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ABSTRACT.

Poverty reduction, food security, and agricultural sustainability require that the livelihoods of poor farmers be improved. The potential of biotechnology to improve the livelihoods and agricultural sustainability of farmers has been hotly debated and primarily focused on "modern" agricultural biotechnology. Biotechnology is much broader than this narrow focus and includes "traditional" biotechnologies, as well as, industrial and medical sectors. Different biotechnology types have different effects and these impacts are molded by the macro-economic policies of the countries where they are implemented. Generally, the problems of poor farmers are not technological and the benefits of biotechnology are unlikely to reach poor farmers unless these 'non-technical' problems are addressed first.

KEYWORDS. biotechnology, poor farmers, sustainable livelihoods, poverty reduction, food security

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ABSTRACT.

Poverty reduction, food security, and agricultural sustainability require that the livelihoods of poor farmers be improved. The potential of biotechnology to improve the livelihoods and agricultural sustainability of farmers has been hotly debated and primarily focused on "modern" agricultural biotechnology. Biotechnology is much broader than this narrow focus and includes "traditional" biotechnologies, as well as, industrial and medical sectors. Different biotechnology types have different effects and these impacts are molded by the macro-economic policies of the countries where they are implemented. Generally, the problems of poor farmers are not technological and the benefits of biotechnology are unlikely to reach poor farmers unless these 'non-technical' problems are addressed first.

INTRODUCTION.

Current debates

The value of biotechnology for food security (Altieri and Rosset, 1999; Serageldin, 1999a), developing countries (Hohn and Leisinger, 1999; Lele, 2003; Sasson and Costarini, 1991) and sustainable agriculture (Mannion, 1992; Serageldin and Persley, 2003; Shantharam and Montgomery, 1999; Zechendorf, 1999) has been hotly debated. Improving the livelihoods of poor farmers is required for food security (Altieri, 2002) and sustainable agriculture (Altieri, 1992). However, the specific case of poor farmers and biotechnology has not received much attention, although some case studies and older reviews exist (Bunders and Broerse, 1991; Morse et al., 2004; Qaim, 2005). Agricultural biotechnology (Dookun, 2001; Hall, 2005; Pinstrup-Andersen and Cohen, 2000; Qaim, 2005) and genetically modified organisms (Chrispeels, 2000;

Qaim, 2005; Qaim and Zilberman, 2003; Serageldin, 1999a) have generally dominated the debate.

Biotechnology and poor farmers defined

Biotechnology has many definitions (Jones, 1990). Narrow definitions equate it with genetically modified organisms (Ridley, 2004), while broad definitions, such as “the application of biological knowledge for a useful end” (Jones, 1990), encompass a large range of technologies. The terms “modern” and “traditional” biotechnology are often attached to these narrow and broad definitions, respectively. Broad definitions include technologies such as nitrogen-fixing bacteria, biological control agents, and fermentation technology because these technologies involve strategic application and manipulation of biological organisms. Modern and traditional biotechnologies can overlap, with genetic modification being used to enhance traditional biotechnologies.

Poor farmers are farmers whose resources (land, water, labor, capital) do not permit a secure livelihood (Chambers and Ghildyal, 1985). The terms resource-poor farmer, smallholder, small-scale farmer, and low-income farmer have also been used. Globally, there may be as many as 450 million resource-poor farmers supporting 1.25 billion people (Mazoyer, 2001). As such, technologies that improve the livelihoods of poor farmers help increase global agricultural sustainability.

Global context: population, poverty, poor farmers, and food

By 2050, world population may total 8.8 billion (Lutz et al., 2001), with ninety eight percent of population growth occurring in developing countries (Bureau, 2004). Currently, poor farmers, their families, and the landless account for 70% (James, 2000) of the world's 1.2 billion poor people (consumption < $1 US/day) (IFAD, 2001). In developing countries, poor farmers produce up to 90% of domestically consumed food (Odulaja and Kiros, 1996) but in many cases do so at a net loss (Perales et al., 1998).

Additionally, many countries will experience local food crises by 2020 (Evenson, 1999). Population growth (Borlaug, 1997), regional shortages (Alexandratos, 1999), and the goal of food security (Rosegrant and Cline, 2003) necessitate increased agricultural production. For instance, grain production in developing countries may have to increase 28% by 2020 (Chrispeels, 2000).

Agricultural pesticides negatively affect human health, with 3 million poisonings annually (Pimentel and Greiner, 1997). Poor farmers in developing countries are especially at risk (Forget, 1991) because of inadequate equipment and knowledge (Paoletti and Pimentel, 2000). Biotechnology could increase the sustainability of poor farmers' livelihoods and agriculture by increasing: 1) food security, 2) health, and 3) income.

AGRICULTURAL BIOTECHNOLOGY

In the 1960s and 70s the "Green Revolution" increased food-grain per capita availability by 18% despite strong population growth (Khush, 1999). Currently, yield may be reaching plateau levels for many major crop species (Cooper et al., 2001; Pinstrup-Andersen and Pandya-Lorch, 1995) and "modern" agricultural biotechnology is being touted as the "gene revolution" that will achieve future food security (Serageldin, 1999b). Technologies such as biological nitrogen fixation, mycorrhizae, biocontrol, molecular markers, and transgenic organisms are forms of agricultural biotechnology.

Biological nitrogen fixation and mycorrhizae

Biological nitrogen fixation occurs when microbes in symbiosis with plants assimilate atmospheric nitrogen and make it available to plants (Hirsch et al., 2001). Mycorrhizae are fungi that that increase plant nutrient uptake through root associations (Sanchez and Salinas, 1981). Different forms/strains of microbes occur naturally and may be specific to certain plant species (Boonkerd, 2002). Selection of optimal microbial strains in the lab can help develop efficient nitrogen fixation (Sanchez and Salinas, 1981) and mycorrhizae (Rengel, 2002) technologies.

Microbe inoculation of plants is thousands of years old (Dart, 1990a). Cover crops that fix nitrogen can re-establish fertility in low-input agriculture (Sanchez and Benites, 1987) and improve the productivity of poor farmers (Bunch, 1985), but poor farmers adoption of cover crops is hindered by insecure land tenure (Honlonkou et al., 1999). In Thailand, soybean inoculation can increase net profits by US $144 ha^{-1} (Boonkerd, 2002). *Azolla* (water fern)-*Anabaena* (blue-green-algae, planktonic cyanobacteria) nitrogen fixing association increases paddy rice yields: China (24%), Egypt (26%), India (9-11%) and is a high protein livestock feed (Bifani, 1992). Mycorrhizae can improve poor farmers yields and permit continuous cultivation of poor soils (Salami and Osonubi, 2002), but their contribution to yield has not been adequately quantified (Ryan and Graham, 2002).

The low transport costs and simplicity of inoculants make them appropriate for developing countries (Bifani, 1992), however poor transportation infrastructure can limit use (Odame, 1997). Inoculants generate employment by increasing labour demand (Bifani, 1992). Nitrogen fixing bacteria vary in their tolerance to soil properties such as soil pH (Date and Halliday, 1979) and in some cases inoculant biotechnology has not been able to overcome the extreme soil conditions (high temperature, acidity, salinity, and drought) of poor farmers (Odame, 1997). Genetic engineering of nitrogen fixing bacteria may help address these constraints and has increased yields by 5-10% in China (Chen and Gu, 1993).

