POTENTIAL IMPACTS OF BT EGGPLANT ON ECONOMIC SURPLUS AND FARMERS' HEALTH IN INDIA

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Abstract

In this article, the potential impacts of Bt eggplant technology in Indian agriculture are analyzed. Several proprietary Bt hybrids are likely to be commercialized in the near future. Based on field trial data, it is shown that the technology can significantly reduce insecticide applications and increase effective yields. Comprehensive farm survey data are used to project farm level effects and future adoption rates. Simulations show that the aggregate economic surplus gains of Bt hybrids could be around US $108 million per year. Consumers will capture a large share of these gains, but farmers and the innovating company will benefit too. As the company has also shared its technology with the public sector, Bt open-pollinated varieties might become available with a certain time lag. This would make the technology more accessible, especially for resource-poor farmers, entailing further improvements in welfare and distribution effects. The wider implications of the private-public technology transfer are discussed. Furthermore, the potential benefits for farmers' health resulting from reduced insecticide applications are examined, using an econometric model and a cost of illness approach. These benefits are worth an additional $3-4 million per year. Yet they only constitute a small fraction of the technology's environmental and health externalities. More research is needed for comprehensive impact analysis.

Keywords: Biotechnology; Bt eggplant; Economic surplus; Health costs; Pesticides; Public-private partnership

1. Introduction

Several recent studies have analyzed the impacts of genetically modified (GM) crops in developing countries, both from ex post and ex ante perspectives (e.g., Pray et al., 2001; Bennett et al., 2003; Huang et al., 2005; Qaim and Traxler, 2005; Bennett et al., 2006; Gouse et al., 2006; Hareau et al., 2006; Qaim et al., 2006). The results consistently show that especially insect-resistant Bt (*Bacillus thuringiensis*) crops can bring about sizeable pesticide reductions and productivity gains. Nonetheless, controversies about the social implications of GM crops in smallholder farming persist. Furthermore, most of the existing impact studies involve major agricultural crops – like cotton, soybean, maize, or rice – which have attracted relatively large biotechnology investments by both the private and public sectors. The question as to whether and how promising GM technologies could be developed also for crops with smaller international area shares is still unresolved. The present article contributes to this debate by analyzing the potential impacts of Bt eggplant technology in India.

Eggplant is a prominent vegetable in India – grown mostly by smallholder farmers on a total of 1.3 million acres (NHB, 2003). Although India ranks second after China in worldwide eggplant production, crop productivity is relatively low (FAOSTAT, 2006). Under the climatic conditions in India, eggplant is infested by a number of insect pests, the most destructive of which is the eggplant shoot and fruit borer (ESFB, *Leucinodes orbonalis* Guen.). Despite heavy insecticide applications, significant yield losses occur on a regular basis (Ghosh et al., 2003). Bt eggplant, containing the Cry1Ac gene, which provides resistance to the ESFB, has been developed by the Maharashtra Hybrid Seed Company (MAHYCO).[1] Several Bt hybrids have been tested in the field and are likely to be commercialized in the near future. We use an economic surplus model to project the welfare and distribution effects among eggplant farmers, consumers, and the innovating company. In doing so, we improve on previous ex ante studies by using more comprehensive field trial and farm survey data, and by estimating future adoption rates based on farmers' stated preferences.

We also scrutinize the implications of different institutional arrangements. Besides commercializing Bt eggplant hybrids itself, MAHYCO has shared its technology and know-how free of charge with the public sector, which is now backcrossing the Bt gene into open-pollinated varieties (OPVs) of eggplant. This is sponsored by the United States Agency for International Development (USAID) through its Agricultural Biotechnology Support Project (ABSP II). The rationale is that relatively better-off farmers would adopt Bt eggplant hybrids sold by MAHYCO, while resource-poor farmers would use cheaper OPVs provided by the public sector. However, since this is one of the first projects of its kind, it is unclear whether such market segmentation between hybrids and OPVs will actually work, or whether the transfer will jeopardize private sector markets and profit potentials. We analyze this by projecting technology adoption patterns and economic surplus effects with and without the availability of Bt OPVs.

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[1] So far, conventional breeding methods have not been effective in developing host plant resistance to the ESFB (Collonnier et al., 2001).

Additionally to the economic surplus effects, we also estimate the potential impact of Bt eggplant technology on farmers' health through reduced insecticide exposure. Several studies related to Bt cotton in different countries found that reductions in insecticide sprays are associated with a decrease in pesticide poisonings (e.g., Huang et al., 2002; Bennett et al., 2003; Hossain et al., 2004). However, none of these studies has evaluated such positive health effects economically. Building on the growing body of literature on the economics of pesticides and farmers' health (e.g., Pingali et al., 1994; Cuyno et al., 2001; Maumbe and Swinton, 2003), we employ an econometric model to estimate the impact of insecticide sprays on pesticide poisonings. Then, Bt-related reductions in the incidence of poisonings are predicted, which are valued with the cost-of-illness method. Although our approach does not capture all possible health effects, it is an important contribution towards a more comprehensive impact evaluation of GM crops.

The remainder of this article is structured as follows. Section 2 describes the Bt eggplant field trial and survey data, which together allow projections of the technology's farm level productivity effects. In section 3, the economic surplus model is introduced and used for simulations under different institutional assumptions, while in section 4, farmers' health effects are analyzed and valued. Section 5 concludes and discusses policy implications.

2. Data

2.1. Field trials with Bt eggplant

Since 2004, MAHYCO has been testing 8 different Bt eggplant hybrids in several states of India. These multi-location field trials were managed by company researchers to test the agronomic and biosafety performance of the new technology. In each location, a Bt hybrid was grown next to an isogenic non-Bt hybrid and other conventional checks, including both popular eggplant hybrids and OPVs. Table 1 summarizes the trial performance of Bt hybrids over two years. Obviously, the technology allows significant insecticide reductions: on average, amounts of insecticides used against ESFB were reduced by 80%, which translates into a 42% reduction in total insecticide quantities. At the same time, there is a large positive yield effect, indicating that chemical insecticides are only of limited effectiveness in controlling ESFB losses. Yields of Bt hybrids were double those of non-Bt counterparts; the yield advantage with respect to other popular hybrids and OPVs was even more pronounced. While the results of these researcher-managed trials might not be replicable exactly under typical farmer conditions, they nevertheless indicate that Bt eggplant technology could lead to important agronomic advantages in the Indian vegetable sector.

About here should appear Table 1.

