The Potential Impact of Biotechnology on the Global Livestock Sector

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Summary
Human population growth, increasing urbanisation and rising incomes are driving a vigorous increase in demand for food of animal origin in developing countries. Globally, livestock production is growing faster than any other agricultural sector. In view of its substantial dynamics, this process has been referred to as the ‘Livestock Revolution’. Important features of this process are: a rapid increase in consumption of livestock products in developing countries with, e.g. per caput meat consumption in the developing world expected to double between 1993 and 2020; a shift of livestock production from temperate and dry areas to warmer and more humid environments; a change to market-oriented production; more large-scale, industrial production units located close to urban centres; decreasing importance of ruminant vis-à-vis monogastric livestock species; and a rapid rise in the use of cereal-based feeds.

Agricultural biotechnology has long been a source of innovation in production and processing profoundly impacting the livestock sector; however, this impact has been and continues to be primarily notable on the animal agriculture in developed countries, while the adoption even of early generation biotechnology in the livestock sector of developing countries tends to be far lower. However, with the market demand for food of animal origin dynamically growing in many developing countries, there will be a commercial, often industrial livestock subsector emerging in many of these countries. This subsector is likely to more readily pick up modern biotechnology options than the traditional small-scale subsector. The existing dichotomy between the modern and traditional subsectors will thus be exacerbated. The impact of biotechnology on the animal sector will also vary substantially from region to region.

Concerns about the potential risks posed by certain aspects of biotechnology are increasingly expressed worldwide. These risks refer to the effects on human and animal health and on the socio-economic and bio-physical environment. It appears prudent to adopt a cautious and science-based case-by-case approach when assessing the risks of the new products and processes before their release.

I. Development Trends in the Global Livestock Sector
Urbanization, population and income growth are fuelling a massive demand increase for food of animal origin in developing countries – this process has been termed ‘Livestock Revolution’ in a recent study (Delgado et al., 1999). The predicted increases in meat consumption for the period 1993 to 2020 are very substantial (Table 1), though with large regional variability.

Consumer demand for food of animal origin starts from a low base in most developing countries, with an average annual per caput consumption of around 40 kg and 20 kg of milk and meat respectively, which is equivalent to approximately one quarter of the per caput consumption in developed countries. The impact which increased intake of food of animal
origin has on the consumers' health under these circumstances is considerable (micronutrients, amino-acids), particularly in children and mothers.

Table 1 Actual and projected per caput meat and milk consumption by region

<table>
<thead>
<tr>
<th>Region</th>
<th>Meat</th>
<th>Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1993 (kg/year)</td>
<td>2020 (kg/year)</td>
</tr>
<tr>
<td>China</td>
<td>33</td>
<td>60</td>
</tr>
<tr>
<td>Other East Asia</td>
<td>44</td>
<td>67</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Other South Asia</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>Latin America</td>
<td>46</td>
<td>59</td>
</tr>
<tr>
<td>West Asia/North Africa</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Developing World</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td>Developed World</td>
<td>76</td>
<td>83</td>
</tr>
<tr>
<td>World</td>
<td>34</td>
<td>39</td>
</tr>
</tbody>
</table>

Source: Delgado et al., 1999

It is almost entirely the developing country consumers who drive the strong and sustained global expansion of the demand for food of animal origin (FAO, 2000). Given the strategic importance of food supplies and the economic importance of the agricultural sector in most developing countries, a considerable degree of self-sufficiency is generally a significant national policy goal. Thus, growth rates for livestock production have generally followed those for consumption quite closely in most regions and overall only a small proportion of the world’s supply of livestock products (e.g. 3% of bovine meat) is traded internationally.

In the past, the majority of the increases in livestock production in developing countries have been achieved by expanding livestock populations and by switching systems rather than by productivity increases within production system. This is no longer the case in many developing countries where strong consumer demand drives a decisive transformation and intensification of the livestock sector. Monogastric animals, i.e. pigs and particular poultry, are the most important source of growth with increasing adoption of industrial forms of production with substantial reliance on grain feeding. Average annual growth in cereal feed use across all developing countries has been 4.2% for the period 1982-94, with Southeast Asia leading with 7.2% annual growth (Delgado et al., 1999). It is estimated that the increase in livestock production in developing countries will require annual feed consumption of cereals to rise by 292 million metric tons between 1993 and 2020 (2.8% per year).

