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Noragric Report No. 14-A

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Noragric Report No. 14-A
April 2003

Noragric
Agricultural University of Norway

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This Noragric Report was commissioned by the Norwegian Agency for Development Cooperation (NORAD) to Noragric. Contributors were: Mohasina Syed, the Norwegian School of Veterinary Science (domestic animals, aquaculture and food safety); Hilde-Gunn Opsahl Ferstad, Department of Chemistry and Biotechnology, NLH (plant science).

A country study in Ethiopia, entitled "Biotechnology Related Policy, Management and Negotiation Competence: Case Study from Ethiopia", was commissioned by Noragric to Dr. Aregay Waktola and Ms. Bayush Tsegaye. The study is available as Noragric Report No. 14-B and should be regarded as an Annex to Noragric Report No. 14-A.

Trygve Berg, Noragric, coordinated the project and wrote chapters about biotechnology in Africa.

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NORAD
DIREKTORATET FOR UTVIKLINGSSAMARBEID
NORWEGIAN AGENCY FOR DEVELOPMENT COOPERATION

NORAGRIC
Centre for International Environment and Development Studies

Berg, Trygve, M. Sayed, H. Opsahl Ferstad, B. Tsegaye and A. Waktola, Noragric Report No. 14-A (April, 2003)
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ISSN: 1502-8127

Photo credits: J.B. Aune, I. Bryceson, I. Jørgensen

Cover design: Spekter Reklamebyrå as, Ås
Printed at: Rotator, Ås.

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Summary and recommendations

- Biotechnology is a common name for various commercial applications that have been generated through research on molecular and cell biology. The research methods that are used in applied biotechnology are also used in further advances opening new frontiers of science where the function of the whole genetic makeup of species is being studied ("functional genomics"). Both commercial applications and basic knowledge of biology relevant to agriculture and food science are now expanding very rapidly.
- Modern agricultural biotechnologies are being used in livestock, fish, cultivated plants, and also in food technology.
- Some of the biotechnology applications are relevant primarily or only in industrial forms of agriculture. However, an increasing range of biotechnology-related research outputs respond to needs and demands in the small-scale farm sector. Technology elements under research include various methods of disease management in both plants and animals, tolerance of stress, and more efficient utilization of resources.
- Developing countries have consistently demanded access to modern biotechnology and the international community has promised to contribute to transfers of such technology both technically and financially. This is explicitly stated in the Convention on Biological Diversity (1992), The Cartagena Protocol on Biosafety (2000), and in several other international agreements.
- In spite of promises and commitments, efforts to build capacity in this field are inadequate in many developing countries, including most of sub-Saharan Africa.
- Countries in southern and eastern and Horn of Africa need assistance in building capacity in order to be able to make policy decisions and to formulate and enforce biotechnology-related laws and regulations. Technical competence to assess, and selectively adopt appropriate and needed technologies as well as arenas in which to negotiate access to technologies are also needed.
- In most countries an institutional framework is in place, but with inadequate capacity and resources to function according to mandates. Assistance can be provided through partnerships with Norwegian institutions with relevant expertise and experiences. This may include short-term projects upgrading existing institutions with respect to facilities and capacity.
- Countries in sub-Saharan Africa also need strengthened international collaboration on
    1. building in-country capacity to educate needed expertise, and
    2. building capacity to undertake independent research as well as capacity to participate in international cooperative projects on strategic technology and policy issues.

  This capacity building must include legal issues including intellectual property rights, ethics, relevant social and political sciences, as well as the technical subjects. The objectives should be to have in-country and independent capacity to advise governments on policy issues and assist in formulation and enforcement of regulations. Research based competence is needed for economic development related to sustainable use of the rich biodiversity in the developing countries, for a critical assessment of controversial technology issues, and to stimulate civil society and an informed public debate.

1. Introduction

Biotechnology in agriculture includes issues and challenges that may be

- non-controversial and with proven merits and relevance, such as cell and tissue cultures, diagnostics and vaccine in animal production,
- controversial (particularly genetic engineering), raising concern about ethics, implications for the environment (biosafety), the healthiness of the food (food safety), and for corporate power through control of the technology.
- biotechnology is also about new scientific advances that are expected to provide methods that could make research more effective and contribute to better resource utilisation, better stress tolerance including disease management in plants and animals. However, this field of research also has unpredictable dimensions and could lead in unexpected directions.

The justification of spending on biotechnology is also disputed. Will it help overcoming food production constraints and contribute to poverty alleviation, or will it only divert resources that could be better spent on conventional approaches?[1]

The need for policies

Confronted by such issues developing countries realize that they need policies and they discover the need of competence and capacity to make and to implement those policies. This became painfully clear when maize from genetically modified varieties were offered as relief food to hunger affected countries in southern Africa in 2002. The Zambian president sent a "fact-finding mission" to USA, EU and Norway. In addition to specific questions about the technology, and about biosafety, food safety, implications for trade etc., the mission also asked about education. The delegates stressed that educational needs had emerged as a major concern for the country when dealing with the issue.

Laws and regulations

Developing countries also realize that they lack laws and capacity to make and enforce the needed laws. In some cases the adoption of new technology is put on hold because the regulatory framework is not in place.

International agreements

When such concerns are brought to our attention, the international community must consider (1) responsibilities according to commitments already made, and (2) relevance and importance relative to major objectives in agreed development strategies.

Representatives of developing countries have, since the emergence of the new biotechnologies in the 1980s demanded access to these technologies. This was clearly stated in the Convention on Biological Diversity (UNEP 1992) and repeated when an attached protocol on biosafety was negotiated (The Cartagena Protocol, UNEP 2000). It is also part of the commitments in the Global Plan of Action on Plant genetic Resources (FAO 1996), in the Treaty on Plant genetic Resources (FAO 2001), and in the World Food Summit Five Years After (FAO 2002).

[1] See for instance IDS Bulletin Vol 33, No 4, 2002: Can Agricultural Biotechnology be Pro-Poor? A Sceptical Look at the emerging "Consensus", by Ian Scoones.

The lack of capacity

Few developing countries have been able to access the technology and build national competence to any significant extent. Countries like China, Brazil, Argentina, India and Cuba are strong in certain fields of biotechnology, but smaller and poorer developing countries, particularly in Africa are lagging behind. Africans who return after Ph.D.-studies in a biological subject are usually updated on the state of the art of biotechnology in their particular field of specialisation. Such experts exist all over Africa. However, they remain scattered, and most, given the option to stay abroad, chose not to return due to bad perspectives on a further scientific development in their home countries. Most often they lack the institutional base that is required to use the expertise effectively for the benefit of their country. Professional milieus that are strong enough to educate others, to maintain and expand competence, and to advice governments are missing in most African countries.

Local resources and policies of utilization and protection

Many developing countries are extremely rich in genetic resources and want to exploit those resources for economic development in a sustainable way. This leads to policies of conservation of the biological diversity, to programmes of research on those resources, and to a desire for technology of economic utilisation. However, many developing countries see that such programmes mainly exist outside their country, most often controlled by corporations in industrial countries. That leads to policies on bioprospecting and "Material Transfer" to ensure that any commercial use of genetic resources from the country is based on agreements that include articles on sharing of benefits.

Patents and power

Patents complicate exchange of genetic resources for use in biotechnological research. Intellectual property rights are not experienced as a level playing field since technical and financial resources to exploit potentials of patents mainly exist in industrial countries. One case that has strongly impacted this debate is the court case of Monsanto vs Schmeiser in Canada[2]. Percy Schmeiser, a farmer in Saskatchewan has been growing his own variety of canola (rapeseed), but samples taken from his field tested positive for a patented gene belonging to Monsanto. Since he had no "Technology user agreement" with Monsanto he was sued for infringing on Monsanto's patent rights. Most likely the patented gene has spread accidentally to Schmeiser's field by pollen carried by insects or wind. However, the court found that, regardless of how the gene was incorporated into Schmeiser's variety, he had used proprietary technology and ruled in favour of Monsanto. The case is appealed and final verdict is still pending. But in the meantime Schmeiser travels around the world telling his story. In developing countries reactions are often very strong since farmers' rights to select and save seeds for further use is considered fundamental. In India Schmeiser has received the Mahatma Gandhi Award for his struggle for farmers' rights.

This case has connected biotechnology and corporate power in a way that is not easy to disentangle. Developing countries may demand access to technology, but under own control and ownership and without risk of losing farmers' customary rights of self-management of seeds.

The technology of genetic modification includes patented methods (enabling technology) and patented gene(s). Often a single product depends on a range of different patents. But rights-holders are usually willing to waive their patent rights in case of philanthropic use of the

[2] See coverage by Canadian Broadcasting Corporation: www.tv.cbc.ca/national/pgminfo/canola/

products. That means dividing the market into non-commercial and commercial segments. Subsistence crops grown by small-scale farmers in developing countries are seen as "non-commercial" and may have access to technology free of charge. That is promised for the vitamin-A-enriched "golden rice" that is expected to be released for cultivation in a few years. But the patents are not cancelled. Patents are waived depending on where and for what purpose it is being used. The issue of control and ownership of technology therefore remains as a source of concern and an issue in policy debates.

Biosafety (Environment and human health)
Concerns about environment and food safety are supposed to be taken care of by procedures of testing and control elaborated in the Cartagena Protocol on Biosafety. Most developing countries have signed the protocol, but few have so far ratified it. Most developing countries and particularly the least developed countries lack the capacity to implement the Cartagena Protocol and depend on the financial and technical support that is stated as a necessity in the protocol itself.

Basic tests do not need to be repeated in all countries, but each country must be able to critically assess tests made by others and do additional testing if deemed necessary because of local circumstances. The risk of uncontrolled spread of transgenes to wild species or to local varieties of the same species depends on local flora and on the local farming and seed supply system.