2.2. Farm survey

In order to get a more detailed picture of agricultural and socioeconomic production conditions, an interview-based survey of 360 eggplant farmers was carried out in 2005. The survey covered three states of India: Andhra Pradesh, Karnataka, and West Bengal, which together account for 42% of total eggplant production (NHB, 2003). Districts and taluks (revenue subdivisions within a district) were selected after detailed consultation with local experts. Within the identified taluks, villages and farmers were selected randomly. Based on expert assessments, the resulting sample can be considered representative of the major eggplant-growing regions of India. The mean farm size is about 4 acres of owned land, and the average eggplant area per farm is 0.65 acres. A typical farmer applies 30 insecticide sprays during a single eggplant crop of 180 days.

For analytical purposes, the Indian eggplant sector is subdivided into two regions, viz. Center/South and East. The Center/South region includes the states of Karnataka, Andhra Pradesh, Maharashtra, Tamil Nadu, Gujarat, Madhya Pradesh, and other minor producing states, whereas the East comprises West Bengal, Orissa, Bihar, and Assam. Sixty-five percent of total eggplant area is located in the East, where farm sizes are smaller, households are poorer, but insecticide use is much higher.[2] Vegetable seed markets, on the other hand, are more developed in the Center/South. While around 60% of the eggplant farmers in the Center/South use hybrid seeds, most of the farmers in the East use farm-saved OPV seeds, and hybrid eggplant adoption is negligible.

2.3. Expected farm level effects of Bt eggplant

Crop enterprise budgets per acre of eggplant are shown in Table 2, separately for the two production regions. The "without Bt" columns show the situation as currently observed. Cost items that are expected to remain unaffected by Bt adoption in the future (e.g.,

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[2] While average farmers in the Center/South apply insecticides around 12 times per eggplant crop, their counterparts in the East spray around 66 times.

fertilizers, fungicides, irrigation, soil tillage) are clubbed together under "other cost". The "with Bt" columns show projections which are based on the field trial results and appropriate adjustments to account for practical farmer conditions. These adjustments were made jointly with local vegetable experts. It is assumed that insecticide use against ESFB would be reduced by 75%, which results in a total reduction in insect pest management cost of 35% and 48% in Center/South and East, respectively. This is reasonable against the background of the Bt cotton experience in India, where mean insecticide reductions of around 50% have been reported (Bennett et al., 2006). Increases in effective yields through Bt eggplant technology are assumed to be significant, but much lower than those observed in the field trials, which is also consistent with the Bt cotton experience (cf. Qaim, 2003; Qaim et al., 2006). In farmers' fields, yield advantages of Bt eggplant hybrids over conventional hybrids are expected to be around 40%, whereas the advantage of Bt hybrids over conventional OPVs could be around 60% (including hybrid vigor and the Bt gene effect).[3] The calculations in Table 2 take into account the current proportion of hybrid use in the two regions.

About here should appear Table 2.

MAHYCO has not yet fixed the price at which Bt hybrid seeds will be sold in future. Using contingent valuation techniques, Krishna and Qaim (2006) estimated that farmers' mean willingness to pay (WTP) for Bt eggplant hybrids is 4,642 rupees (Rs) per acre. This is about five times the price of conventional hybrids, which are sold at around Rs. 900/acre, and a multiple of the cost of OPV seeds. Nonetheless, given the large agronomic advantages and comparing with the price difference between Bt and conventional cotton seeds in India, the magnitude appears reasonable, so that we assume that Bt eggplant hybrids would be priced at mean WTP. The resulting effects of Bt technology on cost of production are shown in Table 2. While the cost per acre of eggplant increases slightly, the cost of production per unit of output is reduced by 13% in the Center/South and 32% in the East. Assuming constant output prices, gross margins are expected to increase by Rs. 16,299/acre (US $361) and Rs. 19,744/acre (US $437) in the two regions.

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[3] The effects of Bt OPVs developed by the public sector are not considered here, but will be taken up later in the article.

3. Potential impacts on economic surplus

3.1. The model

The expected aggregate economic surplus effects of Bt eggplant technology in India are projected using an equilibrium displacement model. The partial equilibrium framework is the most common approach for the evaluation of commodity-related technological progress in agriculture (Norton and Davis, 1981; Alston et al., 1995). Recently, the approach has been used in ex post and ex ante impact assessments of different GM crop technologies (e.g., Pray et al., 2001; Qaim, 2003; Hareau, 2006). Here, we employ a model with linear supply and demand curves and a parallel vertical shift in supply through Bt technology, to minimize possible errors of functional misspecification (cf. Alston et al., 1995). Since in India, foreign trade in eggplant is negligible, we assume a closed economy, where the equilibrium price is entirely determined by domestic supply and demand. Spillovers to other markets are disregarded, which appears acceptable, as eggplant production only employs a small fraction of all factors of production in Indian agriculture. The model is disaggregated for the two production regions, Central/South and East.

Following Alston et al. (1995), the annual change in consumer surplus (ΔCS) and producer surplus (ΔPS) resulting from Bt technology can be calculated as,

$$\Delta CS = P_0\, Q_0\, Z\, (1+0.5Z\eta) \qquad (1)$$

$$\Delta PS = P_0\, Q_0\, (K - Z)(1+0.5Z\eta) \qquad (2)$$

P_0 and Q_0 are initial equilibrium price and quantity, and K is the vertical shift in supply, expressed as a proportion of the initial price. Z is the reduction in price as a result of the supply shift. It is computed as $K\varepsilon/(\varepsilon+\eta)$, where η is the absolute value of the price elasticity of demand, and ε is the price elasticity of supply.

Since Bt eggplant hybrids are developed by the private sector, the expected surplus in gross technology revenue (GTR) accruing to the innovating company is also analyzed, employing the method suggested by Moschini et al. (2000):

$$GTR = A\,(S^{Bt} - S^{non\text{-}Bt}). \qquad (3)$$

A is the potential coverage of Bt hybrids in acres, S^{Bt} is the price charged for Bt hybrid seeds per acre, and $S^{non\text{-}Bt}$ is the price of conventional hybrid seeds. The assumption is that, as the conventional hybrid seed market is competitive, $S^{non\text{-}Bt}$ represents the marginal cost of seed production, which is equal for conventional and Bt hybrids. Therefore, $S^{Bt} - S^{non\text{-}Bt}$

is the gross technology revenue per acre. GTR should not be interpreted as the net innovation rent, as the marginal cost of seed delivery is likely to be higher for Bt than for conventional hybrids. Additional cost components for Bt include company extension and monitoring efforts.

The change in total economic surplus can be computed as the sum of ΔCS, ΔPS, and GTR in any given year. Since adoption of new agricultural technologies is a gradual process over time, we consider a period of 18 years, from 2005 to 2022, and express the average annual welfare effects in terms of annuities. The rate at which future monetary flows should be discounted is a critical parameter in this regard. Kula (2004) calculated the social discount rate for evaluating agricultural projects in India as 5.2%. This rate is used here to calculate the present value of economic surplus.