Biological control of pests

Biological control (biocontrol) involves the control of pests (insects, pathogens, weeds) with beneficial organisms (insects, pathogens), and is an alternative to chemical pest control (Ehlers, 1996). Examples of biocontrol include: 1) Directly applied control agents such as bacteria e.g *Bacillus thurengensis* (Ehlers, 1996), fungi e.g. *Beauveria bassianan* and *Metarhizium aniospliae* (Burges and Pillai, 1987), viruses (Whitten and Oakeshott, 1990), and beneficial insects (Howarth, 1991) to control insects and in some cases weeds (Seastedt et al., 2003), 2) Endophytic microorganisms that live inside plants and confer protection through toxin production (Azevedo et al., 2000), and 3) Viral vaccines that confer resistance to viral diseases (Flasinski et al., 2002).

Biocontrol is the principal pest control strategy of poor farmers (Altieri and von der Weid, 2000). Biocontrol's low capital costs and expertise requirements make it appropriate for developing countries (Bedding et al., 1993) but poor farmers must rely on centralized supply and application expertise (Burges and Pillai, 1987). Biocontrol poses ecological risks (Simberloff and Stiling, 1996). Genetic engineering could increase the virulence of biocontrol agents (Gressel, 2001), but poses unevaluated risks (Paoletti and Pimentel, 1996). Biocontrols have narrow pest ranges, which can limit application to high-value niche markets (Whitten and Oakeshott, 1990).

Molecular markers

Biochemical and molecular markers are used to detect unique proteins or DNA sequences. Glaubitz and Moran (2000) review many of these marker systems and their protocols. These markers can facilitate the detection and selection of genes involved in plant traits, which can be difficult or expensive to select for in the field. Marker assisted selection of plant traits was first purposed by Sax (1923) using associated phenotypic traits. Quantitative trait loci have been identified with markers for many agronomic traits: drought resistance (Quarrie, 1996), disease resistance (Young, 1996), maturity (Lin et al., 1995), and oil and protein content (Diers et al., 1992).

Quantitative traits are plant traits (e.g. yield) that are controlled by a number of genes (Poehlman and Sleper, 1995). Theoretically, marker assisted selection could increase the efficiency of selection for quantitative traits (Lande and Thompson, 1990). Despite claims that markers could reduce breeding cycle times from 15 to 3 years (Kidd, 1994), there are few examples of markers resulting in commercialized varieties to date (Gupta et al., 2002). Currently, most marker associations are not robust enough for efficient breeding (Young, 1999), costs are prohibitive (Charcoset and Moreau, 2004), and selection procedures are largely limited to the crosses used to map the markers (Ayoub et al., 2003). New marker systems such as single-nucleotide-polymorphisms (Rafalski, 2002), new mapping approaches such as association mapping (Stich et al., 2006), and new methods for old mapping approaches (Podlich et al., 2004) could make marker assisted selection more cost effective in the future.

Tissue culture

Tissue culture includes a range of techniques such as micropropagation, embryo rescue, anther culture, and cell cultures. Micropropagation is the clonal propagation of plants from a single parent plant whose parts (usually shoot or root meristem tissue) are grown into new plants (Kyte, 1996). Embryo rescue involves salvaging weak embryos (usually the product of broad crosses) and culturing them into plants (Sharma et al., 1996). Anther culture grows pollen spores into plants that contain only half a genome (haploids) (Guha and Maheshwari, 1964).

Vegetatively propagated crops such as cassava, yam, and bananas are poor farmer staples and their vegetative propagation can spread disease (Aljanabi et al., 2001), which reduces yield (Thro et al., 1999). Micropropagation requires little capital or skill (Dart, 1990b) and can produce disease free materials for rapid distribution to farmers (Larkin and Scowcroft, 1981). Unfortunately, the cultural practices of poor farmers tend to spread disease (Calvert and Thresh, 2002), making disease eradication difficult. Nevertheless, micropropagation has improved potato and tea adoption by poor farmers (Mureithi and Makau, 1992).

Embryo rescue permits interspecific (Mallikarjuna, 1999) and intergeneric (Momotaz, 1998) crosses between normally incompatible breeding materials. These wide crosses can be used to incorporate genes for abiotic and biotic stresses into breeding programs (Mallikarjuna, 1999). Anther culture coupled with chemical treatment produces homozygous plants much faster than inbreeding techniques (Morrison and Evans, 1988). This technique has been used in China to develop high yielding, superior quality, pathogen-resistant rice varieties (Chen and Gu, 1993). Unfortunately, anther culture is 1) difficult in some species, 2) prone to deleterious mutations, and 3) non-random with regards to recovered gametes (Morrison and Evans, 1988).

Transgenic organisms

Inserting foreign DNA into an organism creates a transgenic organism. Agricultural plants and animals have been modified in this way (Serageldin and Persley, 2000). In 2006, 10.3 million farmers planted 102 million hectares of transgenic crops (James, 2006). Notably, 9.3 million (90%) of these farmers were poor farmers planting Bt cotton in China and India (James, 2006). Currently, widely commercialized transgenic crops are either insect or herbicide resistant (James, 2000; Lele, 2003), with the latter being of little use to poor farmers (Qaim, 2005).

Pest resistance has been engineered largely through the use of *Bacillus thuringiensis* genes, which produce crystallized proteins called δ-endotoxins (Cohen, 1999). This technology has reduced pesticide use (Qaim and Zilberman, 2003) and is associated with improved cotton farmer health (Pray et al., 2001). Health benefits may be limited to cotton as it is heavily sprayed whereas most other poor farmer crops (e.g. maize, rice, cassava) are not (Maumbe and Swinton, 2003). In contrast, transgenic herbicide resistance could lead to massive labour displacement (Ahmed, 1991) because manual weeding is an important off-farm work opportunity for poor farmers (Benjamin, 1992).

Transgenic crops with improved nutrient profiles are the next wave of transgenic crops. Beta-carotine enriched transgenic rice (Golden Rice) (Potrykus, 2001) addresses vitamin A deficiency, which results in 1 to 2 million child deaths each year (Ye et al., 2000). Oral vitamin A intervention has distribution problems and general food fortification is excessively costly (Pirie, 1983). Critics suggest golden rice is an inappropriate high-tech solution to the complex problem of food access (Lorch, 2001). Only 12 countries with vitamin A deficiency problems have sufficient rice consumption to make golden rice an effective alternative (RAFI, 2000).

Transgenic crops can be designed to produce rare and valuable oils (Napier and Michaelson, 2001). Use of plants as production factories has been referred to as molecular farming (Horn et al., 2004) and could enhance the value of low-value crop plants in developing countries. Currently, only three molecularly farmed products are marketed (Avidin, b-Glucuronidase, and Trypsin) and food supply contamination is a concern (Horn et al., 2004). Required safety precautions will likely prevent poor farmer involvement in molecular farming.

Phenotypes that are difficult to breed for might be produced through genetic engineering (Paoletti and Pimentel, 1996). Altering a single trait can produce salt-tolerant (Zhang and Blumwald, 2001), aluminum tolerant (de la Fuente et al., 1997), or phosphorous mineralizing (Zimmermann et al., 2003) transgenic plants. Aluminum toxicity (Rao et al., 1993), saline conditions (Malik and Ahmad, 2002) and nutrient deficient soils (Sanchez and Benites, 1987) are characteristic of poor farmers' marginal lands.