Trade
In case of export crops the use of genetically modified varieties also depends on market acceptability. Africans may consider the use of Bt-cotton, but since the cotton is exported to Europe, they must also consider how the European market reacts to such products. Thus trade issues must be taken into account.

Many African countries have a potential of growing organic food for export to industrial countries. GMO-food is not accepted on this market (limit: 1 percent). Therefore genetically modified plants and organic food production must be geographically isolated by distance and fully separated in the food chain.

Food security and poverty reduction
Hunger and famine are caused by structural problems and can therefore not be dealt with as a technology issue only. Conventional technologies of increasing food production are still underutilised in many food deficit areas, particularly in Africa. Still we have to consider seriously both current and potential contributions from new technologies. In some cases biotechnology offers solutions to problems that cannot be otherwise solved, in other cases other options are also available.

Cell- and tissue cultures are simple and non-controversial and with relevance and potentials in the small-scale farm sector. The greatest merit of this method is on crops that are propagated not with seeds but with vegetative plant parts. These include some of the most important subsistence crops in developing countries, such as banana, cassava, sweet potato and potato. A major problem with all of these crops is that diseases (viruses, bacteria, fungi and nematodes) may infest the plant parts that are used for propagation. Yield reduction may be serious when a cropping season is started with a primary infection of planting materials. And in most cases other ways of dealing with such problems do not exist. Cell- and tissue cultures can be used to clean up and mass-propagate disease free planting materials. The method is

simple and it does not require expensive equipment or high operational costs. In European countries such methods are standard in the supply of disease free seed-potatoes.

Biotechnology in animal science includes new methods of diagnostics and vaccine production.

Biotechnology also provides methods that are extensively used in studies of genetic resources of plants and animals including the rich resources in developing countries. New methods of identifying and selecting valuable genes (marker assisted selection) are expected to make crop and livestock improvement much more effective.

Whether transgenic crop varieties (genetically modified plants, GMPs) can contribute to food security in poor countries is disputed. Both structural and biological constraints need to be considered. Structurally the problem is the decline in funding of public plant breeding. The field is dominated by private industries that can only survive by making technology for the commercial sector. Thus it should not be surprising that available GMPs are less relevant in the subsistence farm sector. The biological constraint is related to the fact that current methods of genetic engineering can only deal with single genes while yield basically depends on a complex of many genes.

The structural constraint may be overcome if public funding of technology for the non-commercial sector is made available. One example is the "golden rice". It has little commercial potential but is believed to have a great humanitarian potential (reduction in vitamin A deficits). The project is funded by Rockefeller Foundation. Many ideas of such kind of "pro-poor" biotechnology are discussed in the literature. Most of them suggest better tolerance of stress (drought, saline soil, diseases an pests). Improved nutritional quality, called biofortification, includes vitamine A (the golden rice) but also other ideas related to food quality.

The biological constraints are likely to be affected by advances in biotechnology provided by the functional genomics research that studies the total genetic makeup of organisms.

The public sector

Biotechnology exposes governments to an array if issues that require capacity to make policies, to develop laws and regulations, and to build capacity in ministries and institutions. This and other studies of biotechnology in developing countries point to lack of capacity at all levels. This makes it difficult for governments to make decisions, and to absorb and utilize as well as manage and control the new biotechnologies.

Various well-intended offers of help with safe introduction of relevant biotechnologies are available for developing countries. However, such help should preferably be provided to countries with a national capacity to understand, critically assess and control whatever technology is provided. In countries where this capacity is not sufficiently developed, the most urgent need is education and capacity building. This must include both the technologies and the associated policy issues.

The civil society

In many Asian countries a strong civil society keeps a close watch on the new technologies focusing on environment, public health, power relations, and social and economic implications. In most African countries the civil society is still weak and without sufficient capacity to serve as a critical counter culture. There was an intense public debate in Africa

when GM-maize was imported to southern Africa as relief food last year. That reflected a strong public concern both for having access to needed technology and for the possible risks. Thus there is probably a fertile ground for the growth of a critical civil society. But also that depends on added efforts on public education.

Challenges

Biotechnology is not an objective but methods of solving problems. All countries need independent capacity to assess and make strategic choices of technology relative to their needs and problems.

For this end, developing countries have consistently demanded access to knowledge about the modern technologies and the international community has made unreserved commitments for that in a number of conventions and agreements. Considering also the potential benefits of strategic use of selected elements of those technologies as well as the lack policies and management capacity in many countries, collaboration on education and institution building stands out as the most basic need in this sector.

The next chapter outlines a scheme for achievements of basic objectives in education and institution building in a developing country that is currently behind its own targets in this field.

2. Building biotechnology relevant management and technical competence in developing countries

The needs

With the exception of South Africa representatives of countries in sub-Saharan Africa all complain of lack of needed capacity. Authorities in Swaziland observe that farmers in neighbouring South Africa grow Bt-cotton and "we don't know whether to allow it or forbid it"[3]. In an African conference in Namibia in November 2002, the most advance country present (Egypt) expressed concern over lack of competence to implement the Cartagena protocol on biosafety[4]. Generally the African attitude is that they do not want to close their countries for modern biotechnology, but want to assess critically anything that is offered according to the requirements of the Cartagena Protocol.

The Ethiopian case study and other reviews of biotechnology in Africa indicate that much of the institutional framework is already in place. There are universities and research institutes, some countries have biotechnology advisory bodies, there are science policy institutions, environment protection authorities etc. But capacity and resources are inadequate relative to the needs that are created by the modern biotechnologies. This makes it difficult to make policies, advice governments when decisions have to be made, and to make and enforce laws and regulations.

The gaps and needs vary from country to country, but include short term needs of strengthening the capacity to manage current and pressing issues, and longer term needs of establishing in-country capacity to educate needed expertise on the technical subjects and on the related legal, social and political issues.

Needs of competence building are also included in the recommendations in a recent report to NORAD on Agricultural Development (see box).

> **Landbruksutvikling – en vei ut av fattigdommen**
>
> - Støtte opp om oppbygging av *faglig kompetanse* og *forhandlingskapasitet* i utviklingslandene slik at de har større gjennomslag og kapasitet i forhold til internasjonale regelverk og handel. Dessuten styrke utviklingslandenes kompetanse og kapasitet til å delta i *internasjonale forhandlinger*. Herunder styrke den faglige kompetansen på *nye områder*, som bioteknologi, GMO-problematikken, og immaterielle rettigheter.
> - Bidra til bredere *institusjonssamarbeid* mellom faglige forvaltningsinstanser i Norge og i mottakerland med det mål og bygge kompetanse og kapasitet på disse områdene.
>
> Fra Bie-komiteens innstilling, Februar 2003

[3] Ms. Thandie Lupupa, Drector of the National Genebank in Swaziland. Personal communication July 2002.
[4] Mr. Paulino Munisse, delegate representing National Institute of Agronomy Research in Mozambique. Personal communication.

Short term
When institutions are mandated to work with biotechnology issues and have the potential capacity but not the actual capacity to function according to its mandate, effective assistance can be provided through short-term projects in collaboration with Norwegian sister-institutions.

- **Biotechnology advisory boards**
  States need institutions that can advice governments on biotechnology related legal, regulatory and policy issues. Such institutions exist in some countries, but need support in order to develop adequate capability. In Norway the Norwegian Biotechnology Advisory Board provides these services. Even if such boards are institutionalised and supported by a secretariat including permanent professional staff, they depend on the existence of professional milieus that can help reviewing issues and cases. A parallel building of capacity in other institutions is therefore necessary.

- **Technical issues**
  When important needs in the country require the use of strategic technology elements, such as plant cell and tissue culture, and veterinary diagnostics and vaccine production, the necessary equipment and staff training can be provided through projects where responsible institutions are assisted by a Norwegian institute that has the necessary expertise and experience.

- **Policy and law**
  Institutions that are responsible for management of genetic resources need to be guided by policies on biodiversity collection and international exchange. This includes capacity to negotiate terms, including sharing of benefits.

  In service training or courses organised by international bodies such as International Plant Genetic Resources Institute could help building the required capacity within the institutions.

  Environment law need to be formulated or further developed in many countries. Collaboration with institutions that have expertise and experience with environmental law in Norway could help strengthening capacity in this field.

  Capacity to negotiate and manage access to patented technology and to incorporate intellectual property rights issues into national policies requires strengthening of the professional capacities in various institutions.

- **Biosafety**
  Responsible decision making on requests for importation of GM-food, or the introduction GM-technology, depends on professional assessment of biosafety issues according to the Cartagena Protocol.

  The Norwegian Institute of Gene Ecology (Tromsø) has developed a programme of capacity building related to genetically modified organisms. The programme includes short-term courses, one for senior policy makers and regulators from developing countries, one on risk assessment and gene ecology for senior scientists, and one on risk assessment for NGO/Civil society leaders.

This kind of training is urgently needed and would be helpful for many countries, particularly in sub-Saharan Africa where governments often have problems making decisions on such issues.

Long term

Universities in most of sub-Saharan Africa do not have the capacity and resources to educate needed expertise in biotechnology and biotechnology related social sciences. This means lack of professionals for the growing needs in ministries and institutions, but it also means lack of milieus for critical assessment and well-informed debates.

These shortcomings imply the need of building of in-country capacity to educate and empower expertise for the country, and the building capacity to undertake independent research on strategic technology and policy issues.

When such capacity is built, the country would be able to:

- assess technology needs and potentials in the country,
- use relevant technology elements in national research and development,
- formulate and enforce policies, laws and regulations,
- negotiate contracts with industries,
- participate on equal terms in international collaboration on research, development and policy making.