3.2. Estimating the supply shift

In empirical studies on the impacts of new agricultural technologies, the vertical supply shift K is often calculated as the expected aggregate yield increase divided by ε (Alston et al., 1995). However, Oehmke and Crawford (2002) showed that, using this procedure, K is very sensitive to values of ε, a parameter which is often not known precisely. Therefore, they suggest using accurate enterprise budgets to obtain a direct measure of K, when data availability permits. In that case, K can be calculated as the technology-induced change in the per-unit production cost multiplied by the aggregate technology adoption rate (e.g., Qaim, 2003). The expected change in the per-unit production cost through use of Bt eggplant hybrids was already discussed (Table 2). The procedure employed to estimate future adoption rates is explained in the following.

In ex ante studies, it is fairly common to make assumptions about future adoption rates based on expert estimates (e.g., Hareau et al., 2006). While this approach is useful to get a rough idea of the potential spread of a new technology, we use a more sophisticated method by building on farmers' stated preferences. During the survey, the agronomic properties of Bt eggplant technology were described to farmers, before they were asked whether they would adopt at a certain seed price level. These price levels were varied randomly across questionnaires, allowing us to also analyze demand responsiveness to changing technology prices. Although stated preference data can be misleading when respondents are unfamiliar with the good in question, the properties of Bt eggplant technology are relatively easy to understand, so that we expect farmers' responses to be quite realistic. When explaining the technology to farmers it also helped that many of them were already familiar with Bt cotton, which has been on the market in India since 2002.

Using farmers' binary responses as dependent variable, we estimated a logit model with different socioeconomic variables and the Bt seed price as regressors. The results for Bt hybrid seed adoption are shown in column (1) of Table 3. Evidently, the seed price matters, with higher prices leading to a lower likelihood of adoption. Household income, household size, and the farmer's education level influence adoption positively. Likewise, knowing Bt cotton technology increases the likelihood of Bt eggplant hybrid adoption, indicating that the experience with Bt cotton (either on the own farm or through other information channels) is generally positive. In order to predict future adoption rates of Bt eggplant hybrids, sample mean values were inserted in the estimated model. This was done separately for the two regions. Since the price of Bt seeds is not yet known exactly, we used the mean WTP of Rs. 4,642/acre, as discussed above. The predictions are shown in the lower part of Table 3.

About here should appear Table 3.

Forty-nine percent in the Center/South and 66% in the East are considered the maximum adoption rates. Often, agricultural technology adoption is modeled as a sigmoid function, reflecting risk aspects and necessary adjustments in terms of cultivation practices. Here, however, we assume a linear adoption profile, as Bt eggplant technology actually decreases the risks of crop losses and is relatively easy to use. Moreover, MAHYCO will commercialize several Bt hybrids, which are suitable for diverse agroecological conditions. Experience with Bt cotton in different developing countries shows that the dissemination process is relatively fast, with maximum adoption rates often reached after 5-6 years (Qaim, 2005). However, Bt eggplant adoption might be slower, because it involves a food crop, so that consumer acceptance issues might play a role. It is assumed that maximum adoption would be reached within 9 years of the first commercial release of Bt hybrids, which is projected for 2008. Hence, for the first three years of the time period considered (2005-2007) there is zero adoption, then adoption sets in and increases linearly until the maximum is reached in 2016. After that, adoption remains constant until 2022. Based on this profile, the supply shift K is calculated separately for each year considered.

3.3. Market data

Data on eggplant acreages and production quantities for the two regions were taken from secondary sources (NHB, 2003; FAOSTAT, 2006). Price data were taken from the farm survey; we use average regional farm-gate prices in the Center/South and East. Assuming that prices are equal for eggplant producers and consumers, we disregard the possibility that parts of the additional economic surplus generated are captured by traders or middlemen. Yet, as vegetable markets in India are fairly competitive, the possible error is likely to be small.

Abdulai et al. (1999) estimated that the expenditure elasticity for vegetables is 0.30 in urban and 0.58 in rural India. Since 72% of the Indian population reside in rural areas, we assume that the average expenditure elasticity for eggplant across regions is 0.50. Using Frisch's (1959) method and assuming that the flexibility of money is -2, this translates into an own-price elasticity of eggplant demand of -0.25. Estimates for price elasticities of supply could not be found in the recent literature, neither for eggplant nor for other vegetables. Therefore, we follow the suggestion by Alston et al. (1995) and use a price elasticity of eggplant supply of 1.0. A summary of market data used for the simulations is provided in Table 4.

About here should appear Table 4.

3.4. Simulation results

At first, we simulate the economic surplus effects of Bt eggplant in a scenario where the technology is only incorporated in hybrids sold by MAHYCO, that is, Bt OPVs are not available. The results are shown under scenario I in Table 5. The total surplus generated by the technology amounts to an annual average of Rs. 4.9 billion (US $108 million). This is a large benefit in absolute terms for a vegetable with an aggregate area coverage which is much smaller than that of major food or fiber crops. Unsurprisingly, the largest share of the overall gain accrues in the East, where not only eggplant area is larger, but also farm level productivity gains and adoption rates are assumed to be higher. In terms of surplus distribution by economic agents, consumers turn out to be the main beneficiaries. Because of the closed-economy assumption and the inelastic consumer demand for eggplant, Bt technology would lead to an average price drop of around 15% at maximum adoption rates. Since in India eggplant is often considered the "poor people's vegetable", low-income consumers will benefit over-proportionally from technology-induced price decreases. However, eggplant producers also benefit, in spite of the negative price effect. Their annual gain amounts to Rs. 0.7 billion (US $15 million). Of course, farmers' share of the surplus gains could rise if eggplant exports from India were promoted. MAHYCO as the innovating company captures around one-third of the total surplus in the form of gross technology revenues.

About here should appear Table 5.

To analyze the implications of different institutional aspects, two additional scenarios were simulated. Like scenario I, scenario II assumes that only Bt eggplant hybrids are available. But particular account is taken of the fact that vegetable seed markets are poorly developed in the East. Underdeveloped seed markets are partly responsible for the low current use of eggplant hybrids in that region. Yet another reason is that certain vegetable-producing pockets of Eastern India are particularly affected by soil-borne fungal pathogens, to which many of the available eggplant hybrids are more susceptible than OPVs. Scenario II considers the possibility that adoption rates of Bt eggplant hybrids in the East could be much lower than those assumed initially based on farmers' stated preferences. For illustrative purposes, we assume a maximum adoption rate of only 2% for the East, while adoption in the Center/South remains unchanged. The simulation results for scenario II are also shown in Table 5. As expected, the aggregate surplus gains are much smaller, only reaching about one-fifth of those in scenario I. This clearly shows that Eastern states should receive high priority in technology development and delivery strategies. Apart from putting extra effort in the establishment of local seed market infrastructure, this also involves the deliberate incorporation of Bt technology into hybrids suitable for the particular agroecological conditions of Eastern India.

