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Multiple Uses of Biotechnology

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Cotton farmers are benefiting from the significant research investment that has applied modern tools of biotechnology and genetics to the control of both weed and insect pests. This investment has resulted in the following commercialized insect control and herbicide tolerance genes in elite cotton germplasm: the Cry Bt proteins (Cry 1Ac, Cry 1Ab, Cry 1F and Cry 2Ab), Cowpea Trypsin Inhibitor (CpTI) a non-Bt gene, and the herbicide tolerance genes for bromoxinyl, glyphosate and glufosinate.

In addition to these commercialized genes, the following novel technologies are being tested in cotton: non-Cry insecticidal proteins, additional herbicidal genes, fiber quality, seed quality, stress tolerance and disease tolerance.

Looking towards the future, several biotech traits could play a significant role in improving the efficiency with which farmers can produce cotton. Additional insect control genes could be beneficial to further delay insect resistance to Cry 1 and Cry 2 proteins, and could be essential for production efficiency if resistance develops to these two commercialized classes of proteins. A loss of efficacy from the current Cry genes may necessitate a return to previous insecticidal usage unless alternative insect control genes are developed in elite germplasm. Some of the alternative genes currently being considered in cotton include: lectins, additional protease inhibitors, and a vegetative insecticidal protein.

Herbicide tolerance research continues to expand in cotton with additional glyphosate tolerance mechanisms and novel herbicide tolerance categories. Fiber and seed quality improvement is a long term challenge. However cotton research continues in China (Mainland), Europe, Australia and the US.

Increased tolerance to stress by cotton plants could lower risk and enhance productivity. Targets are being investigated in cotton that could confer drought tolerance, salt tolerance and chilling injury tolerance.

Disease tolerance could have a huge impact on tropical cotton due to weather patterns that favor disease progression and the lack of cold temperatures to break disease cycles. Biotechnology is being applied to traits targeted at both fungal and viral diseases.

Current planting seed adoption patterns suggest that farmers will continue to want seed-based technologies that address multiple efficiency robbing problems. Delivering multiple solutions in the seed is a highly efficient mechanism to address the yield and efficiency robbing hazards that cotton farmers face. Although plant breeders and seed companies will be challenged by the incorporation of multiple traits into elite germplasm, benefits to farmers should encourage the necessary investment. Whether this investment is available depends less on scientific limitations and more on regulatory hurdles and delays, business models that provide a return from the long term investment, and product stewardship and utilization skills.

Why Fear Biotechnology?

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Introduction

The scope of biotechnology is large (ICAC, 2002). Biotechnology includes experimental techniques for evaluating and manipulating the genetic materials of organisms. Experiments indicate molecular analysis of genetic material, hybridization (even among least related parents), organ and cell culture, plant regeneration, microbial biochemistry and molecular biology and genetics. However, this article on "Why fear biotechnology?" is, confined to the biotechnology involving genetically engineered (GE) plants. These are plants whose genetic materials have been altered through recombinant DNA (r DNA) technology making them capable of producing new substances or performing new functions.

GE plants have potential roles in increasing productivity of food and cash crops. This can be through enhanced resistance or tolerance to adverse environments, and resistance to severe pest infestations. GE plants can play a role in easing crop storage and transportation arising from grain/seed resistance to post-harvest micro-organisms and invertebrate pests. GE plants also play a role in the availability of essential nutritional requirements, including vitamins and amino acids. The nutritionally-enhancing or "nutraceutical" GE crops have applications for improving diet and health of people and livestock (Atikins, 2003). These include, for example, rice modified to express increased levels of ?-carotene (precursor of vitamin A) or legumes modified for increased levels of the essential amino acid Methionine. This article will describe the reasons of fear and skepticism about GE cotton. Since the application of modern biotechnology tools is resulting in expanding the number of products in cotton other than those of modified genetic composition, a preferred term for biotechnology-facilitated cotton is "biotech cotton" (ICAC, 2004a). Biotech cotton has been produce commercilly for ten years since it was introduced by Monsanto in 1996 (ICAC, 2000). This was after Perlak et al., (1990), introduced Cry 1Ac and Cry 2Ab genes into cotton plants and showed high levels of resistance to cotton bollworms (Helicoverpa spp.). The genes inserted in the first generation of biotech cotton offered management of production inputs. Bt Cotton offered control of Lepidopteran pests, the *Helicoverpa* group e.g. and Monsanto's Roundup Ready (RR) cotton produced resistant to herbicides. Research on biotech cotton for increased outputs e.g. yields and quality, have come later (ICAC, 2004 a&b). In spite of expanding research on production and use of biotech cotton, there have been fears and skepticism about these varieties specifically and about biotechnology in general.