Biotechnology and the power of Know-How

Modern biotechnologies emerge from largely universal basic knowledge in genetics and molecular biology. Except some minor differences between prokaryote[5] and eukaryote organisms, the genetic code is universal giving global understanding of all living life forms. Genomics and proteomics lift molecular biology from the study of single genes and proteins to a level where the scope is to unravel how all work together in a global perspective. Research-based knowledge on this is necessary for evaluation of available new products, and for setting up regulations of uses.

Language is power and the genetic code may be a new language to conquer the world. Bioinformatics, the tool necessary to master and understand this language, requires knowledge of a range of sciences, from the biology to informatics with mathematics, statistics, program constructions etc. This scientific field has no geographic borders; all it takes is know-how and computer power.

However, know-how is also needed on the interaction of technology and society. This challenges law, including environment law and intellectual property rights, ethics, and social and political sciences.

Ethiopian experts interviewed for this study call for a "Centre of Excellence" rather than efforts scattered on all of the universities and all relevant university departments and research institutes. Most probably this would be a preferable approach in many countries.

A Centre of Excellence is technically convenient because of the universal nature of the genetic code and the mechanisms through which genetic information is "translated" into

[5] Prokaryote: Unicellular organisms that have no nucleus (bacteria and blue-green algae). Organisms with cells that have a nucleus are eukaryotes.

structures and functions in an organism. The basic knowledge, methods and research tools are therefore the same regardless of kind of organism. A common course can educate experts on biotechnology in microorganisms, plants, animals and humans and thereby serve needs related to industry, agriculture, food technology, farmacology and human medicine.

"Centres" are often the structure chosen by universities in order to work with issues that cut across established department borders. A Biotechnology centre could therefore have sections or groups working on the interaction of the biotechnology and law, ethics, and social sciences. This would benefit from having links to relevant departments. But having such expertise and research in the Biotechnology centre would ease the cross-disciplinary communication in both research and teaching.

Building a biotechnology centre

The proposed objectives could be achieved through institutional collaboration involving a designated university in a developing country and a partner university in an industrial country.

Initial stage: Selecting the partners and establishing the platform of collaboration.

Norwegian universities have got extensive experiences of institutional collaboration with universities in developing countries through involvement in NORAD and NUFU funded projects. Institutional and personal relations and partnerships have in many cases grown strong and could be built on when new challenges have to be taken up. Involved institutions should be stable and prepared for long-term commitments. A developing country partner university should be well established with core funding including salaries covered by national budgets so that project funds can be spent on stipends, international studies, research, library, and laboratory equipment. In sub-Saharan Africa institutions that meet those criteria exist in several countries in southern and eastern Africa and in the Horn of Africa.

The Bie-Committee's report on Agricultural Development (February 2003) suggests country studies on needs related to agriculture, food security and poverty reduction. Such country studies could include agricultural biotechnology and thereby help identifying needs and assessing those needs in a context of food security and poverty reduction.

Phase 1: Building the competence.

A Biotechnology Centre is not sufficiently developed unless a critical mass of experts are educated and have returned to permanent positions. Needs and targets depend on the pre-project situation. But when the target is set, say 10 PhDs, all candidates could be selected in year 1 and sent for studies in various specialisations within biotechnology including legal and policy subjects. Although studies could be in a foreign university, research for Ph.D.-theses must be in the home institution requiring the building of research facilities and installing of equipment as a parallel activity. A five-year-project phase would be sufficient to achieve the goal of educating a critical mass and establishing research facilities and making them operational.

Phase 2: Starting and consolidating biotechnology education at MSc-level.

During a second five-year phase, the Centre would have the capacity to run M.Sc.-courses in various biotechnology related subjects. That would require teaching laboratories and other facilities such as computers and library for the students.

Post-graduate courses at M.Sc.-level would secure a regular supply of professionals for institutions in the public sector as well as for needs in an emerging private sector. It would also strengthen the civil society and public awareness and debate.

Teaching staff at such a Biotechnology Centre would have both the capability and the facilities needed for research. The M.Sc.-students as additional resources for research work would, depending on availability of research funds secure a considerable capacity to carry out needed research as well as other professional work that requires biotechnological competence.

3. International agreements

3.1. Convention on Biological Diversity

The Convention obliges parties to conserve their biological diversity, to ensure utilization for sustainable development, and to share benefits arising from such utilisation. Relevant technologies for such purposes, including biotechnology, should be made available for developing countries and be provided or facilitated on fair and favourable terms. This is elaborated in Article 16 on Access to and Transfer of Technology. Article 18: Technical and Scientific Cooperation deals with the promotion of international technical and scientific cooperation, and Article 19: Handling of Biotechnology and Distribution of its Benefits demands measures, including policies, to ensure "biotechnological research activities by those Contracting Parties, especially developing countries, which provide the genetic resources for such research, and where feasible in such Contracting Parties".

These articles are responses to demands by representatives from developing countries who insisted on linking conservation to sustainable development, and on access to technology, including biotechnology, in exchange for access to biodiversity. Ten years after, many developing countries are disappointed. They have not, to a significant extent, gotten what they hoped for, access to the technology and competence building. Instead they are offered what they did not ask for, readymade technology elements under corporate ownership.

3.2 The Cartagena Protocol on Biosafety

In January 2000 a protocol on Biosafety (The Cartagena Protocol) was adopted as an attachement to the Convention on Biological Diversity. The protocol deals with safe utilization and handling of biotechnology. It refers to the great potential of biotechnology and recognizes the "crucial importance to humankind of centres of origin and centres of genetic diversity". Most centres of genetic diversity are located in developing countries. Those include Ethiopia that is used as a case in this study.

The Cartagena Protocol takes into account "the limited capabilities of many countries, particularly developing countries, to cope with the nature and scale of known and potential risks associated with living modified organisms". It devotes one article to Capacity-Building (Article 22) and one article to Financial Mechanisms and Resources (Article 28) where the needs of the developing country Parties, in particular the least developed are explicitly mentioned.

Most developing countries have signed the Cartagena Protocol. Few have ratified so far, but ratification processes are on in many countries. However, policymakers in African countries admit lack of capacity to implement what is required according to the Cartagena protocol[6]. The implementation of the Protocol depends in many developing countries on strengthened efforts to build capacity according to Article 22 and on funding according to Article 28.

[6] In a meeting in Namibia November 2002 the most advanced country present, Egypt, complained of lack of capacity to implement the Cartagena protocol. Mr. Paulino Munisse, delegate representing National Institute of Agronomy Research in Mozambique. Personal communication.

3.3 An FAO statement

In a Statement on Biotechnology (2000) FAO[7] says: "In view of the potential contribution of biotechnologies for increasing food supply and overcoming food insecurity and vulnerability, FAO considers that efforts should be made to ensure that developing countries, in general, and resource-poor farmers, in particular, benefit more from biotechnological research, while continuing to have access to a diversity of sources of genetic material. FAO proposes that this need be addressed through increased public funding and dialogue between the public and private sectors."

3.4 FAO: Code of Conduct on biotechnology

The FAO Commission on Genetic Resources for Food and Agriculture is developing a **Code of Conduct on Biotechnology** aimed at maximizing the benefits of modern biotechnologies and minimizing the risks. While this started with plant biotechnology only, the scope is about to be widened to cover all components of genetic resources including plants, livestock, fish and micro-organisms as they relate to food and agriculture[8]. Also this instrument is likely to emphasise "capacity building for all aspects of biotechnology including biosafety, biotrade and biopolicy" with particular reference to needs in developing countries[9].

3.5. World Food Summit: Five years later (June 2002)

The World Food Summit (1996) agreed on an objective to "reduce by half the number of chronically undernourished people on the Earth by the year 2015". However, five years later FAO statistics revealed that the world was running behind schedule even on that modest target. The new summit "Five years later" (June 2002) reaffirmed earlier commitments to end hunger and passed a Declaration that has a reference to needs of research applying new technologies, including biotechnology[10].

3.6. Other international agreements

Making relevant biotechnologies available in developing countries is also part of the commitment made in the Global Plan of Action on Plant Genetic Resources (FAO 1996) and in the Treaty on Plant Genetic Resources (FAO 2001).

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[7] www.fao.org

[8] Background paper to the October 2002 meeting of the Commission on Genetic Resources for Food and Agriculture: The Status of the Draft Code of Conduct on Biotechnology as it relates to genetic resources for food and agriculture.

[9] Ibid.

[10] World Food Summit: Five years later, Article 25 (www.fao.org.worldfoodsummit/)

4. Policy issues including Intellectual Property Rights

Developing countries must assess available technology and decide on whether to adopt the new biotechnology or rely on conventional technologies. In case of adoption, the countries must negotiate with technology-providers about terms and conditions, deal with complex patent and licensing formalities, and enforce safety regulations. These could be bilateral arrangements, implemented nevertheless in accordance with international agreements such as the Convention on Biological Diversity, the Cartagena Protocol on Biosafety, The International Treaty on Plant Genetic Resources, and The WTO agreements on Trade Related Intellectual Property Rights.

In the process of developing the "Code of Conduct on Biotechnology" mentioned above, a strong demand for associating technical capacity building with policy competence has emerged. This means capacity to deal with formulation and enforcement of regulation particularly as related to biosafety (the Cartagena Protocol), but also negotiations on trade related issues, and access to resources, knowledge and technologies.

Currently the private sector dominates research and development in biotechnology and many products and technology elements are available on commercial terms and under intellectual property protection. In some cases, such as that of Golden Rice mentioned above, industry allows free use of patented technology for non-commercial or philanthropic use in developing countries.

In this context we have restrictions on methods (the enabling technology) and on genetic materials (e.g. patented genes). Sometimes one project depends on an array of patented technologies belonging to many different companies. Dealing with rights-holders may require a considerable legal and administrative capacity. It is likely that access to technology on favourable terms will be possible in case of technology for the small-scale farm sector in developing countries. This requires the separation of commercial and non-commercial segments of the market[11]. It is likely that most food production in developing countries in this context will be considered non-commercial while the production of export crops such as cotton will be considered commercial and expected to access technology on commercial terms.