Scenario III analyzes the implications of the private-public technology transfer. As explained above, public research institutes are using the MAHYCO technology to develop Bt OPVs. Given that Bt OPVs are still at a somewhat earlier stage of development, it is expected that they will be commercialized with a small delay – possibly in 2010. Based on the enterprise budgets in Table 2 and additional expert input, per-unit cost reductions were re-calculated for Bt OPVs. Furthermore, new adoption rates had to be estimated. In a separate part of the survey questionnaire, in which we explained the likely future coexistence of Bt hybrids and Bt OPVs, we gave farmers three options to choose from at randomly varied prices:[4] (i) adoption of Bt hybrids, (ii) adoption of Bt OPVs, or (iii) non-adoption of Bt technology. Logit regressions explaining farmers' choices for options (i) and (ii) are shown in columns (2) and (3) of Table 3. The price linkages and substitution effects are interesting and plausible: the higher the Bt hybrid seed price, the lower the likelihood of Bt hybrid adoption, but the higher the likelihood of Bt OPV adoption. Regional adoption rates were again predicted by inserting sample mean values and using the average WTP for Bt hybrids and Bt OPVs as seed prices. The mean WTP for Bt OPVs was estimated at Rs. 241/acre. Predicted maximum adoption rates are shown in the lower part of Table 3. Obviously, Bt hybrid adoption in scenario III is lower than in scenario I, especially in the East, but overall Bt adoption (in hybrids and OPVs together) is higher.

As can be seen in Table 5, with Rs. 5.7 billion (US $126 million) the total annual surplus gain in scenario III is bigger than in the other two scenarios. As in scenario I, the largest benefit accrues in the East, and in terms of economic agents, eggplant consumers are the main beneficiaries. However, also the producer benefit is increased both in absolute and relative terms. As intended by the private-public sector agreement, especially resource-poor producers will profit from the introduction of Bt OPVs. This becomes obvious from the regression results in Table 3: while household income significantly influences Bt hybrid adoption, income levels do not play a role for Bt OPV adoption. Thus, apart from leading to higher overall welfare gains, MAHYCO's technology transfer also further improves the equity effects of Bt eggplant technology. However, the agreement comes at a cost for the company. Gross technology revenues still occur, but they are much lower than they would be without the transfer. Nonetheless, the difference between company revenues in scenarios I and III should not be considered as the net opportunity cost of sharing the technology with the public sector. Corporate social responsibility can well pay off in the longer run through positive public image effects. More concretely, the technology transfer might facilitate the procedure of getting commercial approval for Bt eggplant technology by the national biosafety authorities. This is especially so in a political environment heavily influenced by pressure groups, which are generally critical of large private

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[4] Seed production costs for eggplant OPVs are much lower than for hybrids. Currently the average market price for OPVs is around Rs. 60/acre, while it is around Rs. 900/acre for conventional hybrids. Accordingly, hypothetical prices used in the survey were also much lower for Bt OPVs than for Bt hybrids.

companies. Experience shows that anti-biotech activists in India have successfully blocked or delayed GM crop approval procedures in the past (cf. Pray et al., 1995).

3.5. Sensitivity analysis

In order to account for uncertainty in ex ante analysis, we carried out sensitivity analyses by changing the values of key parameters in the simulations. Figure 1 shows the effects of drastic changes in the assumptions for the supply shift K. The intermediate category reflects the values described above for the three scenarios. In the optimistic case, both per-unit cost reductions and maximum adoption rates were doubled, while in the pessimistic case they were halved.[5] Unsurprisingly, these parameter changes have a strong influence on the magnitude of economic gains. Yet, even under the pessimistic assumptions, the annual welfare gains in scenarios I and III would still be around Rs. 1.6 billion (US $35 million). The parameter changes have hardly any effect on the regional distribution of benefits, but the distribution between economic agents is influenced somewhat: provided that seed prices remain the same, the optimistic assumptions lead to higher benefit shares for eggplant producers and consumers, while under the pessimistic assumptions the innovating company increases its relative share. Interesting to observe is also the difference in total gains between the scenarios. Even under optimistic assumptions, the gains in scenario II remain much lower than under intermediate assumptions in scenarios I and III. This re-emphasizes the importance for both the private and public sector to give special attention to the Eastern states in technology development and delivery.

About here should appear Figure 1.

Another crucial parameter is the price charged for Bt hybrid seeds. Since MAHYCO has not yet fixed its pricing strategy, we have assumed up till now that Bt hybrid seeds would be priced at farmers' mean WTP of Rs. 4,642/acre. Figure 2 shows the impact of variations in this price for scenarios I and III. Based on the enterprise budget data (Table 2) and the logit models (Table 3), per-unit cost reductions and maximum adoption rates were re-estimated under lower and higher price assumptions for Bt hybrids. The price for Bt OPVs in scenario III was left unchanged. These modifications alter the producer and consumer

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[5] In scenarios I and III, the optimistic assumptions partly would have led to adoption rates above 100%. In those cases, full adoption was assumed as the maximum, whereby in scenario III, the original proportion of Bt hybrid and Bt OPV adoption was maintained.

surplus effects as well as the company’s gross technology revenues. Lowering the Bt hybrid seed price would increase total economic surplus gains, whereas raising the price would decrease the gains. The effects are less pronounced in scenario III, because of the substitution between Bt hybrids and Bt OPVs. Likewise, the distribution effects are influenced, with the producer and consumer benefit share increasing with decreasing Bt hybrid seed prices. The company’s relative and absolute technology revenues rise with increasing prices, indicating that farmers’ demand for Bt hybrid seeds is inelastic. In other words, changing the price leads to under-proportional changes in Bt hybrid seed adoption.

About here should appear Figure 2.

It is worth pointing out that pricing of proprietary GM seeds has become a delicate issue in India. Recently, the Monopolies and Restrictive Trade Practices Commission of the Indian Government ruled that MAHYCO and Monsanto should reduce the monopoly price and royalties charged for Bt cotton seeds. The companies agreed to reduce the price up to a certain level in 2006, but several state governments have demanded further reductions (Mitta, 2006). If this were to happen also in the case of Bt eggplant, company revenues would certainly shrink. The probability of the government interfering in the pricing of Bt hybrid seeds are lower when also the public sector has access to the technology and low-cost Bt OPVs are available. This might be another indirect advantage of sharing technology from the private sector point of view. For instance, if only proprietary Bt hybrids were available (scenario I) and the government would restrict the seed sales price at Rs. 2,000/acre, company revenues would be lower than in the higher price options of scenario III (Figure 2). Such strategic considerations should not be neglected when analyzing the incentives and conditions for private-public technology transfer.

