize
Cuba	<0.1	Maize
Costa Rica	<0.1	Cotton, soybean
Romania	<0.1	Maize

Table 2. The costs paid by farmers to access four main GM cops in 2007.

GM crop	Cost of technology: all farmers	Farm income gain: all farmers	Total benefit of technology to all farmers and seed supply chain	Cost of technology: Developing countries	Farm income gain: Developing countries	Total benefit of technology to farmers and seed supply chain: developing countries
GM HT Soybeans	931	3935	4866	326	2560	2886
GM IR Maize	714	2075	2789	79	302	381
GM HT Maize	531	442	973	20	41	61
GM IR Cotton	670	3204	3874	535	2918	3453
GM HT Cotton	226	25	251	8	8	16
GM HT Canola	102	346	448	N/a	N/a	N/a
Total	3174	10081	13225	968	5829	6797

Table 3.The main opportunities and challenges of GM crops in developing countries.

	Items	Descriptions	references
Opportunities	Independence of farm size	▪ Suitable for small farms	Brookes and Barfoot, 2009; Morse et al 2004; Ismael et al 2002; Gouse, 2006.
	Economic benefits	▪ More income due to high yield ▪ Reducing expenditures (lower cost of pesticide and herbicide etc.)	Sonnino et al., 2009; Qaim and Traxler, 2005; Thirtle et al., 2003; Qaim and Traxler, 2005; Gouseet et al. 2004.
	Environmental benefits	▪ Reduction of toxic chemical inputs ▪ Reduce soil erosion ▪ Increase organic matter ▪ Reduce greenhouse gases through lower fuel use ▪ Lower level of emissions ▪ Dealing with climate change by drought-resistant GM crops	Brookes and Barfoot, 2008; Qaim and Zilberman, 2003; Qaim and de Janvry, 2005; Qaim and Matuschke, 2005; Ismael et al. 2002; Thomson, 2003; Park et al, 2011; ISAAA, 2009.
	Health and nutritional benefit	▪ Less exposure to toxic chemicals ▪ Less pesticide residues	Qaim, 2009; Bennett et al., 2006; Bouis, 2007; Park et al, 2011.
Challenges	Availability and accessibility	▪ Difficulties in Research and Development ▪ Higher price of GM seeds ▪ The shortages of the delivery system ▪ Lack of information about application of GM technology	Virgin et al., 2007; Herrera-Estrella, 1999; Wu and Butz, 2004; Virgin et al., 2007; Tripp, 2001; Glover, 2009.
	Regulations and market	▪ Leading to monopolies by patents on genes ▪ Limited global market due to growing skepticism toward GM foods	Paarlberg, 2001; Virgin et al. 2007; Cohen and Paarlberg, 2004; Zarrilli, 2005.
	Socio-economic concerns	▪ Disrupting traditional cultivation systems	Kuyek, 2002; Shiva and Jafri, 2003; Glover, 2009; Raney, 2006.

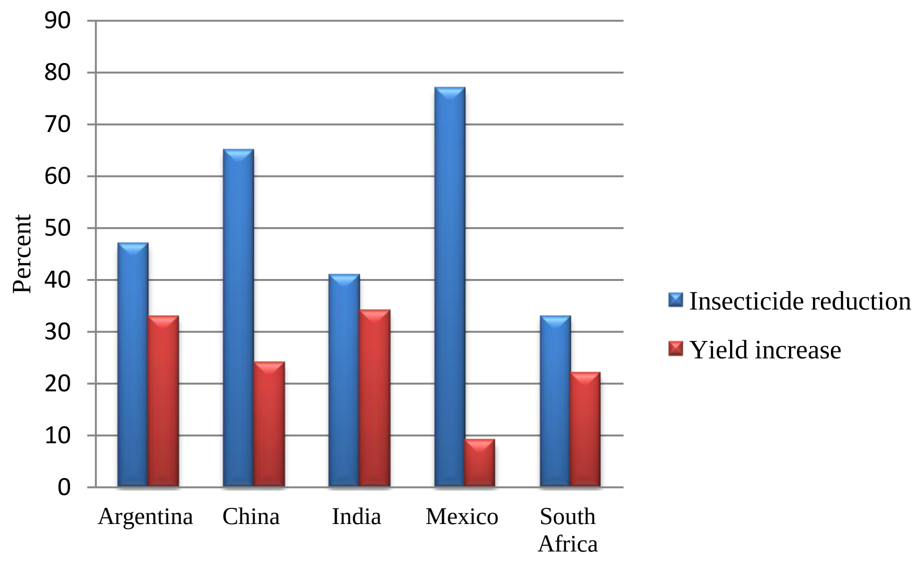

Figure 1. Average agronomic effects of Bt cotton (Adapted from Qaim and Matuschke, 2005).