As an alternative to legal protection commercial biotechnology companies are developing "technology protection systems". One form of technology protection exploits molecular techniques that provide a switch mechanism to prevent further use of a variety or the use of a particular trait. Those have been nicknamed "terminator" by critical activist groups[12]. In technical jargon these methods are called "Genetic Use Restriction Technologies" or GURTs. The molecular switch mechanism can be used (1) to disrupt essential processes in seed development resulting in sterile seeds, or (2) to prevent the expression of an added trait so that it would not appear in the plant. Main motivation for providing seeds with GURTs mechanisms is in the case of sterile seeds to prevent farmers from saving seeds and in the case of trait expression to prevent unlicensed use of an added trait.

[11] C. Spillane 1999: Recent Development in Biotechnology as they relate to Plant genetic Resources cfo food and Agriculture. FAO Comission on Genetic Resources: Background Study Paper No. 9.
[12] See for instance the ETC Group: www.etcgroup.org

In public debate these methods are now mostly referred to as terminator technology. Genetically modified varieties are often believed to be equipped with "terminator genes" preventing farmers from producing their own seeds. So far, however, no GURTs are commercially applied in any known GMP variety. Potentials of GMPs can be exploited independent on GURTs technologies. If any GURTs mechanism is added, it is for intellectual property protection (alternative to patent) or for biosafety (prevent spread of transgenes to other varieties or to wild relatives). It is, however, uncertain whether such technology will ever be commercially applied. Since it is purely for protection, it adds costs but does not add any productive value. The technology is highly controversial and is met with particular scepticism in developing countries.

5. Biotechnology in Africa

5.1 Introduction and overview

The introduction of agricultural biotechnology tends to come in stages where the initial stage may be enhancement of natural processes, such as production of bio-fertilisers by means of biological nitrogen fixation. In the next stage, plant cell and tissue cultures and new methods of diagnostics and vaccine production are being applied. During that stage, countries start working out biosafety guidelines and establishing national biotechnology advisory boards. In the third stage, molecular methods are being added for various research purposes including genetic engineering.

Most African countries have adopted at least some of the elements of the two first stages[13]. Research with molecular techniques has started in Egypt, Nigeria and South Africa, and to a limited extent also in Zimbabwe. The methods of this stage, however, require sophisticated equipment and also depend on high operational budgets (particularly because of consumption of very expensive enzymes). The advancement to the third stage is therefore difficult. In the more organised countries of Sub Saharan Africa, such as Kenya and Zimbabwe[14], the number of scientists in biotechnology has been increasing during he 1990s, but budgets per scientist has declined forcing the research institutes to concentrate on the cheaper methods of stage 1 and 2.

It should be added here that biotechnology is not an activity independent of larger scientific efforts. It can provide new and more efficient tools for use in established research, but in and of itself it does not produce technology ready for use in agriculture. Adoption of biotechnology therefore depends on the existence of already organised research institutes. In the case of plant biotechnology, a public or private seed industry is also needed to make use of some of the products of modern biotechnology. The low standard of national research systems and the absence of seed industries explain why adoption of modern biotechnology is slow in most African countries.

International agricultural research centres are increasingly using molecular techniques. Examples can be found in the research agendas of IITA (International Institute of Tropical Agriculture, Ibadan, Nigeria) and ILRI (International Livestock Research Institute, Nairobi) as well as in research centres in Latin America and in Asia that have sub-centres in Africa, for example CIMMYT (International Maize and Wheat Improvement Center, Mexico) and ICRISAT (International Crops Research Institute for the Semi-Arid tropics, Hyderabad, India). Key research issues include DNA studies of Africa's genetic resources in livestock and crop plants both to support conservation and to enhance utilization. Direct applied projects include vaccine development in livestock, and identification of genes for pest resistance in crop plants. Experimentation with genetic modification of banana has started at IITA. The crop is extremely difficult to breed in conventional ways because the cultivated forms are sterile (seedless). When new diseases now threaten the crop, the transfer of resistance genes by genetic transformation is seen as an attractive approach.

[13] See cross country review in Electronic Journal of Biotechnology, www.ejbiotechnology.info December 1998.
[14] This has been studied by ISNAR (International Service for National Agricultural Research, www.isnar.org) before the current crisis in Zimbabwe.

5.2 The Ethiopian case

A special report about biotechnology in Ethiopia is attached. The report gives an overview of relevant public management and research institutions, and institutions of higher learning including mandates and capacity. It also covers policies and legal/regulatory framework. Based on interviews with responsible staff in relevant institutions, the report summarises gaps and needs with respect to manpower, facilities and other resources, policies and regulations.

Some modest biotechnology activities can be found in universities and research institutes. The survey has found applications related to livestock (artificial insemination, diagnostics and vaccine production), plant tissue culture and micropropagation, studies of biological nitrogen-fixation, biopesticides, biogas, and characterisation of biodiversity using isozymes and molecular methods. Involved scientific staff consider biotechnology to be neglected and under-utilized. Limitations include lack of qualified researchers and facilities, but also lack of policies and regulatory measures. Need of training in safe management of biotechnology is also mentioned.

Policies and legal/regulatory issues
A general **National Science and Technology Policy** was issued in 1994 identifying Biotechnology as one of the priority areas. This is followed up by Ethiopian Science and Technology Commission that has coordinated works to formulate a specific biotechnology policy for agriculture, environment, health and industry. The policy recognises that Ethiopia needs biotechnology for its development challenges including the problem of food deficit.

The draft is submitted to the Council of Ministers and is awaiting approval. However, it is not considered exhaustive since some areas like pharmaceuticals and food safety are missing. It is therefore expected that the draft protocol will have to be complemented on those issues and updated on emerging technologies.

Also **Access Legislation** is on a drafting stage. According to the principles of the Convention on Biological Diversity, access to biodiversity will be linked to benefit sharing including access to and transfer of technologies, particularly biotechnology. Institute of Biodiversity Conservation and Research has developed **Material Transfer Agreements** through which germplasm exchange shall be facilitated. Other relevant policy documents include **National Environment Policy** (1997), **National Seed Industry Policy** (1992), and **National Health Policy** (1993). There is no specific law or regulation regarding food safety other than checking the product quality according to the market labels against the established standards. A national food and nutrition policy is not developed.

A proposal to ratify the **Cartagena Protocol on Biosafety** has been submitted to the Government. Once ratified, the Protocol requires biosafety legislation, scientific capacity, and monitoring and enforcement capabilities. Also capacity for negotiation must be built.

Institutional framework
Ethiopia already has institutions to deal with the various public needs related to the new biotechnologies. The **Ethiopian Science and Technology Commission** is mandated to plan, promote, coordinate, finance and oversee technology activities in the country, and advice the government on issues of science and technology. The **Ethiopian Agricultural Research Organisation** with its network of research stations all over the country is responsible for formulating research strategies and conduct research on crops, livestock, forestry, soil and

water management, and dryland agriculture. **Institute of Biodiversity Conservation and Research** is mandated, inter alia, to explore and survey the diversity and distribution of the country's plant, animal and microbial genetic resources, keep a germplasm collection for conservation and utilization, and implement international conventions and agreements with respect to biodiversity. The institute is also authorised to issue permits to collect, dispatch, import or export biological specimens or samples. **Environment Protection Authority** is responsible for preparing and enforcing environment policies and laws including follow up of international environmental treaties such as the Cartagena Protocol on Biosafety. Other institutions that may play a role in controlling agricultural and food biotechnology applications include: **National Seed Industry Agency**, **National Health and Nutrition Research Institute**, and **The Quality and Standards Authority of Ethiopia**

Scattered efforts are under way by each of the above institutions, but with insufficient coordination. It is hoped that this issue would be resolved when the proposed biotechnology policy is approved by the Government.

Experts within these institutions point to shortcomings with respect to manpower and capacity, facilities and resources, policies and law regarding tasks related to the new biotechnologies. The institutions have huge responsibilities, but lack minimally-required resources.

Ethiopian delegates have been highly visible and influential in many international negotiations on environment issues. However, experts in the institutions that are responsible for follow-up and implementation are disappointed about lack of results with respect to transfer of needed technologies. Experts also express concern about lack of public awareness and understanding about risks and associated dangers of biotechnology.

Education

Ethiopian Universities include Addis Ababa University (1950), Alemaya University of Agriculture (1986) and four recently established regional universities. Scientists dealing with biotechnology related subjects consider that their institutions do not have the capacity and resources that are needed to educate manpower for development and management of biotechnologies in agriculture, industry, health and other services.

All the universities need to upgrade and expand on teaching in biotechnology related subjects, but for a rational and coordinated response to the many needs, a national "Centre of Excellence" is suggested.

6. Current and emerging modern biotechnologies

Biotechnology refers to using living organisms or systems to produce useful substances or to using biological technologies to improve plants, animals, or processes. Although the word "biotechnology" is relatively new, using biological agents isn't. Yeasts, moulds, and bacteria have been used for years to make fermented foods like beer, wine, and bread, and to preserve foods, such as by turning milk into cheese and yoghurt. The newer technologies include the techniques of recombinant DNA, gene transfer, embryo manipulation and transfer, plant regeneration, tissue culture, monoclonal antibodies, and bioprocess engineering.

The research tools that have generated these technologies have also opened new fields of research. Genomics, the sequencing of the entire genetic makeup of a species is advancing fast. New genome projects include several species that are important in agriculture. It has been shown that related species share most of their genes. They also have, to a large degree, common gene orders along the chromosomes. Therefore, the complete sequencing is not necessary in all species. For example, the rice genome that is almost completely sequenced can be used as a model in molecular biology research on other cereal crop species. Such research directs much of current biology and is expected to yield new insight with potentials for better disease management, better stress tolerance, and better resource utilization in both livestock and crop production.