Despite concerns that such large increases in demand for cereals as animal feed will substantially raise cereal prices, inflation-adjusted prices of feed and livestock commodities are expected to fall by 2020. Even with increases in livestock productivity far below historical trends, predictions are that enough livestock products will be available in 2020 without prices rising above 1992-94 levels. The key issue, therefore, is not primarily the availability of livestock products, but access to the products by the consumer and the effect of the ‘Livestock Revolution’ on small-scale producers, the environment and human health.
II. Potential Contributions of Biotechnology to the Livestock Revolution

In livestock production, mechanical, biological and chemical innovations have reduced labour requirements, increased yields and contained the impact of livestock diseases to such an extent that despite the vast increases in demand for livestock products, real prices for meat and milk have fallen by approximately a third between the early 1980s and 1990s. Modern agricultural biotechnology is another source of innovations that will reshape agriculture as profoundly as any of the previous fields of technological innovation.

The application of modern genetic technologies in livestock such as genome mapping, marker-assisted selection, transgenesis, has lagged behind its application in the plant sector. While genetically modified livestock, in contrast to genetically modified crops, are not likely to play a major role in developing countries in the near future, considerable potential exists for the application of biotechnologies in the use of bio-engineered inputs covering the entire food production chain from animal feed to product processing, importantly also including animal health.

**Reproductive Biotechnologies**

The analysis of the use of animal reproductive biotechnologies, both well-established, early generation options and more recent, advanced options highlights a considerable North-South divide which deserves attention in research and development:

**Artificial Insemination** (AI) has had a major impact on cattle, sheep, goat, pig, turkey and chicken improvement programmes of 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 100 million artificial inseminations in cattle, 40 million in pigs, 3.3 million in sheep and 0.5 million in goats are performed annually (Wagner and Thibier, in press; Thibier and Wagner, in press). Only in few developing countries, notably in Asia (China, India), is AI practised to a level that impacts substantially national livestock production (Table 2).

**Table 2** Overall Use of Artificial Insemination in Cattle and Buffaloes

<table>
<thead>
<tr>
<th>Regions</th>
<th>Total Females of Breeding Age (40% of Total Cattle and Buffaloes, in thousands)</th>
<th>Total First Service AI (thousands)</th>
<th>% Inseminated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>69,121</td>
<td>870</td>
<td>1.3</td>
</tr>
<tr>
<td>North America</td>
<td>45,206</td>
<td>11,204</td>
<td>24.7</td>
</tr>
<tr>
<td>South America</td>
<td>140,755</td>
<td>1,366</td>
<td>1.0</td>
</tr>
<tr>
<td>Far East</td>
<td>240,860</td>
<td>58,181</td>
<td>24.2</td>
</tr>
<tr>
<td>Near East</td>
<td>32,600</td>
<td>1,069</td>
<td>3.1</td>
</tr>
<tr>
<td>Europe</td>
<td>67,628</td>
<td>33,873</td>
<td>50.1</td>
</tr>
<tr>
<td>Total</td>
<td>596,172</td>
<td>106,564</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Thibier and Wagner, in press*

Embryo transfer (ET) in the domestic mammalian species, enhanced by multiple ovulation and oestrus synchronisation (MOET), allows the 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 while only maintaining a small number of 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 with more than 75% of these transactions in North America and Europe (IETS, 1999). About 80% of the bulls used in AI are derived from ET (Thibier, pers. comm.). Despite the obvious benefits of ET, its application is thus 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 semen and embryos, cloning, and of transgenesis. These technologies appear to be limited to laboratories in developed countries.

The sampling of somatic tissue may assist collection and transfer of breed samples from remote areas for conservation purposes. Once broadly feasible and viable, somatic cloning will enable regeneration of rare and/or endangered domestic animal resources. Given that the developing countries harbour the bulk of the world's domestic animal biodiversity, this technology appears to have particular relevance for this region.

**Molecular Biotechnologies**

A vast array of molecular biotechnology applications are available and emerging in animal production and health involving both on-farm production and off-farm product processing applications. As animal production intensifies and as it increasingly moves into warmer and more humid ecologies, animal diseases are an 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.

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. Enzyme-immunoassay (EIA) tests, which have the advantage of being relatively easily automated, have been developed for a wide range of parasites and microbes. The relevance of these diagnostic tests to the livestock industry in developing countries is obvious, their accessibility and utilization, however, is lagging far behind the ones in developed countries.

Molecular epidemiology is a fast growing discipline that enables characterisation 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 to pinpoint 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.

Although vaccines developed using traditional approaches have had a major impact on the control of many 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.

As certain parts of livestock production vigorously expand, intensify and industrialize, especially in the poultry sector, economics (high reproduction rates, advanced vertical integration, large numbers of short-lived individuals) may favour the use of transgenic animals rather than the treatment or diagnostics on individuals. Consumer acceptance and ethical considerations will be decisive in the use of such technologies worldwide.