Categories of Fears of Biotechnology in Cotton

Potential Health and Environmental Risks from Biotech Cotton

Biotech cotton may offer many benefits, but potential users have recognized or expressed concern over the potential risks to human health and the environment. These constitute the first category of "fears" of biotechnology or of biotech cotton. The fears in this category have in the 10 years period been discussed and some resolved through scientific-based studies. To address those fears risks to human health and the environment must be assessed before biotech varieties may be released. Risk assessments are the essence of biosafety regulations and protocols in the biotechnology arena. These have become mandatory in countries using biotechnology.

Fears on health include, among other things:

- Toxicity of the Bt proteins to humans and animals
This fear has generated studies ranging from detailed understanding of the biology of cotton and products and biproducts (e.g. cooking oil, livestock meals) through characterization of the introduced proteins and their levels in the products, to feeding studies of the products in rats and other animals.

- Human and animal development of resistance to antibiotics used in treatment of diseases
This arose from a realization that antibiotic genes were inserted in the experimental cotton cells for ease of identifying those transformed from the non-transformed types (ICAC, 2000b).

Fears about environmental degradation are expected to stem mainly from;

- Creation of "super weeds" through gene – flow between biotech cotton and wild relatives. This was coupled with a fear of affecting the composition of plant genetic resources and biodiversity. The incompatibility among, and geographical distribution of the concerned species have alleviated fears to some extent.

- Emergence of other weeds not controlled by the herbicides in use on the herbicide – resistant cotton, and over use of herbicides on biotech cotton which would eventually contaminate the environment.

- Emergence of other pests in cotton not affected by the Bt proteins.

- Lepidopteran target pests developing resistance to the Bt toxins due to their continuous exposure to the delta- endotoxin. Such resistance, and even cross resistance (resistance of a pest to different types of toxins e.g. Cry 1Aa-c series) have been reported (Shen et al., 1998). New technologies involving deployment of Bt genes with different modes of action in biotech varieties over time periods and distances, coupled with use of refugia crops which dilute the build up of resistance through mating of insects susceptible to the toxins with those which have developed resistance, are among the reasons this fear has been alleviated (ICAC, 2002b).

- Adverse effects on non-target insect species by Bt toxins, including beneficial insects in farming systems, which are useful in biocontrol programs for other crop pests. It is now realized that the fears about biotechnology-based risks to human health and the environment will continue as new developments in biotechnology take place. The risks to the environment can be minimized through proper case-by-case assessment of the necessary precautions required while applying biotech innovations to particular uses and environments or geographic regions. Fears of effects on human health can be abated through wide harmonization of regulatory requirements (ICAC, 2004a).

Fears due to Impediments to Biotechnology Applications

The second category of fears about biotechnology arises out of impediments, or hurdles, in the course of effecting biotechnology applications. This is the major source of fear about biotechnology today in developing countries. The magnitudes and impacts of this category vary with the type and levels of the national economy and the development of agricultural farming systems such as large commercial scale vis-avis subsistence farming. These impediments can be sub-categorized as:

Requirements of Enabling Policies and Regulatory Legal Frameworks on Biotechnology

The required assessments for risks toward health and the environment mentioned above require individual countries or regions having policies and legal frameworks on development, testing, application and protection of biotechnological innovations. These include, among others:

- Policies on biotechnology and biosafety regulations. Scientists may realize the need for the legal framework to be in place before they can introduce or work on biotechnological options. This is especially so on requirements for handling, containment and confinement of materials during testing. Scientists depend on the perception and pace of policy makers who may have biased attitudes toward biotechnology and may slow the regulatory processes. There are a number of guidelines and options on the formulation of policies and regulations on biotechnology. There are, for example, international treaties and conventions, which if the country is a party to, could be ratified for preliminary use before being fully domesticated into national laws. These include, inter alia, the United Nations Convention on Biodiversity (1992), and the Cartagena (2004) protocol on biosafety. There are also examples of regional guidelines for countries intending to formulate bio-safety regulations, for example the OAU (now African Union) Model on Biotech Regulations (OAU, 2001). The required policies need to be widely embraced to safeguard human health and the environmental prior to use. The use of biotechnology requires multidisciplinary teams to formulate required policies and to be enacted into laws by legislative bodies.
    - Once regulations are developed, a regulatory authority is needed, and this must be an infrastructure that empowers the authority to monitor and enforce the regulations. These add costs to the processes of biotechnology application and regulation.
    - It is encouraging to note that, in addition to existing guidelines on biosafety regulations, there are international programs which are ready to support interested countries in setting up biosafety regulations. These programs offer technical, financial and information resources. Many African countries have utilized programs funded by the United Nations Environment Program (UNEP) and its associated unit our Global Environment Facility (UNEP-GEF) biosafety unit, the United Nations Industrial Development Program (UNIDO) and United Nations Development Program (UNDP) to develop biosafety regulations (Atikins, 2004). Uganda, with the assistance of UNEP-GEF, developed a draft biotechnology biosafety framework (Anon., 2000).
- Intellectual property (IP) management policies are essential at institutional and national levels to provide protection for technologies. Effective negotiations are needed on appropriate terms for use of biotechnological innovations by needy countries/firms. Lack of basic policies discourage private technology suppliers from operating in countries where there are no agreements on the disclosure of information, licensing for exchange/accessing of material and deciding on royalties for the technologies. In return, the licensee (recipient) of the technology in countries lacking such policies lacks confidence to negotiate the terms of use (Erbisch and Maredia, 2003). Such arrangements call for having in place Intellectual Property Offices (IPOs) and officers, which have associated costs. The guiding principles for developing IP management programs can be drawn from international conventions or agreements. For example, the Trade Related Intellectual Property Right (TRIPS) agreement, the CBD convention and the FAO's International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) are available.

Costs of Infrastructure and Capacity for Biotechnology Development

The development of biotechnology innovations requires investments in laboratory infrastructure and trained personnel. In countries with still developing economies the costs become prohibitive. Solutions could be produced by the development of international or regional co-operations/networks which can enable sharing of resources for laboratories and personnel. For example the East African Regional Program and Research Network for biotechnology, biosafety and biotechnology policy development (BIO-EARN) is now developping biotechnology regulations for Ethiopia, Kenya, Tanzania and Uganda (Anon., 2003). The absence of relevant national policies on biotechnology is a hindrance at the start of such cooperation, even if a country decided to deal with multinational private companies.

Systems of Input Supply and Costs

- Additional fears towards biotech/biotechnology stem from the development levels of agriculture in individual countries. This is especially so with regard to arrangements for the source and distribution of transgenic planting seed.

In subsistence agriculture, farmers depend traditionally on farm-saved seed and exchanges between farmers for food and cash crops. In Uganda, for example, cotton farms average one hectare. There is organized seed replacement regulated by the Cotton Development Organization (CDO). Seed from line-varieties developed through conventional breeding by public research institutions traverse through five generations of planting. Seed moves from a small production area in a given season to cover a larger zone the following season. This arrangement makes planting seed affordable to subsistence farmers. Biotech seed is replantable over seasons while maintaining their intended attributes (ICAC, 2000 and 2002b) but intellectual property requirements of the biotech seed developers prohibit seasonal seed saving and replanting. Seasonal replenishment of planting seed will disrupt arrangements for input distribution in such a case.

- The cost of the biotech seed is unaffordable for resource-poor farmers such as those targeted in a Uganda development program, Poverty Eradication Action Plan (PEAP). Cotton is a poverty alleviation crop in Uganda and is produced in 35 of 56 districts in the country by over 500,000 farm-families of approximately five people per family. Production is about 30,000 metric tons of lint annually that provides increased livelihoods for poor framers. Twelve kilos of seed required for planting one hectare cost $4.5 in Uganda. However, farmers cannot afford to pay in advance and seek credit to be settled at the end of the season to be included in seed cotton prices. When the situation is compared to the reports on the costs of biotech seeds in South Africa at $60 for 25 kg of seeds to plant a hectare in 2001 (ICAC, 2002a), the cost was expected to rise to $ 70 in 2002/03 season). In India (Madhya Pradesh, Andra Pradesh, Tamil Nadu etc areas), Bt seed was expected to be sold at $71 for planting a hectare in comparison to $20 for conventional hybrids (ICAC, 2004b). In China, Bt seed costs $60/ha (Russel, 2004). The cost of seeds alone would drive most cotton farmers in Uganda (and in other developing countries) out of production. It should be noted that in Uganda, the use of scouting and other integrated pest management (IPM) options has led to a reduction from four calendar sprays per season to three or fewer. Seed cotton yields have been reported to range between 500-2,500 kg/ha (Russel, 2004). Therefore the cost of insecticides, or the load of pesticides in the environment, would not justify the farmers high cost of biotech seeds. South Africa farmers use an average of eight sprays, (ICAC, 2002b), and India reported over 19 sprays per season. The most appropriate biotech options would be those which do not exclude resource-poor farmers from cotton production. In addition to the cost of biotech seeds, farmers in Uganda would still need to control other pests, including aphids, lygus and stainers. Furthermore, the high cost of biotech seeds would be a disadvantage in Uganda where seed cotton prices have never been above $0.50/kg since they are dependant on international prices for lint. The high cost of biotech seeds have also been decried as prohibitive in Mali according to BBC-News of November 2004.