7. Current and emerging modern biotechnologies in domestic animals, aquaculture and food safety

7.1. Biotechnology in Animal Breeding

For many years biotechnological procedures such as artificial insemination and embryo transfer have been an integral part of modern animal husbandry, and they have resulted in the well-known and recognized improvements in performance in agricultural animals. But certain disadvantages could not be countered by these techniques: the relatively slow annual rate of genetic progress (1-3%), the lack of a way to separate desirable from undesirable traits by breeding, the impossibility of transferring genetic information between species.

New biotechnology and novel molecular-genetic tools already available and others under development indicate that it will be possible to overcome these limitations to breeding. Today "biotechnology in farm animals" basically includes techniques in reproductive and molecular biology intended to enhance performance, efficiency and health for sustainable animal production.

- In the very near future the complete sequencing of the genomes of important domestic animals will make it possible to distinguish molecular phenotypes and thus improve the use of genetic resources.

- In view of the world's limited resources and increasing population, biotechnology and novel genetic-molecular tools will provide important resources for making animal production more efficient, environmentally appropriate and economically viable.

- Cloning and transgene technology will open new horizons both for biomedicine and for many agricultural applications, particularly in the area of product diversification.

- The development and application of biotechnology and genetic technology in animal breeding must be accompanied by interdisciplinary research leading to more rational and factual social and ethical discourse.

Selective breeding has produced enormous improvement in farm livestock in the latter part of the twentieth century. Such progress has largely been achieved through selection on phenotype: the identification of genetically elite animals through their own performance and physical characteristics and those of their relatives. However, the explosion in our understanding of the genome and accompanying technological innovations are opening up possibilities for direct identification and selection of animals carrying the best genes: selection on genotype.

The first uses of DNA based selection in livestock have been to control or eliminate deleterious alleles such as the HAL n allele in pigs and the BLAD mutation in cattle. The HAL mutation provides an interesting example of a gene with both positive and negative effects. Pigs that are homozygous for the n allele (i.e. carry two copies) have a high frequency of deaths caused by stress, produce meat of low quality but are leaner.

Positive selection for beneficial alleles has also been initiated based on association tests. Selection at the estrogen receptor (ESR) locus in pigs provides a good example. Rothschild et

al. (1996) have demonstrated that variation at this locus is associated with litter size in pigs. One of the major alleles identified, the B allele, seems to increase litter size. Thus using selection based on DNA information to increase the frequency of the B allele within a population or to move the B allele into a population that does not carry it are both predicted to increase litter size.

Selection for ESR genotypes is being undertaken in breeding populations of the pig breeding company, PIC. This involves both selection of the desired genotype in populations where it was already present and the introgression of the B allele into populations where it was previously absent. PIC reports that there has been an increase in the rate of genetic response by up to 30% by incorporating the ESR genotype in selection indices for dam lines in nucleus herds. Furthermore, the increase in average litter size is also observed in crossbred products derived from these lines.

With developments in DNA marker technology, it became possible to genotype individuals for several thousand closely spaced markers at the same time and hence find and use associations that will be valid in any population.

Alleles conferring disease resistance would be prime candidates for marker-assisted introgression where such alleles can be found and projects probing the practicality of this approach are underway. Trypanosomosis, for example, is a disease that effectively keeps susceptible cattle breeds, such as the Boran, out of large areas of sub-Saharan Africa. The N'Dama breed has a much higher level of resistance and is currently being used in a cross with Boran to map the loci associated with resistance. If this is successful, it should be possible to use the markers identified to introgress the resistance alleles into the Boran without need to challenge the animals with disease.

One current area of research is focusing on enhancing the rate and efficiency of meat production - increasing lean tissue and decreasing fat tissue with hormones and other compounds that alter metabolic pathways. Pharmaceutical companies are working on biological compounds, somato-tropins and beta adrenergic agonists, for example, that partition energy away from fat and into muscle.

Somatotropins (growth hormones) may be the first products of biotechnology to significantly influence animal agriculture. Originally available only from pituitary glands of animals, somatotropin now can be produced in pure form and in large quantities at relatively low cost through recombinant DNA technology. Recombinant somatotropins have impressive effects on growth, feed efficiency, and carcass composition in pigs and can dramatically increase milk production in dairy cattle. Multi-year tests of bovine somatotropin (BST) on tens of thousands of dairy cows have shown a 10- to 20-percent boost in milk production with a 10-percent reduction in feed consumed. Porcine somato tropin (PST) allows pigs to convert more feed into muscle and less into fat and improve feed efficiency as much as 20 percent.

Artificial insemination and frozen semen can be considered among the first developments in animal biotechnology. Since then, embryo manipulation (including embryo collection and transfer) has been used successfully with cattle. The process involves inducing superovulation and artificial insemination, with the resulting embryos implanted in surrogate mothers. During transfer, the embryos can be split, fused, sexed, or frozen. The success rate for splitting is excellent, and thousands of calves have been produced from split embryos. Embryo transfer

techniques can be used to produce "litters" of calves from a single superior mother that would otherwise produce only one calf at a time.

Infectious diseases remain the leading cause of death and reduced productivity in livestock. Biotechnology offers the potential to produce powerful vaccines for foot-and-mouth disease, scours, shipping fever, and other animal illnesses. Biotechnology has already led to a vaccine for pseudorabies, a herpes virus that infects cattle, pigs, and sheep.

Along with superior vaccines, biotechnology techniques using monoclonal antibodies are being developed to detect animal diseases, estrus and pregnancy, and aflatoxin[15] in livestock feed. Recombinant DNA can be used to make "probes" to diagnose disease, and monoclonal antibodies can be used to diagnose diseases, monitor drug efficacy, and develop therapeutic treatments and vaccines. We can already diagnose scours, pseudorabies, bluetongue, transmissible gastroenteritis, and several major poultry ailments. Monoclonal antibodies currently are available as therapeutic treatments against both calf and pig scours.

Researchers are currently investigating alternative uses for farm animals. Because mammals can efficiently convert feed sources into valuable proteins scientists in the future may be able to develop animals that can produce high-value pharmaceutical or therapeutic products in their milk or blood. Transgenic animals that produce these blood factors in their milk could be a viable and safe alternative production system. They may be more economical than microbial fermentation that is used for the large-scale production of human and animal vaccines, drugs, peptide hormones, monoclonal antibodies, and other high-value pharmaceutical products. Although raising such animals would employ a relatively small number of farmers, it's an example of the potential opportunities that might come from biotechnological advances.

7.2. Biotechnology in Aquaculture

The tools of modern biotechnology can be used to improve the health, reproduction, development, growth, and overall well-being of cultivated aquatic organisms; and promote the interdisciplinary development of environmentally sensitive, sustainable systems that will enable significant commercialization of aquaculture.

The application of biotechnology promises significant benefits to both producers and consumers of aquacultural products. The use of genetically enhanced organisms may improve production efficiency through improvements in growth rates, food conversion, disease resistance, and product quality and composition. The application of biotechnology to aquaculture also may help conserve wild species and genetic resources and provide unique models for biomedical research.

7.3 Enhancing Reproduction and Early Development

Biotechnology can be applied to enhance reproduction and early development of cultivated aquatic organisms. The resulting benefits could include year-round production of gametes and fry of economically valuable species and creation of new markets for specialized, genetically improved broodstock. Similarly, biotechnology may provide techniques for improving the

[15] Aflatoxin is a toxic substance that is sometimes found in feed that has been affected by the mould fungus *Aspergillus flavus*.

reproductive success and survival of endangered species, thereby helping to preserve the diversity of life on Earth.

7.4. Improving Health and Well-Being

Biotechnology offers substantial opportunities to improve the health and well-being of cultivated aquatic organisms. More than 50 diseases affect fish and shellfish cultured causing losses of tens of millions of dollars annually. Biotechnology not only can improve the survival, growth, vigor, and well-being of cultivated stocks, but also can reduce disease transfer between cultivated and wild stocks. New products and market opportunities can be developed related to aquatic animal health and well-being.

The tools of molecular biology can provide a basic understanding of host immunity, resistance, and susceptibility to diseases and associated pathogens by furnishing information about life cycles and mechanisms of pathogenesis, antibiotic resistance, and disease transmission. Improved technologies must be developed for detecting and diagnosing pathogens and diseases and for enhancing the genetic basis of disease resistance, thereby reducing the need for antibiotics and other drugs.

Potential products resulting from this research include gene therapy techniques; broodstock free of pathogens; safe, effective prophylactic agents, including immune modulators, antigens, and vaccines; safe, effective therapeutic agents; and improved systems for administering prophylactic and therapeutic agents.

7.5. Improving Quality and Value

Biotechnology can be an invaluable tool to help ensure the safety and quality of food supplies. Biotechnology can be employed to assess and improve the safety, freshness, color, flavor, texture, taste, nutritional characteristics, and shelf life of aquacultural food products. In addition, practical technologies can be developed to detect and assay toxins, contaminants, and residues in seafood, and to reduce or eliminate contaminants. There are also opportunities to apply biotechnology in improving seafood processing. Research should be conducted to develop and improve technologies for all these applications.

7.6. Conserving Genetic Resources

Biotechnology can be employed in two ways to conserve genetic resources of aquatic species. First, the tools of biotechnology can be used to identify and characterize important aquatic germplasm, including endangered species. Genomes of aquatic species can be analyzed and characterized, and quantitative trait loci identified. Second, biotechnology can be applied to improve understanding of the molecular basis of gene regulation and expression as well as sex determination and thereby improve methods for defining species, stocks, and populations. Approaches include developing marker- assisted selection technologies, improving precision and efficiency of transgenic techniques, and improving technologies for the cryo-preservation of gametes and embryos. Ultimately, stocking certain areas with selected, cultivated species and strains could help maintain biodiversity in natural aquatic ecosystems.