4. Potential impacts on farmers’ health

4.1. Pesticide poisoning and cost of illness

Compared to most developed countries, pesticide use in Indian agriculture is relatively low. This is different, however, for certain crops and regions. Fruit and vegetable crops, in particular, are sprayed quite heavily in India: while they only cover 3% of the gross cropped area, they receive 13% of total pesticides used (Jeyanthi, 2003). Eggplants account for a significant share of the total, with serious negative environmental and health implications. The health hazards for farmers and farm workers applying pesticides have been analyzed in different countries (e.g., Pingali et al., 1994; Sunding and Zivin, 2000; Sivayoganathan et al., 2000; Maumbe and Swinton, 2003). Often, the problems are greater in developing than in developed countries, because environmental and health regulations are laxer, pesticides are mostly applied manually, and farmers are less educated and less informed about negative side effects. Indeed, recent studies on eggplant production in Bangladesh and India revealed that illnesses attributed to pesticide applications are widespread (Rashid et al., 2003; Kolady and Lesser, 2005).

This is confirmed by our farm survey data. The most frequently used insecticides include organochlorins, organophosphates, and carbamates, which are known for their high mammalian toxicity. For example, the most popular insecticides used among sample farmers are endosulfan and monocrotophos; both fall into toxicity category I of the World Health Organization's classification and are legally banned in many other countries. Table 6 shows that the majority of eggplant farmers is aware of potential health hazards associated with pesticide applications, and around one-fourth of them have suffered personally from acute pesticide poisonings during the 12 months prior to data collection. Pesticide poisonings are defined here as farmers' self-reported health symptoms experienced during or shortly after pesticide applications. Such health symptoms include stomach poisoning, eye and skin irritations, and breathing problems, among others. Pesticide poisonings were reported jointly over all types of pesticides used and all crops grown on a particular farm.[6]

About here should appear Table 6.

The cost of illness caused by pesticide poisonings was calculated as shown in Table 6. Lost workdays were valued at the local average wage rate of male laborers. The cost of physician treatment includes fees, medicines, and travel costs to reach the physician. Although in only one-third of the cases, a physician was actually consulted, this cost component accounts for the largest share of the total. The total cost of illness related to pesticide poisonings averaged over all farm households is Rs. 393 per year. This translates into an average cost per case of poisoning of Rs. 91. It should be noted that these values

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[6] On average, farmers spray their eggplant crop 30 times with insecticides and twice with other pesticides (i.e., fungicides and herbicides). All other crops together account for 17 cumulated pesticide applications per year (cf. Table 7). Capturing data on pesticide poisonings only for insecticides in eggplant production proved impracticable, because often different applications are performed on the same day.

underestimate the full health costs associated with pesticide sprays. The reason is that chronic diseases resulting from long-term pesticide exposure are not considered here; this would have required more detailed medical assessments. Moreover, only poisonings directly involving family members were reported by farmers. That is, poisonings occurring to hired farm laborers are not included.

4.2. Determinants of pesticide poisonings

In order to analyze the determinants of pesticide poisonings and isolate the net effect of insecticide sprays in eggplant, we employ an econometric model. Pingali et al. (1994) used a logit model with a binary dependent variable to estimate the effect of different explanatory variables on the probability of observing health problems. A similar approach was employed by Hossain et al. (2004). Instead of building on a binary choice model, Maumbe and Swinton (2003) regressed the number of self-reported pesticide poisonings on a set of explanatory factors using a Poisson model. We follow this latter approach, as we are particularly interested in analyzing the impact of insecticide sprays in eggplant on the incidence of pesticide poisonings. We use different farm and farmer characteristics as explanatory variables, similar to those used by Pingali et al. (1994). Summary statistics of the explanatory variables and estimation results of the Poisson model are displayed in Table 7.

About here should appear Table 7.

The number of insecticide sprays in eggplant is positively associated with the number of pesticide poisonings, and the marginal effect is much higher than that of pesticide sprays in other crops. This is probably due to the higher relative toxicity of insecticides used in eggplant cultivation. Unsurprisingly, also the coefficients for the average dosage used per insecticide spray in eggplant and the plot size are positive and significant. Covering the face while applying pesticides reduces the risk of poisonings, whereas smoking increases the risk. The farmers' body weight-to-height ratio also plays a significant role. A low ratio indicates that farmers are likely to be undernourished. Since undernutrition is often associated with an inferior overall health status, the negative coefficient is plausible: ceteris paribus, poor nutrition makes the body more susceptible to pesticide poisonings and vice versa. Better education should actually lead to fewer pesticide poisonings, so the positive coefficient is somewhat surprising. A possible explanation is that better-educated farmers might easier comprehend the linkages between pesticides and adverse health symptoms. Since we build on self-reported data, it is possible that farmers with little education suffered from adverse symptoms without recognizing them as pesticide poisonings. This would lead to an under-reporting of pesticide poisonings. Strikingly, Maumbe and Swinton (2003), who similarly used self-reported data in their study in Zimbabwe, also found a positive relationship between formal education and pesticide poisonings.

4.3. Potential health cost savings through Bt eggplant

Since Bt eggplant technology allows sizeable reductions in insecticide applications, the technology is likely to bring about significant benefits for farmers' health. As the experience with Bt cotton in different countries shows (Huang et al., 2003; Bennett et al., 2006; Qaim et al., 2006), technology-related insecticide reductions primarily occur in the form of fewer sprays. We used the Poisson model estimates to predict the impact of a reduced number of insecticide sprays in eggplant on cases of pesticide poisonings. Separate predictions were made for the Center/South and East. Then, each case averted was valued at the region-specific cost of illness (cf. Table 6). The resulting health cost savings are shown in Figure 3, expressed in Rs/acre. With the expected insecticide reductions through Bt eggplant technology in the Center/South (35%) and East (48%), health cost savings would be around Rs. 50/acre and Rs. 470/acre, respectively. The big regional differences are due to the higher initial number of insecticide applications and pesticide poisonings in the East.

About here should appear Figure 3.