To date, transgenic crops have not substantially increased yields (Lauer and Wedberg, 1999; Mara et al., 2002; Miflin, 2000; Ruttan, 1999; Sinclair et al., 2004), which is a concern given the need for yield increases in developing countries (Ruttan, 1999). Lack of yield gains at present may not reflect future performance (Qaim and Zilberman, 2003). Recent case-studies (Ismael et al., 2002; Qaim and de Janvry, 2005; Qaim and Zilberman, 2003) suggest yield increases may be possible. Yield gains are occurring because insect resistant transgenic crops are now being introduced into the fields of poor farmers, which are characterized by elevated pest pressure that normally goes uncontrolled. Even without yield increases, poor farmers may benefit from increased profits due to reduced input costs (pesticides, labor) (Ismael et al., 2002; Pray et al., 2001).

Often yield-enhancing technology reduces global prices and indirectly serves to impoverish poor farmers who do not adopt the technologies (Ahmed, 1988). The introduction of Bt cotton in the United States reduced prices and is estimated to have cost international cotton producers US $21.6 million (Falck-Zepeda et al., 2000). Alternatively, poor farmers could increase productivity faster than falling prices (IFAD, 2001). Claims have been made that biotechnology is scale-neutral and therefore easily adoptable (Prakash, 1999), but even scale-neutral technology is often not adopted by farmers with low levels of education (Arends-Kuenning and Makundi, 2000). Furthermore, transgenic crop development currently bypasses many crops and traits important to the developing world (Huang et al., 2002; Lele, 2003).

GENERAL CONSTRAINTS

In discussing various forms of biotechnology, specific constraints have been outlined. More general constraints also prevent biotechnologies from reaching poor farmers. The private sector conducts most biotechnology research (Pray and Umali-Deininger, 1998) and is unwilling to address the problems of poor farmers because they do not represent a lucrative market (Kenney and Buttel, 1985).

Developing countries have difficulties transferring technology from laboratories to industry because of weak organizational and administrative mechanisms and obsolete legal rules (Zilinskas, 1993). Transfer of transgenic sweet potato technology to Kenya took 10 years of negotiation to approve preliminary trials (Cohen and Paarlberg, 2004). Public institutions often cannot conduct biotechnology research because private companies hold most of the relevant patents (Qaim, 2000). Nevertheless, Cuba has developed an applied biotechnology sector that benefits its people (Kenney and Buttel, 1985) and China has made substantial advances because it has many well-trained scientists, large germplasm collections, and a low-cost research environment (Huang et al., 2002). A number of developing countries including: Brazil (Ferrer et al., 2004), Cuba (Thorsteinsdottir et al., 2004b), India (Jayaraman, 2005), and South Africa (Burton and Cowan, 2002) have and are making in roads in "modern" biotechnology.

Public-private partnerships that transfer technology from private firms in developed countries to public institutions in developing countries (Brumby et al., 1990) can help develop biotechnology in developing countries. The International Service for the Acquisition of Agribiotech Applications facilitates the transfer of agricultural biotechnology to developing countries with the aim of alleviating poverty and increasing productivity in developing countries (James, 2001). Only large developing countries (China, Brazil, and India) have developed public-private linkages for co-development (Pray, 2001).

The brain-drain (movement of scientists from developing to developed countries) may be a greater obstacle to biotechnology development than capital resources (Kenney and Buttel, 1985). The biotechnology brain-drain negatively affects the ability of the public sector (La Montagne, 2001) and developing countries (Thorsteinsdottir et al., 2004a) to conduct research and development. Currently, developed countries have 10 times more scientists than in developing countries (Lele, 2003) and only a few developing countries (Mexico, Brazil, India, Cuba and China) have the critical mass of researchers needed to sustain biotechnology research (Kenney and Buttel, 1985).

Many biotechnologies are tools used within larger programs. For instance, molecular marker and tissue culture biotechnologies are tools used by breeding programs (Brenner, 1996). Conventional breeding programs typically focus on high-input environments and often neglect the marginal environments of poor farmers (Ceccarelli et al., 2001). Until the focus of breeding programs changes, the benefits of these biotechnologies will not reach poor farmers.

CONCLUSIONS

Agricultural biotechnology provides clear benefit where traditional technologies (biological nitrogen-fixation and biocontrol) are concerned. Transgenic biotechnologies seem to have had some success in increasing the sustainability of poor farmers' agriculture and livelihoods in terms of increased revenues and health, respectively. However, transgenic agricultural biotechnology remains largely oriented towards the developed world. If transgenic crops reduce global commodity prices faster than poor farmers can increase production, the net effect will be erosion of sustainability.

Constraints and power incongruities (manifested in subsidies and regulatory frameworks) will largely determine how biotechnologies affect the lives of poor farmers. Some developing countries with large economies (China, Brazil, India, Mexico, Egypt), or with well-developed social and physical infrastructure (Cuba), have and will be able to develop biotechnologies that help poor farmers practice more sustainable agriculture. Traditional biotechnologies such as biological nitrogen fixation, biocontrol, and fermentation have a long history of use by poor farmers and are recognized as sustainable practices. Focusing on these technologies and their improvement using "modern" biotechnologies could result in immediate utility to poor farmers. The consequences of biotechnology for poor farmers will continue to unfold and will vary with the technology in question and the country where it is applied. Rigid proclamations that biotechnology will "benefit" or "marginalize" poor farmers or "increase" or "decrease" sustainability do not do justice to the complex and dynamic development of biotechnology. Nevertheless, it is fair to say that the ability of biotechnology to improve the sustainability of the livelihoods and agriculture of poor farmers across all developing countries is currently speculation rather than a reality.

CITED LITERATURE

Acharya T, Kennedy R, Daar AS et al (2004) Biotechnology to improve health in developing countries - a review. Memorias do Instituo Oswaldo Cruz 99: 341-350.

Ahmed I (1988) The bio-revolution in agriculture: Key to poverty alleviation in the third world? International Labour Review 127: 53-72.

Ahmed I (1991) Biotechnology and rural labour absorption. In: Costarini V (ed) Biotechnologies in perspective: Socio-economic implications for developing countries. UNESCO, France.

Aldovini A and Young R (1991) Humoral and cell-mediated immune responses to live recombinant bcg-hiv vaccines. Nature 351: 479-482.

Alexandratos N (1999) World food and agriculture: Outlook for the medium and longer term. Proceedings of the National Academy of Science USA 96: 5908-5914.

Aljanabi SM, Parmessur Y, Moutia Y et al (2001) Further evidence of the association of a phytoplasma and a virus with yellow leaf syndrome in sugarcane. Plant Pathology 50: 628-636.

Altieri MA (1992) Sustainable agricultural development in latin america: Exploring the possibilities. Agriculture, Ecosystems and Environment 39: 1-21.

Altieri MA (2002) Agroecology: The science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems and Environment 93: 1-24.

Altieri MA and Rosset P (1999) Ten reasons why biotechnology will not ensure food security, protect the environment and reduce poverty in the developing world. AgBioForum 2: 155-162.

Altieri MA and von der Weid J (2000) Prospects for agro-ecological natural resource management in the 21st century. Global Forum on Agricultural Research, Dresden, Germany.

Ananda-Rao R, Swaminathan S, Fernando S et al (2005) A custom-designed recombinant multiepitope protei as a dengue diagnostic reagent. Protein Expression and Purification 41: 136-147.

Andre FE (2001) The future of vaccines, immunization concepts and practice. Vaccine 19: 2206-2209.