7.7. Biotechnology in Food safety and quality assurance

The production of food is subject to constant change, and higher and higher demands are being made on products and the production processes. This development is driven by consumer expectations of food safety, animal welfare and the environment, and progress in biotechnology and genetics. Food safety and quality assurance will be the decisive factors for the processing industry.

- For product safety and quality assurance, the indispensable elements of a concept of sustainable animal production will be future measures for improving food safety before processing and methods for improving quality during primary production.

- As with animal welfare and environmental concerns, these aspects will also play a role in animal production worldwide.

- Efforts to set up programs of quality assurance and product safety at every point in the chain of production should be centered on the development of systems able to meet these goals.

- In order to ultimately attain this goal it is reasonable to formulate a working model, implement and evaluate it and then extend it step by step, in order to determine all parameters necessary to attain an effective system of food safety and quality assurance.

Biotechnology offers effective techniques to address consumer concerns about microbial contamination of foods. Biotechnical methods may be used to decrease the time necessary to detect foodborne pathogens, toxins, and chemical contaminants and to increase detection sensitivity. Enzymes, antibodies, and microorganisms produced using rDNA techniques are being used to monitor food production and processing systems for quality control. Microbial probes, biosensors based on adenosine triphosphate (ATP) content, are being used experimentally as indicators of bacterial contamination. Biosensors to detect animal disease, alterations in product quality, or temperature abuse are under investigation. These developments offer the potential of lowering the cost and improving the safety of the food supply in a timely manner.

7.8. Relevance of biotechnology in livestock, aquaculture and food safety in developing countries

Animal and aquaculture production in developing countries is, to a large extent, low-input and small-scale enterprises. Technologies related to animal health, genetic resources, and utilization of low-quality feed resources have great potentials in such production systems.

A sector with intensive animal production similar to that of industrial countries exist in most developing countries and is crucial for supply of milk, eggs and meat to urban centres. Such production may also be essential for effective utilization of some of the locally produced agro-industrial by-products. These production systems could use and benefit from much of the same technology elements as those considered in industrial countries.

Reproductive biotechnologies
The main objective of biotechnologies in reproduction is to increase reproductive efficiency and rates of animal genetic improvement there by contributing to an increased output from the livestock sector. They also offer potential for greatly extending the multiplication and transport of genetic material and for conserving unique genetic resources in reasonably available forms for possible future use.

Artificial insemination (AI)
AI has already had a major impact on cattle, sheep, goat, pig, turkey and chicken improvement programmes in developed countries by accelerating breeding progress primarily through increased intensity of selection of males and through diffusion of breeding progress, initially with fresh, and later with frozen, semen, offering rapid world-wide transport of male genetic material. Globally, more than a 100 million AIs in cattle, 40 million in pigs, 3.3 million in sheep and 0.5 million in goats are performed annually. Only in very few developing countries is AI practised to a level that impacts substantially livestock production.

Embryo transfer (ET)
ET in the mammalian species, enhanced by multiple ovulation and oestrus synchronisation (MOET), allows acceleration of genetic progress through increased selection intensity of females, and freezing of embryos enables low cost transport of genetic material across continents, and also conservation of diploid genomes. MOET may also be used to produce crossbred replacement females whilst only maintaining a small number of the straightbreds. In 1998, worldwide 440,000 ETs have been recorded in cattle, 17,000 in sheep, 1,200 in goats, and 2,500 in horses. About 80 % of the bulls used in AI in the developed world are derived from ET. Despite the potential benefits of ET, its application is largely limited to developed countries.

ET is also one of the basic technologies for the application of more advanced reproductive biotechnologies such as ovum pick-up (OPU) and in vitro maturation and fertilisation (IVM/IVF), sexing of embryos, cloning, and of transgenics.

OPU and IVM/IVF
OPU in mammals allows the repeated pick-up of immature ova directly from the ovary without any major impact on the donor female and the use of these ova in IVM/IVF programmes. Making much greater use of genetically valuable females at a very early age may substantially increase genetic progress.

Sexing
Technologies for rapid and reliable sexing of embryos allow the generation of only the desired sex at specific points in a genetic improvement programme, markedly reducing the number of animals required and enabling increased genetic progress. Sexing of semen using flow-cytometric sorting has decisively progressed in recent years but still with limited sorting rates, even for IVF. Sexed semen could markedly increase genetic improvement rates and have major implications for end-product commercial production.

Cloning
IVM/IVF are a source of large numbers of low cost embryos required for biotechnologies such as cloning and transgenesis. Three different types of clones are distinguished, as a result of: (1) limited splitting of an embryo (clones are genetically identical); (2) introducing an embryonic cell into an enucleated Zona (clones may differ in their cytoplasmic inheritance);

(3) introducing the nucleus of a somatic cell (milk, blood, dermal cells), after having reversed the DNA quiescence, into an enucleated Zona (clones may differ in their cytoplasmic inheritance and there is likely to already exist substantial knowledge of the phenotype of the parent providing the somatic cell). Cloning will be used to multiply transgenic founder animals. Cloning technologies offer potential as research tools and in areas of very high potential return. The sampling of somatic tissue may assist collection and transfer of breed samples from remote areas for conservation purposes.

Molecular biotechnologies
Various molecular biotechnology applications are available in animal production and health.

DNA technologies and animal health
Animal diseases are a major and increasingly important factor reducing livestock productivity in developing countries. Use of DNA biotechnology in animal health may contribute significantly to improved animal disease control, thereby stimulating both food production and livestock trade.

Diagnostics and epidemiology
Advanced biotechnology-based diagnostic tests make it possible to identify the disease-causing agent(s) and to monitor the impact of disease control programmes, to a degree of diagnostic precision (sub-species, strain, bio-type level) not previously possible. For example, DNA analysis of bovine viral diarrhoea virus (BVDV) has shown to be composed of two genotypes, BVDV1 and BVDV2. Only the latter was found to produce haemorrhagic and acute fatal disease, and diagnostic tests to distinguish between the two are under development. Enzyme-immunoassay (EIA) tests, which have the advantage of being relatively easily automated, have been developed for a wide range of parasites and microbes.

Molecular epidemiology is a fast growing discipline that enables characterization of pathogen isolates (virus, bacteria, parasites) by nucleotide sequencing for the tracing of their origin. This is particularly important for epidemic diseases, where the possibility of pinpointing the source of infection can significantly contribute to improved disease control. Furthermore, the development of genetic probes, which allow the detection of pathogen DNA/RNA (rather than antibodies) in livestock, and the advances in accurate, pen-side diagnostic kits considerably enhance animal health programmes.

Vaccine development
Although vaccines developed using traditional approaches have had a major impact on the control of foot-and-mouth disease, rinderpest and other epidemic and endemic viral, mycoplasmal and bacterial diseases affecting livestock, recombinant vaccines offer various advantages over conventional vaccines. These are safety (no risk of reversion to virulent form, reduced potential for contamination with other pathogens, etc.) and specificity, better stability and, importantly, such vaccines, coupled with the appropriate diagnostic test, allow the distinction between vaccinated and naturally infected animals. The latter characteristic is important in disease control programmes as it enables continued vaccination even when the shift from the control to the eradication stage is contemplated. Recombinant DNA technology also provides new opportunities for the development of vaccines against parasites (e.g. ticks, helminths, etc.) where conventional approaches have failed.

DNA technologies in animal nutrition and growth

Applications are being developed for improving the performance of animals through better nutrition. Enzymes can improve the nutrient availability from feedstuffs, lower feed costs and reduce output of waste into the environment. Prebiotics and probiotics or immune supplements can inhibit pathogenic gut microorganisms or make the animal more resistant to them. Administration of recombinant somatotropin (ST) results in accelerated growth and leaner carcasses in meat animals and increased milk production in dairy cows. Immunomodulation can be used for enhancing the activity of endogenous anabolic hormones.

In poultry nutrition, possibilities include the use of feed enzymes, probiotics, single cell protein, and antibiotic feed additives. The production of tailor-made plant products for use as feeds and free from antinutritional factors through recombinant DNA technology is also a possibility.

DNA technologies in animal genetics and breeding

Most animal characteristics of interest to food and agriculture are determined by the combined interaction of many genes with the environment. The genetic improvement of locally adapted breeds will be important to realising sustainable production systems.

The DNA technologies provide a major opportunity to advance sustainable animal production systems of higher productivity, through their application in:

i). Characterizing and better understanding animal genetic variation.

ii). Manipulating the variation within and between breeds to realise more rapid and better-targeted gains in breeding value.

i) Characterizing genetic variation:

The use of DNA markers (microsatellites) in genetic distancing of breeds is gaining momentum. While most breeds are located in the developing world, this work is confined to developed countries. How is it possible to more effectively involve the developing country breeds? Are the current protocols adequate or what further standardisation is required?

ii) Increasing the speed of genetic improvement of locally adapted breeds

There are many links in the chain to realising rapid genetic progress in the desired goals, with the objective being to rapidly transmit from selected breeding parents to offspring those alleles which contribute to enhanced expression of the traits of interest. In developing countries, generation intervals are generally longer for all animal species of interest than in developing countries. How can DNA technologies be used to reliably realise intense and accurate selection and short generation intervals and to enable genetic improvement of these many locally adapted breeds to contribute to the required livestock development?

There is rapid progress in the preparation of sufficiently dense DNA Marker (microsatellite) linkage maps to assist in the search for genetic traits of economic importance. Can these linkage maps be used to develop strategies of marker-assisted selection (MAS) and marker-assisted introgression (MAI) to meet developing country breeding goals? How should this be approached ? Given the limited financial resources, how might work for the developing country breeding programmes strategically utilise the rapidly accumulating functional genomic information of other species such as humans, mice and drosophila (fruit fly)?