Aggregate health cost savings through Bt were calculated by multiplying the per acre savings with regional technology adoption rates. Following the same procedure as discussed in section 3, we computed annuities using a discount rate of 5.2% over a time period of 18 years. The results are presented in Table 8 for the three scenarios. In scenario I, average annual health cost savings from Bt hybrid adoption would be Rs. 135 million (US $3 million). If this health benefit is added to the producer surplus gain, overall welfare for farmers increases by 20%. As expected, the major health impacts occur in the East (96%). When Bt OPVs are introduced additionally (scenario III), aggregate health cost savings would further increase to Rs. 184 million (US $4 million) per year. These are large benefits, which are often neglected in economic analyses.

About here should appear Table 8.

It should be stressed, however, that the health cost savings reported in Table 8 are only a fraction of the overall potential health benefits of Bt eggplant technology. As noted above, our data are inadequate to capture the relationship between pesticide use and chronic health conditions. Furthermore, health costs occurring to farm workers other than family members are not included in our approach. And finally, likely health benefits to consumers through reduced pesticide residues in eggplant are neglected here. High pesticide residues in vegetables are a serious problem in India (e.g., Kole et al., 2002).

Beside Bt technology, there are certainly other options that could help reduce pesticide use in the Indian vegetable sector. Integrated pest management (IPM) techniques, for instance, have been advocated, but so far with limited success, as they are often labor intensive and require particular knowledge and skills. Nonetheless, all promising options should be further promoted and considered as complementary to each other. Bt technology could well become an integral part of a broader IPM strategy.

5. Conclusions and policy implications

In this article, we have analyzed the potential impacts of Bt eggplant technology in Indian agriculture. Several Bt eggplant hybrids are likely to be commercialized by the private sector in the near future. Based on field trial data, we have shown that the technology can reduce insecticide applications and pest-related yield losses, thus increasing the productivity of eggplant production. Comprehensive survey data have been used to project farm level impacts and future adoption rates. Simulations show that the aggregate economic surplus gains of Bt eggplant hybrids could be in a magnitude of Rs. 4.9 billion (US $108 million) per year. More than 50% of the overall gains will be captured by consumers, who will benefit from a technology-induced decrease in eggplant prices. Since eggplant in India is an important vegetable also in low-income consuming households, this price decrease is pro-poor. Positive nutritional effects can be expected from increased vegetable consumption. But also eggplant farmers will profit from Bt technology, as the increase in total factor productivity is larger than the drop in market prices. The innovating company can capture technology revenues, as Bt hybrid seeds will be sold at a premium. In terms of regional distribution effects, the lion’s share of the welfare gains would accrue in the Eastern states of India (West Bengal, Orissa, Bihar, and Assam), where most eggplants are produced and where pest problems are particularly severe. Model simulations underline that – for the full realization of welfare potentials – these states will need particular attention in terms of technology product development and delivery. This includes the need to strengthen local seed market infrastructure.

The innovating company has also shared its Bt technology free of charge with the public sector for incorporation into eggplant OPVs, which can be sold to farmers at much lower prices than Bt hybrids. Additional availability of Bt OPVs will further increase the annual welfare gains to Rs. 5.7 billion (US $126 million). Again, a major share of these gains will be captured by eggplant consumers, but also farmers' benefits increase both in relative and absolute terms. Lower-cost Bt OPVs will especially improve technology access for resource-poor farmers, who might not adopt more expensive Bt hybrids due to income constraints. However, also some of the better-off farmers are likely to switch from Bt hybrids to Bt OPVs, once these become available. Accordingly, technology revenues for the innovating company will shrink, as shown in a separate scenario simulation. Against this background, the rationale to share the technology with the public sector is not immediately apparent. Yet the scenario calculations do not capture all direct and indirect implications of the agreement. Corporate social responsibility can pay off in multiple ways, especially in an environment like India, where the GM debate is highly politicized and public distrust towards large private companies is widespread. Apart from general image improvements, the agreement could facilitate regulatory approval procedures and lessen the probability of public calls for government price interventions, as recently observed in Bt cotton seed markets. These considerations suggest that private-public technology transfers can well be beneficial for all parties involved, if appropriately designed and managed.

Apart from the economic surplus effects, we have also analyzed potential impacts of Bt eggplant technology on farmers' health. We show that Bt technology could significantly reduce the large number of insecticide applications currently observed in eggplant. An econometric model is used to demonstrate that this would also reduce the incidence of occupational pesticide poisonings. Based on a detailed account of the cost of illness associated with such poisonings, we have calculated that farmers' expected health cost savings through Bt eggplant technology are worth around Rs. 135-184 million (US $3-4 million) per year. Adding these health benefits to the gains in producer surplus increases farmers' welfare effects by approximately 20%. While this is significant, farmers' health cost savings only constitute a small fraction of the positive externalities of Bt technology. Additional effects of reduced pesticide applications, which were not considered here, include possible health benefits for hired farm workers and consumers, as well as a reduction in environmental hazards.

On the other hand, also environmental and health risks need to be considered in a comprehensive impact assessment. Recent research suggests that Bt crops pose no significant risks to the environment or to human health, and that their positive externalities exceed the potential negative ones (Shelton et al., 2002; Mendelsohn et al., 2003). Nevertheless, especially secondary effects of Bt crops are not yet fully known and understood, so that further monitoring is required to avoid undesirable consequences. This holds particularly true for Bt eggplant in India, as the country is a biodiversity hotspot for eggplant. Further research is needed to identify and value external and secondary effects for comprehensive impact analysis of GM crops. Our study is only a small step in this direction.

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Table 1.
Summary of field trial results with Bt eggplant hybrids

	Reduction in insecticide use (%)		Increase in uninfected fruit yield (%) over		
	Against ESFB	Against all insect pests	Non-Bt counterparts	Popular hybrids	Popular OPVs
2004-05 ($n = 9$)	80	44	117	120	179
2005-06 ($n = 6$)	79	40	76	110	147
Average	80	42	100	116	166

Source: MAHYCO (unpublished data).

Table 2.
Average eggplant enterprise budgets with and without Bt hybrids

	Center/South		East	
	Without Bt	With Bt	Without Bt	With Bt
Seed cost (Rs/acre)	638	4,642	48	4,642
Insecticide cost (Rs/acre)	1,972	1,282	6,776	3,543
Labor cost for insecticide sprays (Rs/acre)	186	121	499	261
Harvesting/marketing cost (Rs/acre)	4,049	5,993	1,309	2,094
Other cost (Rs/acre)	11,052	11,052	14,462	14,462
Total variable cost (Rs/acre)	17,897	23,090	23,094	25,002
Marketable yield (quintals/acres)	106	157	71	114
Per-unit production cost (Rs/quintal)	169	147	325	220
Gross revenue (Rs/acre)	44,670	66,162	32,907	52,651
Gross margin (Rs/acre)	26,773	43,072	9,813	27,649

Note: US $1 = Rs. 45.2 (official exchange rate in October 2006).