Arends-Kuenning M and Makundi F (2000) Agricultural biotechnology for developing countries. American Behaviroal Scientist 44: 318-349.

Aultman KS, Gottlieb M, Giovanni MY et al (2002) *Anopheles gambiae* genome: Completing the malaria triad. Science 298: 13.

Ayoub M, Armstrong E, Bridger G et al (2003) Marker-based selection in barley for a qtl region affecting α-amylase activity of malt. Crop Science 43: 556-561.

Azevedo JL, Maccheroni WJ, Pererira JO et al (2000) Endophytic microorganisms: A review on insect control and recent advances on tropical plants. Electronic Journal of Biotechnology 3: 40-65.

Bedding RA, Akhurst RJ and Kaya HK (1993) Future prospects of entomogenous and entomopathogenic nematodes. In: Kaya HK (ed) Nematodes and the biological control of insect pests. CSIRO, Australia, pp 157-170.

Bell J (2004) Predicting disease using genomics. Nature 429: 453-456.

Benjamin D (1992) Household composition, labor markets, and labor demand: Testing for separation in agricultural household models. Econometrica 60: 287-322.
Bifani P (1992) New biotechnologies for rural development. In: Ahmed I (ed) Biotechnology: A hope or a threat? International Labour Organization, Great Britain.
Bodine AB and Mertens DR (1983) Toxicology, metabolism, and physiological effects of aflatoxin in the bovine. In: Dickens JW (ed) Aflatoxin and aspergillus flavus in corn. Alabama Agriculture Experimental Station, Alabama, pp 46-50.
Bojang KA, Milligan PJ, Pinder M et al (2001) Efficacy of rts, s/as02 malaria vaccine against *plasmodium falciparum* infection in semi-immune adult men in the gambia: A randomised trial. Lancet 358: 1927-1934.
Boonkerd N (2002) Development of inoculant production and utilization in thailand. In: Herridge D (ed) Inoculants and nitrogen fixation of legumes in vietnam. ACIAR, Vietnam.
Borlaug NE (1997) Feeding a world of 10 billion people: The miracle ahead. Plant Tissue Culture and Biotechnology 3: 119-127.
Borrell B and Duncan RC (1992) A survey of the costs of world sugar policies. World Bank Research Observer 7: 171-194.
Boyd MD (1997) Discoverty of cyanovirin-n, a novel human immunodeficiency virus-inactivating protein that binds vival surface envelope glycoprotein gp120: Potential applications to microbicide development. Antimicrobial Agents and Chemotherapy 41: 1521-1530.
Brenner C (1996) Integrating biotechnology in agriculture: Incentives, constraints and country experiences. OECD, France.
Brown D (2007) Bush renews efforts to cut malaria deaths. Guardian Weekly, UK, p 28.
Brumby P, Pritchard A and Persley GJ (1990) Issues for the world bank. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London, pp 429-436.
Bunch R (1985) Two ears of corn: A guide to people-centered agricultural improvement. World Neighbors, Oklahoma.
Bunders JFG and Broerse EW (eds) (1991) Appropriate biotechnology in small-scale agriculture: How to reorient research and development. CAB International, UK.
Bureau UC (2004) Global population profile: 2002. US Government Printing Office, Washington, DC.
Burges HD and Pillai JS (1987) Microbial bioinsecticides. In: Nyns EJ (ed) Microbial technology in the developing world. Oxford University Press, New York, pp 121-151.
Burton SG and Cowan DA (2002) Development of biotechnology in sourth africa. Electronic Journal of Biotechnology 5: 21-22.
Calvert LA and Thresh JM (2002) The viruses and virus diseases of cassava. In: Hillocks RJ, Thresh JM and Bellotti AC (eds) Cassava: Biology, production and utilization. CAB International, London, pp 237-260.
Carol AN and Sacksteder KA (2002) New tuberculosis vaccine development. Expert Opinion on Biological Therapy 2: 741-749.
Caswell JA, Bredahl ME and Hooker NH (1998) How quality management metasystems are affecting the food industry. Review of Agricultural Economics 20: 547-557.
Ceccarelli S, Grando S, Amri A et al (2001) Decentralized and participatory plant breeding for marginal environments. In: Cooper HD, Spillane C and Hodgkin T (eds) Broadening the genetic base of crop production. CABI Publishing copublished with Food and Agriculture Organization of the United Nations and International Plant Genetic Resources Institute, UK, pp 115-135.

Chambers R and Ghildyal BP (1985) Agricultural research for resource-poor farmers: The farmer-first-and-last model. Agricultural Administration 20: 1-30.
Charcoset A and Moreau L (2004) Use of molecular markers for the development of new cultivars and the evaluation of genetic diversity. Euphytica 137: 81-94.
Chen D, Endres RL, Erickson CA et al (2000) Epidermal immunization by a needle-free powder delivery technology: Immunogenicity of influenza vaccine and protection in mice. Nature Medicine 6: 1187-1190.
Chen Z and Gu H (1993) Plant biotechnology in china. Science 262: 377-378.
Chrispeels MJ (2000) Biotechnology and the poor. Plant Physiology 124: 3-6.
Cohen J (2002) Gates foundation rearranges public health universe. Science 295: 2000.
Cohen JI and Paarlberg R (2004) Unlocking crop biotechnology in developing countries - a report from the field. World Development 32: 1563-1577.
Cohen MB (1999) Environmental impact of crops transformed with genes from bacillus thuringiensis (bt) for insect resistance. In: Mongomery JF (ed) Biotechnology, biosafety, and biodiversity: Scientific and ethical issues for sustainable development. Science Publishers Inc., New Hampshire, pp 31-39.
Coler RN, Campos-Neto A, Ovendale P et al (2001) Vaccination with the t cel antigen mtb 8.4 protects against challenge with *mycobacterium tuberculosis*. Journal of Immunology 166: 6227-6235.
Cooke GS and Hill AVS (2001) Genetics of susceptibility to human infectious disease. Nature Reviews Genetics 2: 976-977.
Cooper HD, Spillane C and Hodgkin T (2001) Broadening the genetic base of crop production. CABI Publishing, London, 452 pp.
Daar AS, Thorsteinsdottir H, Martin DK et al (2002) Top ten biotechnologies for improving health in developing countries. Nature Genetics 21: 229-232.
Dale JL (1990) Banana and plantain. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London, pp 225-240.
Dart PJ (1990a) Agricultural microbiology introduction. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London, pp 53-77.
Dart PJ (1990b) Plant production: Introduction. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London, pp 31-52.
Date RA and Halliday J (1979) Selecting rhizobium for acid, infertile soils of the tropics. Nature 227: 62-64.
Davey S (ed) (2000) The 10/90 report on health research 2000. The Global Health Forum 2000, Switzerland.
de la Fuente J, Ramirez-Rodriguez V, Cabrera-Ponce JL et al (1997) Aluminum tolerance in transgenic plants by alteration of citrate synthesis. Science 267: 1566-1568.
de Silva S, Fisher CA, Premawardhena A et al (2000) Thalassaemia in sri lanka: Implications for the future health burden of asian populations. Lancet 355: 786-791.
de Waal A and Whiteside A (2003) New variant famine: Aids and food crisis in southern africa. Lancet 362: 1234-1237.
Delorenzi M, Sexton A, Shams-Eldin H et al (2002) Genes for glycosylphosphatidylinositol toxin biosynthesis in *plasmodium falciparum*. Infection and Immunity 70: 4510-4522.
Diers BW, Keim P, Fehr WR et al (1992) Rflp analysis of soybean seed protein and oil content. Theoretical and Applied Genetics 83: 608-612.