8. Current and emerging modern biotechnologies in cultivated plants

8.1 Introduction

Plant biotechnology includes a range of methods. Cell and tissue culture are used for micro-propagation and disease-cleaning of clonal materials (relevant in banana, most root crops and an increasing number of other species). Various DNA-techniques are used to study biological diversity, identify and sequence genes, and for genetic modification of plants.

Plant breeders are under increasing pressure to provide varieties that yield more and withstand parasites and pests with less need for pesticides and also tolerate other stress factors. To develop the improved varieties that are required to meet such challenges, we need to understand the genetic basis of plant traits that are essential for sustainability, quality, and yield. Genomics[16] offers new tools needed for determining this genetic basis in a rapid and comprehensive manner. The understanding gained from the genomic approach can be applied for more efficient and targeted plant breeding.

We are experiencing a genetic revolution, with a huge body of information that has been rapidly growing since we acknowledged genes as the basis of heredity, the DNA structure was understood, and the genetic code unraveled. Now we are about to understand overall gene and protein activities in micro-organisms, plants, animals and humans.

Transgenic plant varieties are some products of this new knowledge resulting from techniques learned from nature. However, the first GMOs (genetically modified organisms) and GMPs (genetically modified plants) have been received with scepticism and discussion. It is important to spread correct information and to stimulate a sound debate of potential benefits and risks related to the use of such techniques.

With increasing whole genome sequences released, i.e. *Arabidopsis*[17], rice and *Agrobacterium*[18], the access to improved evolutionary and genetic understanding and genes for transformation is vast (Arabidopsis 2000; Goodner et al. 2001; Goff et al. 2002; Yu et al. 2002). Application of **functional genomics** revealing gene regulation and function, improves the possibilities not only for genetic transformation and metabolic engineering, but also for traditional breeding. The release of the rice genome, construction of the first barley microarray, and development of better transformation techniques open new possibilities in generating transgenic cereals. **Microarray** technology allows study of expression of 5-20 000 genes simultaneously, giving research on single genes a wider perspective. Hand in hand with **bioinformatics** to study and understand the sequences, this offers a new dimension and opportunities for research on gene interactions and genomes.

Another challenge not to be ignored is communication with consumers and the public in general. **Bioethics** describes and clarifies some of the gap between the scientific and industrial world developing the new technologies, and the intended users of them.

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[16] Genomics/Functional Genomics: The sequencing and subsequent research on the function of the whole genome – all the genes in an organism.
[17] Arabidopsis is a common weed that is used as a model species in plant biotechnology.
[18] Agrobacterium is a bacterium that can infect and insert foreign genes into plants. It is therefore used as a vector in genetic engineering.

While part of the discrepancy may be lack of knowledge, misinformation and some unidentified scepticism, some is due to a sound fear that possible environmental damage is not acceptably considered and that we still need to do more research in order to understand how the genetic set up works on the whole genome basis. New techniques and access to whole genomes are rapidly adding to our knowledge and understanding of parts of the puzzle, such as sequence utilization, gene regulation and function.

Transgenic plants do not only give agriculture new varieties, they additionally increase our understanding of how plant metabolism is regulated. Transgenic studies have further generated new challenges, by highlighting the enormous flexibility and complexity inherent in plant metabolism (Fernie et al. 2002). Tools like genomics and **proteomics**[19] in cultivated plants address the role of science in meeting global food and health demands, and possibly gain increased positive consumer interest (Leung et al. 2002).

8.2 Cell- & Tissue Culture

Cell and tissue culture is generally considered non-controversial. It does not require expensive equipment and chemicals (fairly simple laboratory facilities with sterile benches and growth incubators). It is therefore easier to establish in developing countries than i.e. transformation techniques. Those techniques are particularly applied for disease cleaning of planting materials (reproduction of tissues that are free of viruses and other pathogens) and for rapid multiplication (micropropagation). This is important in species that are naturally propagated by vegetative means, such as potato, sweet potato, cassava, banana, and many tree crops (oil palm, fruits). However, cell and tissue cultures are also necessary to make use of molecular biology and are therefore often used in combination with other techniques.

8.2.1. Meristem Culture

Meristem culture is used to clean contaminated materials for viruses, by regenerating new materials from meristematic cells free of viral infections.

8.2.2. Anther Culture

Anther culture is used to produce plants having only one genome by generating them directly from pollen. By doubling the genome spontaneously or by chemical treatment (colchicines) homozygote genotypes are obtained in one generation. In conventional plant breeding this is achieved through inbreeding, e.g. self-pollination for seven generations which takes many years. Such homozygotes might be used directly as new varieties or might be crossed to generate hybrids, depending on interests and results. Such material can also be used to place markers on chromosomes and next be used in marker-assisted selection.

8.3 Genetically Modified Plants (GMP)

One major area of importance in modern applied biotechnology is genetically modified organisms (GMO) and genetically modified plants (GMP) in particular. Plants resulting from genetic transformation (GMPs) were grown by 5.5 million farmers on a total of 52.6 million hectares in 2001. Those figures are projected to increase in coming years. More than one forth of this production is in developing countries, having the highest increase in GMP production. Several GMO crops are waiting to be released due to stricter regulations on GMPs, the need

[19] Studies of the whole set of proteins that result from expressed genes.

of more trials for acceptance, or simply the legislations to be in place before possible release of the crops.

8.3.1 Gene Transformation

Transfer of genes by gene technology is called "transformation" and results in "transgenic" or genetically modified organisms (GMOs). Transgenic plants are mainly produced in two ways, by a particle gun (Biorad) or by *Agrobacterium tumefaciens*. *Agrobacterium* naturally infects plants and causes disease by inserting its own DNA into plant cells. In gene technology the bacterium is used to carry selected genes into plants, thus producing genetically modified plants.

The first major GMPs resulted from the use of the particle gun since it could be applied to any species that could be regenerated in tissue culture. However, the equipment is expensive, the integration of the transgene leads to massive rearrangements of DNA-pieces and subsequent gene silencing[20]. *Agrobacterium* is now by large the preferred technique.

8.3.1.1 Particle Gun Transformation

Transforming plants using the particle gun, also called biolistics, initially got a wide adoption since it could be performed in any species that could get through tissue culture. However, the physical forces perhaps combined with the cell's ability to carry out DNA repair, might cause recombinations and ligations (joining) of all the transgene fragments. These rearrangements before incorporation on the chromosomes cause a large degree of gene silencing. However, due to patenting of the *Agrobacterium* transformation technique, some prefer to use the particle gun when transforming for commercial purposes.

8.3.1.2 Agrobacterium transformation

Researchers continue to seek ways to bio-engineer plants using *Agrobacterium* for societal (non-commercial) benefit. In nature *Agrobacterium* depends on the transfer of selected genes into plant cells. This natural process is used to make this plant pathogen transfer genes that are pre-selected and engineered in the laboratories (Chilton et al. 1977; Binns 2002). The completed genomic sequencing of *Agrobacterium tumefaciens* can provide knowledge of the evolution of plant-microbe interactions and help utilize *Agrobacterium* even better in plant transformation (Goodner et al. 2001). *Agrobacterium* is by large the preferred method of transformation due to fewer rearrangements of the introduced genes, less silencing and lower copy numbers introduced (Jones et al. 1999). In the beginning *Agrobacterium* could be used only on broad-leaved plants, but strains that can infect also cereal species are discovered. Therefore transformation is about to be efficiently developed also for cereals, with rice having highly promising responses (Phillipe Vain, personal communication), maize having acceptable frequencies in specialized laboratories, and wheat and barley might be getting there. The remaining challenges are control of integrated copy numbers, localization of introduced transgenes, avoiding transgene silencing and removal of selectable marker genes. These challenges might be solved mastering homologous recombination in plants (Kumar and Matthias 2001). After choosing the preferred location of transgene integration, the transgene construct is flanked by a stretch of DNA sequence homologous to the chromosomal localization of the species to be transformed. This is called **precision biotechnology** and may meet some of the critique of transgenic plants, since unwanted genes efficiently could be removed and the transformation using the genes of interest would be more predictable and give reproducible results. Also having the genes in the same place, should give clear results as

[20] Gene regulation includes mechanisms that turn genes on and off according to the needs for the encoded protein. A silenced gene is permanently turned off.

to how the introduced genes work in the new genetic environment and genome. However, the different nature of plant genomes compared to animal genomes might cause homologous recombination difficult to achieve. Large genome sizes, repetitive DNA and short time for recombination (plants with short cell cycles to adapt to changing environments) might cause homologous recombination frequencies to be very low for huge plant genomes like wheat and maize particularly.

8.3.1.3 Global Results from GMP

8.3.1.3.1 Global overview of GMP production 1995-2001[21]

Table 3. Global Area of Transgenic Crops in 2000 and 2001: by Country (million of hectares)

	2000	%	2001	%	+/-	%
USA	30.3	68	35.7	68	+5.4	+18
Argentina	10.0	23	11.8	22	+1.8	+18
Canada	3.0	7	3.2	6	+0.2	+6
China	0.5	1	1.5	3	+1.0	+200
South Africa	0.2	<1	0.2	<1	<0.1	+33
Australia	0.2	<1	0.2	<1	<0.1	+37
Mexico	<0.1	<1	<0.1	<1	<0.1	--
Bulgaria	<0.1	<1	<0.1	<1	<0.1	--
Uruguay	<0.1	<1	<0.1	<1	<0.1	--
Romania	<0.1	<1	<0.1	<1	<0.1	--
Spain	<0.1	<1	<0.1	<1	<0.1	--
Indonesia	--	--	<0.1	<1	<0.1	--
Germany	<0.1	<1	<0.1	<1	<0.1	--
France	<0.1	<1	--	--	--	--
Total	**44.2**	**100**	**52.6**	**100**	**+8.4**	**+19%**

Source: Clive James, 2001.