Inadequate Knowledge on Intentions for Biotechnology Innovations

Other fears about the use of biotechnology products arise from inadequate knowledge of users about the intentions of the innovations.

- An outstanding example is the system developed by the US Department of Agriculture, jointly with Delta and Pine Land Company, that would have caused transgenic cotton plants to produce sterile seeds. The technology was called "Terminator" or "Technology Protection System." It was meant to protect companies' investments in biotech cotton. It was patented in 1998 (ICAC 1998, 2000 and 2002b). It was not commercialized due to the implications for small scale farmers and their supporting organizations who wished to save seeds. However, even though the technology was abandoned, it sent harmful signals about the intentions of biotechnologists. In many debates today on biotechnology, the issue of terminator still dominates other issues and leads to wrong decisions even by policy makers who suspect that the technology could also "terminate" or affect reproduction ability of humans.
- Atikins (2004) cited other examples where the use of biotechnologies could be inhibited by the potential users' inability to adhere to the required precautions in the use of a given technology. For example, one management practice to reduce the risk of transfer of modified genes from a GE crop to wild relatives could be to harveste the plant before it flowers. If there were chances of farmers or users neglecting such a step, through lack of understanding of the implications, then the use of technology would affect the level of risk posed by biotechnology. In such cases, the fear of release of biotechnology would be on the innovator not the user.

In essence some of the fear about biotechnology arises through a lack of inadequate information and training on the part of potential users or policy makers.

Efficiency and Implications of Technology Use on Conventional Breeding Programs

- The first generation of biotech provided varieties having single gene attributes with limited efficiency on pest control (type and period of control), For example, Monsanto's Bollgard cotton with the Cry 1Ac gene. This continued narrow spectrum of bollworms and had little effect on late pests due to low expressions of Bt toxins in floral parts. Whereas the breadth of control has now been expanded in Bollgard II with the addition of the Cry 2Ab gene (ICAC, 2004b), and in Wide Strike™ cotton from Dow Agro Sciences with a combination of Cry 1Ac and Cry 1F Bt proteins which offer season-long protection against a wide spectra of lepidopteran pests. However, the initial limitations on biotech efficiency instilled fear in some users. Additionally, the Roundup Ready cotton had a limited window of application of up to only 4 leaf-stages when cotton would be safely protected from herbicide. The difficulty in adhering to such a narrow window raised fears. There are new options providing a large application window of up to 10 leaf-stages in the Bayer Crop Sciences Liberty® Link cotton and up to 14 leaf-stages in Monsanto's Roundup Ready Flex variety. (ICAC, 2004 b).

- Whereas producing countries may wish to utilize biotech. they may be limited by the acceptability of the resultant produce in traditional markets. A case for citation is Uganda which produces high quality *G. hirsutum* cotton: The fibers have been improved and now classified as long-stapled and even fetch premium prices in some markets. Uganda exports 90% of its cotton, mainly to European market. If Europe demanded non-biotech products, Uganda would lose the market. On the other hand, changing to biotech cotton may not offer another market, since already in 2003/04 biotech contributed to 21% of world cotton area, 30% of the world production and 34% of international trade (ICAC, 2004b). Uganda would therefore not be able to compete with its limited production with the already enlarging biotech supply after losing its traditional markets. This fear is now being alleviated on learning that European consumers are not rejecting biotech products.

- The procedures for regenerating transformed cotton cells into plants raised concerns among conventional breeder because not all cotton varieties had the capability of regeneration. Transformation was therefore made in "foreign" varieties, rather than a recipients' own elite lines which were endowed with specific attributes to increase yields and or important fiber quality or provide resistance to disease and pests other than lepidopteran pests. East African varieties are selected for hairiness on leaves and stems for the control of jassid. The jassid problem would resurge if the varieties were replaced by hairless or glaburescent types. (The situation though could be corrected by a series of backcrosses of the transgenics to the "elite", desired varieties). The consequences of adopting biotech varieties in foreign countries would mean the loss of traditional attributes such as fiber quality, resistance to the local races of bacterial blight and wilt diseases incorporated in traditional varieties over decades would be lost. It is notable that new methods of genetic engineering are being developed where the need to regenerate plants from a single cell is avoided (ICAC, 2004 b).