Dobson CM (2004) Chemical space and biology. Nature 432: 824-828.
Dookun A (2001) Agricultural biotechnology in developing countries. Biotechnology Annual Review 7: 261-285.
Dvorackova I (1976) Aflatoxin inhalation and alveolar cell carinoma. British Medical Journal 1: 691.
Ehlers R (1996) Current and future use of nematodes in biocontrol: Practice and commercial aspects with regard to regulatory policy issues. Biocontrol Science and Technology 6: 303-316.
Engvall E and Perlmann P (1971) Enzyme-linked immunosorbent assay (elisa) quantification assay of immunoglobulin g. Immunochemistry 8: 871-874.
Evenson RE (1999) Global and local implications of biotechnology and climate change for future food supplies. Proceedings of the National Academy of Science USA 96: 5921-5928.
Falck-Zepeda JB, Traxler G and Nelson RG (2000) Surplus distribution for the introduction of a biotechnology innovation. American Journal of Agricultural Economics 82: 360-369.
Farmer P, Leandre F, Mukherjee JS et al (2001) Community-based approaches to hiv treatment in resource-poor settings. Lancet 358: 404-409.
Feldbaum C (2002) Some history should be repeated. Science 295: 975.
Ferrer M, Thorsteinsdottir H, Quach U et al (2004) The scientific muscle of brazil's health biotechnology. Nature Biotechnology 22: DC8-DC12.
Flasinski S, Aquino VM, Hautea RA et al (2002) Value of engineered virus resistance in crop plants and technology cooperation with developing countries. In: Zilberman D (ed) Economic and social issues in agricultural biotechnology. CAB International, London.
Folch E, Hernandez I, Barragan M et al (2003) Infectious diseases, non-zero-sum thinking, and the developing world. American Journal of Medical Science 326: 66-72.
Forget G (1991) Pesticiedes and the third world. Journal of Toxicology and Environmental Health 32: 11-31.
Giddings LV (1990) Microbial bioprocessing. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London, pp 151-158.
Glaubitz JC and Moran GF (2000) Genetic tools: The use of biochemical and molecular markers. In: Young A, Boshier D and Boyle T (eds) Forest conservation genetics: Principles and practice. CABI Publishing, New York, pp 39-59.
Goeddel DV, Heyneker HL, Hozumi T et al (1979) Direct expression in escherichia coli of a DNA sequence coding for human growth hormone. Nature 281: 544-548.
Graven A, St. Hilaire PM, Sanderson SJ et al (2001) Combinatorial library of peptide isosters based on diels-alder reactions: Identification of novel inhibitors against a recombinant cysteine protease from leishmania mexicana. Journal of Combinatorial Chemistry 3: 441-452.
Gressel J (2001) Potential failsafe mechanisms against the spread and introgression of transgenic hypervirulent biocontrol fungi. Trends in Biotechnology 19: 149-154.
Guardian (2007) Field notes. Guardian Weekly, UK, p 28.
Guereña-Burgueño F, Hall ER, Taylor DN et al (2002) Saftey and immunogenicity of a prototype enterotoxigenic *escherichia coli* vaccine administered transcutaneously. Infection and Immunity 70: 1874-1880.
Guha S and Maheshwari SC (1964) In vitro production of embryos from anthers of *datura*. Nature 204: 497.
Gupta PK, Varshney RK and Prasad M (2002) Molecular markers: Principles and methodology. In: Aholoowalia BS (ed) Molecular techniques in crop improvement. Kluwer Academic Publishers, London.

Gwatkin DR and Guillot M (2000) The burden of disease among the global poor: Current situation, future trends, and implications for strategy. World Bank, Washington, DC.
Hall A (2005) Capacity development for agricultural biotechnology in developing countries: An innovation systems view of what it is and how to develop it. Journal of International Development 17: 611-630.
Hardin G (1968) The tradegy of the commons. Science 162: 1243-1248.
Harris E, Kropp G, Belli A et al (1998) Single-step multiplex pcr assay for characterization of new world *leishmania* complexes. Journal of Clinical Microbiology 36: 1989-1995.
Harrison JC, Carvajal M and Garner RC (1993) Does aflatoxin exposure in the united kingdom constitute cancer risk? Environmental Health Perspectives 99: 99-105.
Haskell PT (1977) Report of the steering group on pest control under the conditions of small farmer food crop production in developing countries. Development Centre of the Organisation for Economic Co-operation and Development, Paris.
Hirsch AM, Lum MR and Downie JA (2001) What makes the rhizobia-legume symbiosis so special? Plant Physiology 127: 1484-1492.
Hohn T and Leisinger KM (eds) (1999) Biotechnology of food crops in developing countries. Springer-Verlag, New York.
Honlonkou AN, Manyong VM and Tchetche N (1999) Farmers' perceptions and the dynamics of adoption of a resource management technology: The case of mucuna fallow in southern benin, west africa. International Forestry Review 1: 228-235.
Horn ME, Woodard SL and Howard JA (2004) Plant molecular farming: Systems and products. Plant Cell Reports 22: 711-720.
Howarth FG (1991) Environmental impacts of classical biological control. Annual Review of Entomology 36: 485-509.
Huang J, Rozelle S, Pray C et al (2002) Plant biotechnology in china. Science 295: 674-677.
Huete-Perez JA, Flores-Obando RE, Ghedin E et al (2005) Genomic and proteomic approaches for chagas' disease: A critical analysis of diagnostic methods. Expert Review of Molecular Diagnostics 5: 521-530.
IFAD (2001) Rural poverty report 2001: The challenge of ending rural poverty. Oxford University Press, New York.
Ismael Y, Bennett R and Morse S (2002) Farm-level economic impact of biotechnology: Smallholder bt cotton farmers in south africa. Outlook on Agriculture 31: 107-111.
James C (2000) Transgenic crops worldwide: Current situation and future outlook. In: von Braun J (ed) Agricultural biotechnology in developing countries: Towards optimizing the benefits for the poor. Kluwer Academic Publishers, London, pp 11-23.
James C (2001) The activities of the international service for the acquisition of agribiotech applications (isaaa) in crop biotechnology transfer. Journal of the Science of Food and Agriculture 81: 813-821.
James C (2006) Global status of comercialized biotech/gm crops: 2006. ISAAA, Ithaca, NY.
Jayaraman KS (2005) Biotech boom. Nature 436: 480-483.
Jomaa H, Wiesner J, Sanderbrand S et al (1999) Inhibitors of the nonmavalonate pathway of isoprenoid biosynthesis as antimalarial drugs. Science 285: 1573-1576.
Jones KA (1990) Classifying biotechnologies. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London.
Juma C and Yee-Cheong L (2005) Reinventing global health : The role of science, technology, and innovation. Lancet 365: 1105-1107.