Source: Own calculation with survey data.

Table 3.

Logit adoption models based on farmers' stated preferences (*n* = 360)

		(1) Bt hybrids in the absence of Bt OPVs	(2) Bt hybrids in the presence of Bt OPVs	(3) Bt OPVs in the presence of Bt hybrids
Bt hybrid seed price (thsd Rs/acre)		-0.203***	-0.211***	0.160***
		(0.058)	(0.066)	(0.060)
Bt OPV seed price (thsd Rs/acre)			1.377	-3.111**
			(1.617)	(1.504)
Currently cultivating hybrids (dummy)		-0.158	-0.580	1.534***
		(0.335)	(0.376)	(0.360)
Insecticide expenditure to control ESFB (thsd Rs/acre)		0.051*	0.079***	-0.056***
		(0.027)	(0.024)	(0.020)
Experienced insecticide poisoning (dummy)		0.453	-0.160	0.347
		(0.316)	(0.349)	(0.326)
Cultivation on leased-in land (dummy)		-0.577*	-0.586	0.385
		(0.344)	(0.418)	(0.367)
Farm land owned (acres)		0.006	0.053	-0.039
		(0.034)	(0.036)	(0.035)
Per capita annual household income (thsd Rs)		0.050***	0.063***	-0.019
		(0.017)	(0.019)	(0.015)
Square of per capita income		-0.0003***	-0.0004***	0.0001
		(0.0001)	(0.0002)	(0.0001)
Proportion of off-farm income		0.178	1.106**	-1.871***
		(0.533)	(0.563)	(0.568)
Use of credit for eggplant cultivation (dummy)		0.499	0.715**	-0.763**
		(0.313)	(0.335)	(0.324)
Farmer age (years)		-0.001	0.005	-0.009
		(0.010)	(0.012)	(0.011)
Farmer education (years of schooling)		0.055*	0.060*	-0.042
		(0.029)	(0.033)	(0.030)
Number of household members		0.125***	0.125***	-0.061
		(0.050)	(0.046)	(0.045)
Extension service is major source of information (dummy)		-0.297	-0.491	0.658**
		(0.301)	(0.340)	(0.322)
Input dealer is major source of information (dummy)		0.377	0.252	-0.398
		(0.293)	(0.337)	(0.317)
Public media are major source of information (dummy)		0.570*	0.330	-0.314
		(0.324)	(0.347)	(0.324)
Knowing Bt cotton (dummy)		1.266**	1.983***	-2.669***
		(0.575)	(0.584)	(0.789)
Located in the East (dummy)		0.648*	-0.625	1.881***
		(0.373)	(0.439)	(0.407)
Intercept		-1.536**	-2.749***	0.971
		(0.726)	(0.869)	(0.799)
Log likelihood		-211.24	-176.82	-199.45
Chi-square value		76.48***	92.75***	96.94***
Predicted adoption rate at mean WTP (%)	Center/South	49	37	41
	East	66	24	69

Note: Standard errors are shown in parentheses.

*, **, *** Statistically significant at the 10%, 5%, and 1% level, respectively.

Table 4.
Summary of market data used for simulations

	Center/South	East
Production (million quintals)	31.38	58.27
Price of eggplant fruits without Bt adoption (Rs/quintal)	421	463
Price elasticity of demand	-0.25	-0.25
Price elasticity of supply	1.00	1.00

Sources: NHB (2003), FAOSTAT (2006), Abdulai et al. (1999), Alston et al. (1995), and farm survey data.

Table 5.
Simulated gains in economic surplus and surplus distribution (annuities in million Rs)

		Surplus distribution				
		By region		By economic agent		
	Total	Center/South	East	Consumers	Producers	Company
Scenario I	4,896	888 (0.18)	4,008 (0.82)	2,716 (0.55)	679 (0.14)	1,501 (0.31)
Scenario II	1,008	888 (0.88)	120 (0.12)	416 (0.41)	104 (0.10)	487 (0.48)
Scenario III	5,676	1,112 (0.20)	4,564 (0.80)	3,886 (0.68)	972 (0.17)	819 (0.14)

Notes: US $1 = Rs. 45.2 (official exchange rate in October 2006). Figures in parentheses indicate the share of total economic surplus.

Table 6.
Incidence of pesticide poisonings and cost of illness

	Center/South	East	Overall
Share of farmers using insecticides in eggplant (%)	95.42	97.50	96.11
Share of farmers recognizing potential health hazards (%)	56.77	76.07	63.29
Share of farm households with own experience of pesticide poisoning during the last 12 months (%)	14.58	45.00	24.72
Average incidence of pesticide poisonings (number/household/year) [a]	1.13	10.78	4.34
Average cost of illness related to pesticide poisonings (Rs/household) [a]			
Annual opportunity cost of lost workdays	79.16	92.71	83.67
Annual cost of physician treatment	200.33	512.46	304.37
Annual cost of self treatment	2.23	10.01	4.82
Total annual cost of illness	281.71	615.18	392.86
Average cost per case of poisoning	249.30	57.07	90.52

[a] These are averages over all households, not only those that experienced pesticide poisonings themselves.

Note: US $1 = Rs. 45.2 (official exchange rate in October 2006).

Source: Own calculation with survey data.

Table 7.

Poisson model for the self-reported number of pesticide poisonings per year ($N = 360$)

	Mean (Std. dev.)	Coefficient (Std. error)
Number of insecticide sprays in eggplant per year [a]	29.69 (60.19)	0.442*** (0.030)
Average insecticide dosage per spray in eggplant (kg/acre) [a]	0.37 (0.40)	0.202*** (0.033)
Number of other pesticide sprays in eggplant per year [a]	2.00 (2.14)	-0.018 (0.012)
Number of pesticides sprays in other crops per year [a]	17.05 (22.21)	0.048*** (0.016)
Average time taken for each pesticide spray (h/acre) [a]	4.45 (2.56)	-0.062 (0.063)
Size of eggplant plot (acres) [a]	0.65 (0.57)	0.606*** (0.056)
Gross cropped area under other crops (acres) [a]	5.65 (5.74)	0.357*** (0.041)
Farmer age (years) [a]	40.03 (12.59)	-0.424*** (0.093)
Farmer education (years of schooling) [a]	6.31 (4.81)	0.235*** (0.019)
Farmer body weight-to-height ratio (kg/m)	34.10 (4.78)	-0.016** (0.005)
Share of family labor in total labor used for pesticide spraying	0.77 (0.35)	1.651*** (0.149)
Cigarette smoking while applying pesticides (dummy)	0.57	0.578*** (0.064)
Face covered while applying pesticides (dummy)	0.32	-0.774*** (0.076)
Located in the East (dummy)	0.33	1.854*** (0.110)
Intercept		-0.704 (0.444)
Log likelihood		-1914.93
Chi square value		2910.75***

[a] Variables are expressed in natural logarithms.