8..3.1.3.2 Results from GMP: Bt Cotton

Cotton is more troubled by insect pests and more subjected to pesticide spraying than any other crop. Varieties that resist certain insect pests have been developed by genetic modification using genes from the soil bacterium *Bacillus thuringiensis* (Bt). Such varieties are called Bt cotton. This might be the GMP with the largest impact so far. The popularity with farmers is due to the reduced need of pesticides. This kind of transgenic seeds are also easy to introduce in developing countries since a whole package (seeds + inputs) is not needed to gain maximum benefit from the new variety.

[21] **(ISAAA:** http://www.isaaa.org/)

Cotton-seed oil is an edible by-product of cotton production. The use of the oil may face more problems of consumer acceptance than the use of fibres for spinning. Australia has found uses of the oil, even though the consumers have stopped the oil used in the burger chains.

8.3.1.3.3 Another Result from GMP: Golden Rice

Golden rice is one example of potentially successful applications of transgenic breeding in collaborations between public and private interests (Potrykus 2001). The ability to produce provitamin A, controlled by an endosperm specific promoter (ensures that the genes are activated only in the seed) is introduced to rice by genetic transformation.

This may trigger a new generation of transgenic breeding, where the interest of consumers and environment is met with better success than was the case for the first transgenic crops released. Ingo Potrykus (Zurich/ETH) gave a presentation of the development of the Golden Rice on the EPSO (European Plant Science Organisation) meeting in Switzerland 27-31 Oct. 2002. The new variety could have been released to the areas with A-vitamin deficiencies in 1999, but since there are other regulations for GMPs than for traditionally bred varieties it will not be on the market until 2006 at the earliest. Ingo Potrykus is retired, but the work is continued at the ETH. The golden rice project is heavily funded by Rockefeller Foundation[22]. Transformed rice strains are handed over to public sector breeding institutes that develop vitamin A enriched varieties for the target areas.

In the public debate Botrykis stresses that the golden rice is a philanthropic project that is designed to benefit poor people. It has not been developed by or for the industry and the industry will not benefit from it. It offers a sustainable, cost-free solution to the problem of vitamin A deficiency that does not require any other resources[23]. However, the project is met with opposition from groups that see this as a Trojan Horse that will pave the way for general acceptance of GMOs and eventually create dependence on technology and seeds that are owned and controlled by foreign industries. These groups suggest crop and diet diversification as a more natural and sustainable solution to the problem of deficiency of vitamin A.

8.4 Genetic Regulation and Resistance Breeding

Increased understanding of plant-pathogen interaction helps improve the development of better plant fitness and plant production, with more efficient and targeted resistance breeding. Genomics and proteomics open for more basic research to address plant-pathogen interactions (Xing et al. 2002).

Choosing the promoters[24] controlling the transgene is of major importance as to when and where the gene is to be expressed, and at what level. Applying such genetic control, resistance genes could be expressed only in the cells needing them and only when necessary, ideally only when triggered by the environment. Expression of resistance genes in i.e. pollen

[22] www.rockfound.org

[23] Potrykus, I. 2001. Golden Rice and beyond. *Plant Physiol.* 125: 1157-1161

[24] The promoter is the "start button" that determines when and where a gene is to be turned on (being expressed) or off.

should be avoided, since it is an unnecessary spread of transgenic products and basically only wasted energy.

Resistance breeding means searching for new ways of reducing plant diseases, cutting losses and improving agricultural output. These weapons involve strategies from high-tech genetic engineering to techniques to activate the plants' own defence mechanisms, to rather low-tech cultivation strategies to disturb plant-pest interactions (Moffat 2001a). Genetic engineering has offered new tools that, together with strategies of Integrated Pest Management, could help staying ahead of rapidly evolving pests. Plant 'vaccination' activating the plant's own defence by exposing it to the pathogens protein is an appealing strategy. Work concerning transgenic silencing with the use of pathogen vectors, are further nice examples of excellent basic science with implications to resistance breeding (Angell and Baulcombe 1999; Baulcombe 2001; Vance and Vaucheret 2001). Two plant disease resistance genes, RPW8.1 and RPW8 using the same mechanisms as specific resistance, cause broad-spectrum mildew resistance in *Arabidopsis* (Xiao et al. 2001). We can expect to get a number of such genes available in the time to come.

8.5 Transgenic Plants as Bioreactors to Produce i.e. Medical Compounds

There are many laboratories working with molecular farming, were the goal is to produce pharmaceutical compounds in plants (Daniell et al. 2001). Such compounds can be recombinant antibodies (rAb) against i.e. caries or tumours. These compounds can be extracted from the plant parts producing them and added to toothpaste or incorporated in pills, or be taken directly as oral vaccination. The latter has been suggested for developing countries to avoid the use of syringes, strict control around controlling the medication and cheaper storage as in for instance seeds. Banana is a species with great potential for oral vaccination.

8.6 Transgenic Plants to Clean Polluted Land (Phytoremediation)

Water pollution from mercury (from gold mining) is a problem in India, Bangladesh and the Amazons, poisoning the drinking water. Transgenic plants can be used to convert mercury to less poisoning substances to improve the uses of such water (Pilon-Smits and Pilon 2000; Kramer and Chardonnens 2001). Arsenic is another environmental compound that can be less toxic by incorporating it in plants (Fitz and Wenzel 2002; Ruiz and Romero 2002).

8.7 Plant Products as Fuel

Biofuel is another use of plants. Such fuels can be burned and used as heating. Some petrol companies sell plant oils as fuel in competition with fossil fuels/oil. Shell has decided not to use eatable plant products like valuable oils as fuel, but find the exploitation of wastes of other plant productions of interest.

8.8 Hybrid Seed Production & Apomixis

Hybrid varieties have been developed for certain crops, due to the assumed increase in productivity from hybrid vigour and increased uniformity. New pollination systems have been developed applying genetic engineering generating nuclear-encoded male sterility (Goetz et al. 2001). Large-scale hybrid seed production based on these systems depends on efficient

propagation of the male-sterile female parent line, representing the limiting factor for large-scale hybrid seed production for many crops (Perez-Prat and van Lookeren Campagne 2002).

Understanding the genetic mechanism of self-incompatibility in *Brassica*[25], is additionally one of the first receptor-ligand interactions detected in plants, demonstrating how close basic and applied molecular biology might be (Kachroo et al. 2001; Takayama et al. 2001; Franklin-Tong 2002). Understanding gene regulation and function is essential to apply new genetic understanding in producing transgenics for plant breeding, i.e. floral development and regulatory genes (Radicella et al. 1992; Sablowski and Meyerowitz 1998).

Apomixis is another potential solution to achieve large-scale uniform plant production, involving seed production without fertilization and unwanted spread of genes (Chaudhury and Berger 2001; Grimanelli et al. 2001; Moffat 2001b).

8.9 Microarrays & Bioinformatics

Comprehensive transcription profiling moves the earlier single gene studies to the level of the entire genome. Using microarray technology and DNA chips with up to 20 000 EST/Genes[26] spotted, differences in transcript concentration can be studied in one hybridising experiment. Such studies demand expensive equipment and can be source of large errors if not performed accurately and interpretated with caution. Statistics is crucial and the joint efforts of several scientific fields in order to succeed and gain increased significant biological understanding. Microarray hybridisation is promising in order to achieve general understanding of gene utilization, regulation and function.

When the transcription profiling is achieved, the next challenge is extracting accurate biological and genetic information from the accumulated data of genes expressed and the differences in expression levels. There are concerns as to whether the microarray studies are yet correctly performed and answers the genetic questions raised, or if there is still some way to go before the technology is adequately developed and the bioinformatics tools are sophisticated enough to deal with the enormous genetic flexibility in nature. The data from microarray hybridisation experiments are analysed with adapted software and increasingly improved bioinformatics (Pan 2002), however the statistical approaches to these experiments are not yet as routine as they are in other sciences (Nadon and Shoemaker 2002).

Transcription profiling is the most complete technique in order to get a total overview and understanding of whole organism genetic activity. Additional studies at the protein level are necessary in order to extract the functional transcripts and genes, and their corresponding functions. This because of errors producing inaccurate transcripts, and more importantly the many levels of post-transcriptional regulation before the final functional gene products are synthesised.

Protein studies are more complex and so far less developed, partly because the variation is vast compare to the variation caused by the four nucleotides at the DNA and RNA level. Monoclonal antibodies (mAb) might be one solution, with the corresponding mAb-libraries and identification by phage-display (Nord et al. 2001). There is a considerable effort to develop reporterligands, but it is still a gap before protein-arrays get close to DNA-arrays

[25] Brassica: A number of cultivate species including cabbage, kales, and rapeseed. They are pollinated by insects and normally do not produce seeds if they are self-pollinated (self-incompatible).
[26] EST: Expressed Sequence Tag. Such sequences can be used as a "bar code" to recognise genes.

concerning expression detection of many proteins simultaneously. Proteome[27] arrays and functional organization of the proteome is developing (Zhu et al. 2001; Gavin et al. 2002).

Bioinformatics is a new scientific field of crucial importance in order to extract and explore the huge body of information coming from the increasing number of genome sequencing projects with the release of the first plant genome Arabidopsis in 2000, the human genome in 2001, and the rice genome in 2002 and microarray hybridisation. Large parts of the world are investing major recourses to build up competence in this field where the US is still regarded as world leading, but Europe isn't too far behind and parts of Asia might be having the fastest growing number of people being put into this field.

[27] The entire set of expressed proteins.

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