Kenney M and Buttel F (1985) Biotechnology: Prospects and dilemmas for third world development. Development and Change 16: 61-91.
Khush GS (1999) Green revolution: Preparing for the 21st century. Genome 42: 646-655.
Kidd G (1994) Analyzing the future of worldwide agrobiotech. Bio/Technology 12: 859-860.
Kim W, Koo H, Richman AM et al (2004) Ectopic expression of a cecropin transgene in the human malaria vector mosquito *anopheles gambiae* (diptera: Clicidae): Effects on suceptibility to *plasmodium*. Journal of Medical Entomology 41: 447-455.
King H, Aubert RE and Herman WH (1998) Global burden of diabetes, 1995-2025: Prevalence, numerical estimates, an projections. Diabetes Care 21: 1414-1431.
Kiyono M and Pan-Hou H (2006) Genetic engineering of bacteria for environmental remediation of mercury. Journal of Health Science 52: 199-204.
Korkusuz F, Korkusuz P, Eksioglu F et al (2001) *In vivo* response to biodegradable controlled antibiotic release systems. Journal of Biomedical Materials Research 55: 217-228.
Krings U and Berger RG (1998) Biotechnological production of flavours and fragrances. Applied Microbiology and Biotechnology 49: 1-8.
Kyte L (1996) Plants from test tubes: An introduction to micropropagation. Timber Press, Portland, OR, 240 pp.
La Montagne J (2001) Biotechnology and research: Promise and problems. Lancet 358: 1723-1724.
Lande R and Thompson R (1990) Efficiency of marker-assisted selection in the improvement of quantitative traits. Genetics 124: 743-756.
Larkin PJ and Scowcroft WR (1981) Somaclonal variation- a novel source of variability from cell cultures for plant improvement. Theoretical and Applied Genetics 60: 197-214.
Lauer J and Wedberg J (1999) Grain yield of initial bt corn hybrid introductions to farmers in the northern corn belt. Journal of Production Agriculture 12: 373-376.
Leisinger KM (1999a) Biotechnology and food security. Current Science 76: 488-500.
Leisinger KM (1999b) The contribution of genetic engineering to the fight against hunger in developing countries. In: Leisinger KM (ed) Biotechnology of food crops in developing countries. Spinger-Verlag/Wien, Austria, pp 1-24.
Lele U (2003) Biotechnology: Opportunities and challenges for developing countries. American Journal of Agricultural Economics 85: 1119-1125.
Levine MM (2003) Can needle-free administration of vaccines become the norm in global immunization? Nature Medicine 9: 99-103.
Levine MM and Sztein MB (2004) Vaccine development strategies for improving immunization: The role of modern immunology. Nature Immunology 5: 460-464.
Li DN (1987) Biogas production in china: An overview. In: Nyns EJ (ed) Microbial technology in the developing world. Oxford University Press, New York, pp 196-208.
Lin YR, Schertz KF and Paterson AH (1995) Comparative analysis of qtls affecting plant height and maturity across the *poaceae* in reference to an interspecific sorghum population. Genetics 141: 391-411.
Lorch A (2001) Is this the way to solve malnutrition? Biotechnology and Development Monitor 44: 18-22.
Louie M, Louie L and Simor AE (2000) The role of DNA amplification technology in the diagnosis of infectious disease. Canadian Medical Association Journal 163: 301-309.
Lutz W, Sanderson W and Scherbov S (2001) The end of world population growth. Nature 412: 543-545.

Ma LQ, Komar KM, Tu C et al (2001) A fern that hyperaccumulates arsenic. Nature 409: 579.
Maa Y-F, Zhao L, Payne LG et al (2003) Stabilization of alum-adjuvanted vaccine dry powder formulations: Mechanisms and application. Journal of Pharmaceutical Sciences 92: 319-332.
Madkour MA (2003) Biotechnology and its application in agriculture and food production: The egyptian experience. In: Persley GJ (ed) Biotechnology and sustainable development: Voices of the south and north. CAB International, London.
Malik KA and Ahmad R (2002) Prospects for saline agriculture. Springer, New York, 460 pp.
Mallikarjuna N (1999) Ovule and embryo culture to obtain hybrids from interspecific incompatible pollinations in chickpea. Euphytica 110: 1-6.
Mannion AM (1992) Sustainable development and biotechnology. Environmental Conservation 19: 297-306.
Mara MC, Pardey PG and Alston JM (2002) The payoffs to transgenic field crops: An assessment of the evidence. AgBioForum 5: 43-50.
Masignani V, Lattanzi M and Rappuoli R (2003) The value of vaccines. Vaccine 21: S110-S113.
Maumbe BM and Swinton SM (2003) Hidden health costs of pesticide use in zimbabwe's smallholder cotton growers. Social Science and Medicine 57: 1559-1571.
Mazoyer M (2001) Protecting small farmers and the rural poor in the context of globalization. Food and Agricultural Organization of the United Nations, Rome.
McMichael AJ and Hanke T (2003) Hiv vaccines 1983-2003. Nature Medicine 9: 874-880.
Mendez-Albores JA, Arambula-Villa G, Preciado-Ortiz RE et al (2004) Aflatoxins in pozol, a nixtamalized, maize-based food. International Journal of Food Microbiology 94: 211-215.
Meulenberg EP, Mulder WH and Stoks PG (1995) Immunoassays for pesticides. Environmental Science and Technology 29: 553-561.
Miflin B (2000) Crop improvement in the 21st century. Journal of Experimental Botany 51: 1-8.
Miller SA and Williams RJ (1990) Agricultural diagnostics. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London, pp 87-107.
Momotaz A (1998) Production of intergeneric hybrids between brassica and sinapis species by means of embryo rescue techniques. Euphytica 103: 123-130.
Mor TS, Gomez-Lin MA and Palmer KE (1998) Perspective: Edible vaccines - a concept coming of age. Trends in Microbiology 6: 449-453.
Morrison RA and Evans DA (1988) Haploid plants from tissue culture: New plant varieties in a shortened time frame. Bio/technology 6: 684-689.
Morse S, Bennett R and Ismael Y (2004) Why bt cotton pays for small-scale producers in south africa. Nature Biotechnology 22: 379-380.
Morse SS (1995) Factors in the emergence of infectious diseases. *Emerging Infectious Diseases* 1: 7-15.
Mudur G (2000) Half of bangladesh population at risk of arsenic poisoning. BMJ 320: 822.
Mueller A-K, Labaied M, Kappe SHI et al (2005) Genetically modified *plasmodium* parasites as a protective experimental malaria vaccine. Nature 433: 164-167.
Mukhawana EJ (2003) Biotechnology and smallholder agriculture in sub-saharan africa. In: Persley GJ (ed) Biotechnology and sustainable development: Voices of the south and north. CAB Internaitonal, London.
Mureithi LP and Makau BF (1992) Biotechnology and farm size in kenya. In: Ahmed I (ed) Biotechnology: A hope or a threat? International Labour Organisation, Great Britain.