, * Statistically significant at the 5% and 1% level, respectively.

Table 8.

Farmers' health benefits due to Bt technology adoption

	Annual health cost savings (million Rs)			% increase in farmers' welfare gain [a]
	Center/South	East	Overall	
Scenario I	6	129	135	19.88
Scenario II	6	4	10	9.62
Scenario III	9	175	184	18.93

[a] This percentage increase is the proportion of annual health cost savings in annual producer surplus gains as shown in Table 5.

Note: US $1 = Rs. 45.2 (official exchange rate in October 2006).

Fig 1.

Total economic surplus effects under different assumptions

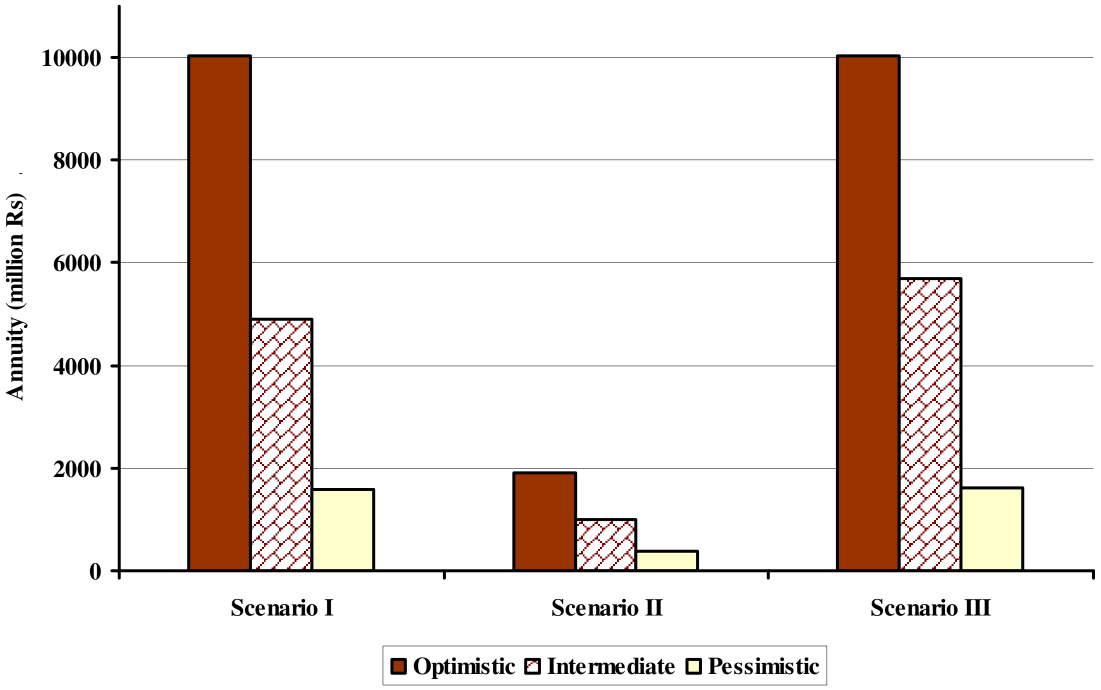

Fig. 2.

Impact of Bt hybrid seed price (P) on total economic surplus and surplus distribution

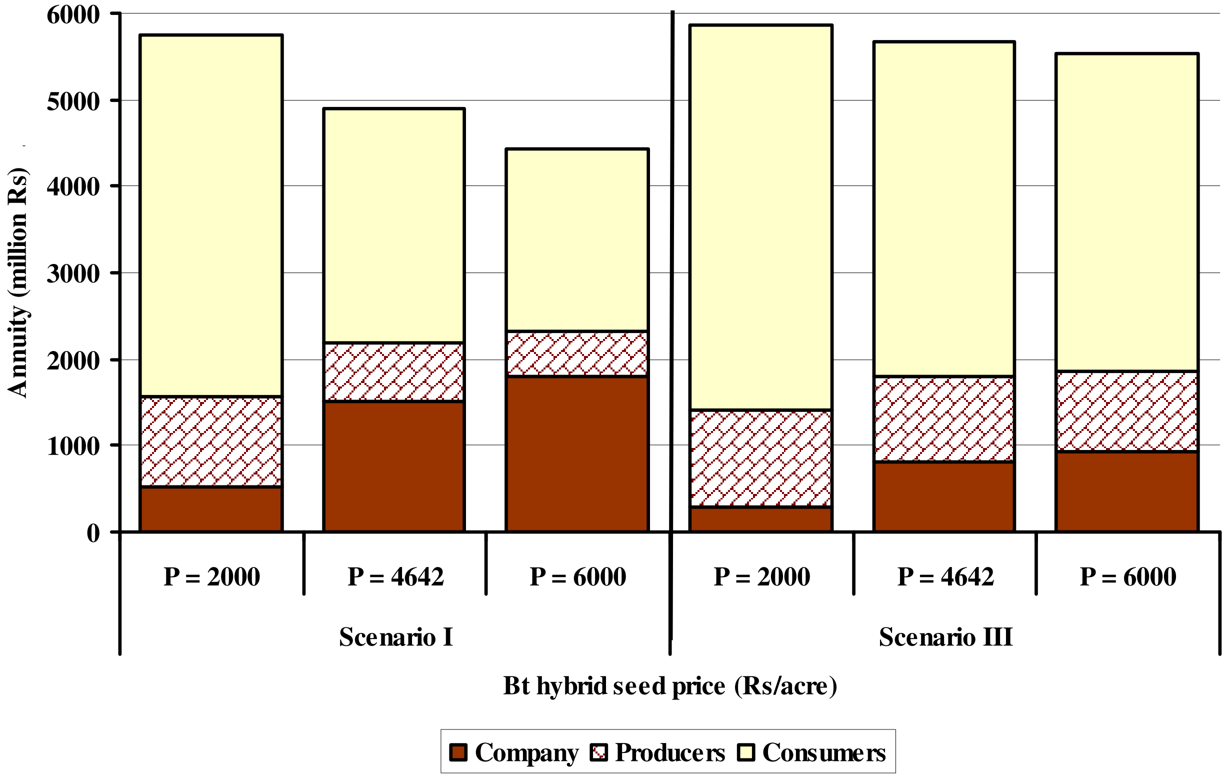

Fig 3.
Health cost savings from insecticide reductions in eggplant