- Another source of fear to potential users of biotech arises from the number of biotech varieties to be used. This arises from having a single or a few advantageous genes put in the transgenics separately rather than stacking them in single varieties for insect resistance and resistance to herbicides. Large numbers of varieties are difficult to handle in small scale production systems. This may lead to "Technology Fatigue" on the side of the farmers and the input supplying agents.

- As new transgenic varieties come into countries, ethical issues arise on the side of conventional breeders in local programs. Will conventional breeders lose their life-long career as policy makers may opt for the new biotech cottons, or will appropriate collaborations and partnerships be drawn up between conventional breeder and the biotech innovators? If the "elite" lines or local varieties (developed for decades for incorporation of attributes) are not thrown away but used for the transformation with new genes, will conventional breeders or their domestic institutions share royalties out of the biotech varieties?

- The number of players in the development of biotech is expanding in the form of multinational companies. The biotech products developed may differ in a number of transformed genes or in their mode of action. Examples are genes in the Monsanto Bollgard I and II vis-à-vis the Vegetative Insecticidal Protein (VIP) biotech by Syngenta; and the Wide Strike Cotton by Dow Agro Sciences with Cry 1Ac and Cry 1F Bt genes against bollworms (ICAC, 2004b). When so many innovators approach new potential users, they searouse fears over the ultimate intentions of the proposed technology especially when the 'new innovations' appear similar to the policy makers who may not be familiar with the technology details. This may also lead to "technology or partnership fatigue". The solution to this would be the creation of mergers among the innovators for a particular regions e.g. for East and Central Africa.

Summary

The fears about the risks of biotechnology on health and the environment have been around for over a decade. Science-based studies have alleviated in fears to some extent. There are impediments or constraints to the application of biotech which translate into fears, especially in the developing countries. Since some of these countries are already running IPM programs using biological control, host-plant genetic resistance in the domestic elite lines, cultural practices and other options which have kept levels of spraying low, the use of biotech may not be advantageous to all agricultural systems. Such countries should be given time to develop their policies and legal frameworks on biotechnology regulations and on intellectual properly management without pressures for hasty decisions. Biotech may be introduced gradually as part of IPM options. This approach would help to keep resource-poor farmers in cotton production. Training and educating potential users and policy makers about the intended benefits of biotech would alleviate some of the fears and enable than to take appropriate decisions on whether to use biotech cottons or not.

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Nine Years of Transgenic Cotton in Mexico

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Introduction

The use of transgenic crops continues to grow worldwide and it is estimated that 67.7 million hectares were planted to biotech varieties in 2004 by an estimated seven million farmers in 18 countries. Almost one-third of the area planted to transgenic crops was located in developing countries. It is also estimated that in the next five years, 10 million growers in 25 countries will grow 100 million hectares of transgenic crops (James, 2003). Mexico has adopted this new technology, and since its release in 1996, Bt cotton has been used by farmers interested in obtaining better yields with reductions in pesticide use and production costs. Nine years after commercial release, biotech cotton reached 61% of 107,346 hectares planted in Mexico in 2004/05. In some states more than 70% of the area was planted to transgenic cotton.

Cotton production in Mexico has been influenced by international cotton prices, drought and high production costs. These factors cause cotton area to fluctuate. In 1993, only 42,539 hectares were planted to cotton, mainly due to whitefly outbreaks observed in the early 1990's (Martinez-Carrillo, 1994). In 1994, 175,375 hectares were planted to cotton, and area reached a peak of 314,776 hectares in 1996. This was mainly due to an increase in prices that reached US$2.04 per kg of lint in 1994. After 1994, cotton area and production in Mexico decreased. By 2001/02 only 40,483 hectares were planted to cotton, a record low. Higher prices in 2003, and better government support stimulated cotton area to 62,892 hectares and the area grew to 107,346 hectares in 2004/05. Good yields and better pest control have motivated growers, and another increase in area is expected for 2005/06.

The main cotton producing states are Chihuahua, Sonora, Baja California, Coahuila, Durango and Tamaulipas in northern Mexico. Cotton is irrigated in all these areas. In 2003/04, Chihuahua planted 49% of the area in Mexico, Sonora, 18%, Baja California 17% and Comarca Lagunera, (a region that includes the states of Coahuila and Durango) 15% (Table 3).

Main Insect Pests

The key insect pests differ in each region. In Chihuahua, pink bollworm, stink bugs, whiteflies, bollworm and tobacco budworm are important pests in the northern part of the state, while boll weevil is the key pest in the rest of the state. In