Napier J and Michaelson LV (2001) Towards the production of pharmaceutical fatty acids in transgenic plants. Journal of the Science of Food and Agriculture 81: 883-888.
Nemchinov LG, Liang TJ, Rifaat MM et al (2000) Development of a plant-derived subunit vaccine candidate against hepatitis c virus. Archives of Virology 145: 2557-2573.
Nevill CG (1990) Malaria in sub-saharan africa. Social Science and Medicine 31.
Nicolaou KC, Namoto K, Li J et al (2001) Synthesis and biological evaluation of vancomycin dimers with potent activity against vancomycin-resistant bacteria: Target-accelerated combinatorial synthesis. Chemistry 7: 3824-3843.
O'Connell RJ, Merritt TM, Malia JA et al (2003) Performance of the oraquick rapid antibody test for diagnosis of human immunodeficiency virus type 1 infection in patients with various levels of exposure to highly active antiretroviral therapy. Journal of Clinical Microbiology 41: 2153-2155.
Odame H (1997) Biofertilizer in kenya: Research, production and extension dilemmas. Biotechnology and Development Monitor 30: 20-23.
Odulaja A and Kiros FG (1996) Modeling agricultural production of small-scale farmers in sub-saharan africa: A case study in western kenya. Agricultural Economics 14: 85-91.
Okereke GU (1992) Biotechnology to combat malnutrition in nigeria. In: Ahmed I (ed) Biotechnology: A hope or a threat? International Labour Organisation, Great Britain.
Ortholand J-Y and Ganesan A (2004) Natural products and combinatorial chemistry: Back to the future. Current Opinion in Chemical Biology 8: 271-280.
Otero G (1991) Biotechnology and economic restructuring: Towards a new technological paradigm in agriculture? In: Costarini V (ed) Biotechnologies in perspective: Socio-economic implications for developing countries. UNESCO, France.
Palmer CJ, Lindo JF, Klaskala WI et al (1998) Evaluation of the optimal test for rapid diagnosis of *plasmodium vivax* and *plasmodium falciparum* malaria. Journal of Clinical Microbiology 36: 203-206.
Paoletti MG and Pimentel D (1996) Genetic engineering in agriculture and the environment. Bioscience 46: 665-673.
Paoletti MG and Pimentel D (2000) Environmental risks of pesticides versus genetic engineering for agricultural pest control. Journal of Agricultural and Environmental Ethics 12: 279-303.
Pathania MS and Sharma KNS (1995) Economic viability and constraint analysis in biogas technology. Asian Economic Review 37: 423-436.
Perales H, Brush SD and Qualset CO (1998) Agronomic and economic competitiveness of maize lanraces and *in situ* conservation in mexico. In: Smale M (ed) Farmers, gene banks and crop breeding: Economic analyses of diversity in wheat, maize, and rice. Kluwer Academic Press, USA.
Pimentel D and Greiner A (1997) Environmental and socio-economic costs of pesticde use. In: Pimentel D (ed) Techniques for reducing pesticide use: Economic and enviornmental benefits. John Wiley & Sons, Toronto.
Pinstrup-Andersen P and Cohen MJ (2000) Agricultural biotechnology: Risks and opportunities for developing country food security. International Journal of Biotechnology 2: 145-163.
Pinstrup-Andersen P and Pandya-Lorch R (1995) Prospects for future world food security. IDRCurrents 9: 4-9.
Piot P, Bartos M, Ghys PD et al (2001) The global impact of hiv/aids. Nature 410: 968-973.
Pirie A (1983) Vitamin a deficiency and chld blindness in the developing world. Proceedings of the Nutrition Society 42: 52-64.

Podlich DW, Winkler CR and Cooper M (2004) An effective approach for marker-assisted selection of complex traits. Crop Science 44: 1560-1571.
Poehlman JM and Sleper DA (1995) Breeding field crops. Iowa State University Press, Ames, 494 pp.
Porter G (2002) Living in a walking world: Rural mobility and social equity issues in sub-saharan africa. World Development 30: 285-300.
Potrykus I (2001) Golden rice and beyond. Plant Physiology 125: 1157-1161.
Prakash CS (1999) Feeding a world of six billion. AgBioForum 2: 223-225.
Pray C, Danmeng MA, Huang J et al (2001) Impact of bt cotton in china. World Development 29: 813-825.
Pray CE (2001) Public-private sector linkages in research and development: Biotechnology and the seed industry in brazil, china, and india. American Journal of Agricultural Economics 83: 742-747.
Pray CE and Umali-Deininger D (1998) The private sector in agricultural research systems: Will it fill the gap? World Development 26: 1127-1148.
Qadir M, Qureshi RH and Ahmad N (1997) Nutrient availability in a calcareous saline-sodic soil during vegetative bioremediation. Arid Soil Research and Rehabilitation 11: 343-352.
Qaim M (2000) Welfare prospects of transgenic crops in developing countries. In: von Braun J (ed) Agricultural biotechnology in developing countries: Towards optimizing the benefits for the poor. Kluwer Academic Publishers, London, pp 155-173.
Qaim M (2005) Agricultural biotechnology adoption in developing countries. American Journal of Agricultural Economics 87: 1317-1324.
Qaim M and de Janvry A (2005) Bt cotton and pesticide use in argentina: Economic and environmental effects. Environment and Development Economics 10: 179-200.
Qaim M and Zilberman D (2003) Yield effects of genetically modified crops in developing countries. Science 299: 900-902.
Quarrie SA (1996) New molecular tools to improve the efficiency of breeding for increased drought resistance. Plant Growth and Regulation 20: 167-178.
Rafalski JA (2002) Novel genetic mapping tools in plants: Snps and ld-based approaches. Plant Science 162: 329-333.
RAFI (2000) Golden rice and trojan trade reps: A case study in the public sector's mismanagement of intellectual property. Rural Advancement Foundation International, Osborne.
Rao IM, Zeigler RS, Vera R et al (1993) Selection and breeding of acid-soil tolerance in crops. BioScience 43: 454-465.
Rao SR and Ravishankar GA (2000) Vanilla flavour: Production by conventional and biotechnological routes. Journal of the Science of Food and Agriculture 80: 289-304.
Reddy DVR, Nambiar PTC, Rajeswari R et al (1988) Potential of enzyme-linked immunosorben assay for detecting viruses, fungi, bacteria, mycoplasma-like organisms, mycotoxins, and hormones. In: Preston TA (ed) Biotechnology in tropical crop improvement: Proceedings of the international biotechnology workshop 12-15 jan 1987, icrisat center, india. ICRISAT, India.
Reddy KS and Yusuf S (1998) Emerging epidemic of cardiovascular disease in developing countries. Circulation 97: 596-601.
Rengel Z (2002) Breeding for better symbiosis. Plant and Soil 245: 147-162.
Ridley WP (2004) Introduction to agricultural biotechnology: Challenges and prospects. In: Seiber JN (ed) Agricultural biotechnology: Challenges and prospects. American Chemical Society, Washington, DC.

Rosegrant MW and Cline SA (2003) Global food security: Challenges and policies. Science 302: 1917-1919.
Rowlandson K and Tackaberry E (2003) Edible vaccines: Alternatives to conventional immunization. AgBiotechNet 5: 1-7.
Ruivenkamp G (1992) Can we avert and oil crisis? In: Ahmed I (ed) Biotechnology: A hope or a threat? International Labour Organization, Great Britain.
Ruttan VW (1999) Biotechnology and agriculture: A skeptical perspective. AgBioForum 2: 54-60.
Ryan MH and Graham JH (2002) Is there a role for arbuscular mycorrhizal fungi in production agriculture? Plant and Soil 244: 263-271.
Ryan TM, Ciavatta DJ and Townes TM (1997) Knockout-transgenic mouse model of sickle cell disease. Science 278: 873-876.
Sahai O and Knuth M (1985) Commercializing plant tissue culture processes: Economics, problems and prospects. The technology of phytoproduction in plant tissue culture and process economics. Biotechnology Progress 1: 1-9.
Sala F, Rigano MM, Barbante A et al (2003) Vaccine antigen production in transgenic plants: Strategies, gene constructs and perspectives. Vaccine 21: 803-808.
Salami AO and Osonubi O (2002) Improving the traditional landuse system through agro-biotechnology: A case study of adoption of vesicular arbuscular mycorrhiza (vam) by resource-poor farmers in nigeria. Technovation 22: 725-730.
Sanchez PA and Benites JR (1987) Low-input cropping for acid soils of the humid tropics. Science 238: 1521-1527.
Sanchez PA and Salinas JG (1981) Low-input technology for managing oxisols and ultisols in tropical america. Advances in Agronomy 34: 279-406.
Santini JM, Sly LI, Schnagl RD et al (2000) A new chemolithoautotrophic arsenite-oxidizing bacterium isolated a gold mine: Phylogenetic, physiological, and preliminary biochemical studies. Applied Environmental Microbiology 66: 92-97.
Sasson A and Costarini V (1991) Biotechnologies in perspective: Socio-economic implications for developing countries. UNESCO, France.
Sax K (1923) The association of size differences with seed-coat pattern and pigmentation in *phaseolus vulgaris*. Genetics 8: 522-560.
Schaeffeler E, Eichelbaum M, Brinkmann U et al (2001) Frequency of c3435t polymorphism of mdr1 gene in african people. Lancet 358: 383-384.
Seastedt TR, Gregory N and Buckner D (2003) Effect of biocontrol insects on diffuse knapweed (*centaurea diffusa*) in a colorado grassland. Weed Science 51: 237-245.
Serageldin I (1999a) Biotechnology and food security in the 21st century. Science 285: 387-389.
Serageldin I (1999b) Biotechnology and food security in the 21st century. Science 285: 387-389.
Serageldin I and Persley GJ (2000) Promethean science: Agricultural biotechnology, the environment, and the poor. Consultative Group on International Agricultural Research, Washington, DC.
Serageldin I and Persley GJ (eds) (2003) Biotechnology and sustainable development: Voices of the south and north. CAB International, London, 318 pp.
Shand HJ (1989) The socio-economic impact of biotechnology on thrid world farmers. AAAS Annual Meeting Abstracts: 100.

Shantharam S and Montgomery JF (eds) (1999) Biotechnology, biosafety, and biodiversity: Scientific and ethical issues for sustainable development. Science Publishers, Enfield, NH, 237 pp.
Sharma DR, Kaur R and Kumar K (1996) Embryo rescue in plants - a review. Euphytica 89: 325-337.
Simberloff D and Stiling P (1996) How risky is biological control? Ecology 77: 1965-1974.
Simosen L, Kane A, Lloyd J et al (1999) Unsafe injections in the developing world and transmission of bloodborne pathogens: A review. Bulletin of the World Health Organization 77: 789-800.
Sinclair TR, Purcell LC and Sneller CH (2004) Crop transformation and the challenge to increase yeild potential. TRENDS in Plant Science 9: 70-75.
Singer PA and Daar AS (2001) Harnessing genomics and biotechnology to improve global health equity. Science 294: 87-89.
Smith T (1999) Biotechnology and global justice. Journal of Agricultural and Environmental Ethics 11: 219-242.
Steinberg MH (1999) Management of sickle cell disease. The New England Journal of Medicine 340: 1021-1030.
Stich B, Melchinger AE, Piepho HP et al (2006) A new test for family-based association mapping with inbred lines from plant breeding programs. Theoretical and Applied Genetics 113: 1121-1130.
Streatfield SJ and Howard JA (2003) Plant-based vaccines. International Journal of Parasitology 33: 479-493.
Szostak JW (1997) Introduction: Combinatorial chemistry. Chemical Reviews 97: 347-348.
Thorsteinsdottir H, Quach U, Daar AS et al (2004a) Conclusions: Promoting biotechnology innovation in developing countries. Nature Biotechnology 22: DC48-DC52.
Thorsteinsdottir H, Saenz TW, Quach U et al (2004b) Cuba-innovation through synergy. Nature Biotechnology 22: DC19-DC24.
Thro AM, Fregene M, Taylor N et al (1999) Genetic biotechnologies and cassava-based development. In: Leisinger KM (ed) Biotechnology and food crops in developing countries. Springer-Verlag, New York, pp 142-185.
Towie N (2006) Malaria breakthrough raises spectre of drug resistance. Nautre 440: 852-853.
Trouiller P and Olliaro PL (1999) Drug development output from 1975 to 1996: What proportion for tropical diseases. International Journal of Infectious Diseases 3: 61-63.
Tzotozos GT (2000) Industrial biotechnology: Challenges and opportunities. In: Skryabin KG (ed) Biotechnology in the developing world and countries in economic transition. CABI Publishing, New York.
Van Eerd LL, Hoagland RE, Zablotowicz RM et al (2003) Pesticide metabolism in plants and microorganisms. Weed Science 51: 472-495.
Vanderlaan M, Watkins BE and Stanker L (1988) Environmental monitoring by immunoassay. Environmental Science and Technology 22: 247-254.
Vennerstrom JL, Arbe-Barnes S, Brun R et al (2004) Identification of an antimalarial synthetic trioxolane drug development candidate. Nature 430: 900-904.
Warhurst A (1985) Biotechnology for mining: The potential of an emerging technology, the andean pact copper project and some policy implications. Development and Change 16: 93-121.
Watkins K (2003) Farm fallacies that hurt the poor. Development Outreach - World Bank Institute.

Weatherall DJ (2003) Genomics and global health: Time for a reappraisal. Science 304: 597-599.
Weatherall DJ and Clegg JB (2002) Genetic variability in response to infection: Malaria and after. Genes and immunity 3: 331-337.
Wheeler C and Berkley S (2001) Initial lessons from public-private partnerships in drug and vaccine development. Bulletin of the World Health Organization 79: 728-734.
Whitten MJ and Oakeshott JG (1990) Biocontrol of insects and weeds. In: Persley GJ (ed) Agricultural biotechnology: Opportunities for international development. CAB International, London, pp 108-122.
WHO (2002) Genomics and world health. World Health Organization, Geneva.
Widdus R (2001) Public-private partnerships for health: Their main targets, their diversity, and their future directions. Bulletin of the World Health Organization 79: 713-720.
Woolford MK (1984) The silage fermentation. M. Dekker, New York, 350 pp.
Xuan-An B, Preston B and Dolberg F (1997) The introduction of low-cost polyethylene tube biodigesters on small scale farms in vietnam. Livestock Research for Rural Development 9: 27-35.
Ye X, Al-babili S, Kloti A et al (2000) Engineering the provitamin a (ß-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science 287: 303-305.
Young MD, Rosenthal MH, Dickson B et al (2001) A multi-center controlled study of rapid hepatitis b vaccination using a novel triple antigen recombinant vaccine. Vaccine 19: 3437-3443.
Young ND (1996) Qtl mapping and quantitative disease resistance in plants. Annual Review of Phytopathology 34: 479-501.
Young ND (1999) A cautiously optimistic vision for marker-assisted breeding. Molecular Breeding 5: 505-510.
Zechendorf B (1999) Sustainable development: How can biotechnology contribute? Trends in Biotechnology 17: 219-225.
Zhang HX and Blumwald E (2001) Trangenic salt-tolerant tomato plants accumulate salt in foliage but not in fruit. Nature Biotechnology 19: 765-768.
Zilinskas RA (1993) Bridging the gap between research and applications in the third world. World Journal of Microbiology and Biotechnology 9: 145-152.
Zimmermann P, Zardi G, Lehmann M et al (2003) Engineering the root-soil interface via targeted expression of a synthetic phytase gene in trichoblasts. Plant Biotechnology Journal 1: 353-360.