Biotechnology 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 anti-nutritional factors through recombinant DNA technology is also a possibility.

The inclusion of genetically modified organisms in animal feeds raises issues of risk, e.g. of the transfer of foreign genes introduced into GM (genetically modified) feed grain crops, especially antibiotic resistance marker genes, to bacteria, which might render common infectious diseases untreatable. The main conclusion of research to-date (Ryan and Mae-Wan, 2000) is that DNA is not degraded under most commercial processing conditions, nor in silage, and that therefore further studies on GM use in animal feeding would be indicated. Potential feed safety problems related to the use of antibiotic marker genes may be avoidable through the use of alternative transgenic systems which are now becoming available.

Plant biotechnology may produce forages with improved nutritional value or incorporate vaccines or antibodies into feeds that may protect animals against diseases. Rumen biotechnology has the potential to improve the nutritive value of ruminant feedstuffs that are fibrous, low in nitrogen and of limited nutritional value for other animal species. Biotechnology can alter the amount and availability of carbohydrate and protein in plants as well as the rate and extent of fermentation and metabolism of these nutrients in the rumen. The potential applications of biotechnology to rumen microorganisms are many but technical difficulties are limiting its progress.

The use of 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. Its application to concerted animal genetic resources utilization and conservation programmes is a major objective of the Global Strategy for the Management of Farm Animal Genetic Resources which FAO has been mandated to implement.

There is rapid progress in the preparation of sufficiently dense microsatellite linkage maps to assist in the search for genetic traits of economic importance. These linkage maps can be used to develop strategies of marker assisted selection (MAS) and marker assisted introgression.
Potential Impact of Biotechnology on the Global Livestock Sector

Transgenesis technologies in domestic animals offer considerable opportunities in the areas of increasing productivity, product quality and even adaptive fitness. Transgenesis technology is currently very costly and inefficient and applications in the near future seem to be limited to the production of transgenic animals as bio-reactors. Consumer acceptance and ethical considerations may reduce considerably the scope of this technology for some time, and rigorous risk evaluation will be required increasingly as all societies adopt precautionary approaches on all technologies, procedures and systems affecting humans.

A large number of biotechnology applications are available and coming on-stream in the areas of modification of product quality; reduced contamination and perishability; mitigation of environmental impact of livestock production; and new products (‘pharming’). Transgenic animals are increasingly designed for a number of non-food purposes, including medical research, the production of pharmaceutical products in milk and the production of organs for transplantation to humans. The livestock production sector is unlikely to be involved to a considerable degree in the ‘pharming’ business, which is estimated to require less than 400,000 animals (Wall, 1996; Cunningham, 1999).

Biotechnology thus offers considerable potential for improvements in agro-industrial processing, particularly for more environmentally friendly or energy-efficient processes. While such technologies are not likely to be accessible to traditional animal agriculture and post-harvest product treatment, they will be accessible to a considerable degree to the emerging commercial and industrial sector in many developing countries. The dichotomy between the small-scale producers and the emerging commercial, large-scale livestock industry is thus likely to determine the further development of the livestock sector in many developing countries. The commercial subsector is far more likely to use and benefit from the up-market technology options than the small-scale subsector.

There are, however, substantial region-specific issues to consider:

Global market forces strongly impinge on the development of animal agriculture in Asia. In the coming two decades there will be an explosive growth of industrial poultry production throughout Asia. China will modernise and expand pork, poultry and red meat production while India will concentrate on dairy and poultry development, introducing novel technologies and economies of scale. Aggregation of large scale bio-protein production in densely populated areas will pose very considerable environmental, health and safety problems.

The main livestock product in South Asia is milk from cattle and buffalo, the majority being kept in small units in mixed, irrigated farming systems, with crop by-products being the main source of feed. Major prospects for productivity increases in the region therefore would stem from enhancing nutritive value and feed conversion efficiency of poor quality feeds to enhance milk production. Technological capacity in South Asia is available to drive biotechnology research and development in this area of very high potential return.

Poultry and pork constitute the bulk of livestock products produced in East Asia with highest growth rates recorded for poultry. Vertical integration and industrialisation of both the pig and poultry sector are not as far advanced as in other regions (e.g. Latin America) with more than
60% of the pigs and poultry currently still kept by small-scale producers. The control and efficient management of epidemic and endemic diseases of pigs and poultry is a prerequisite for integration of small-scale producers into the production chain by large-scale finishers and processors; these are presumably the entry points for biotechnology applications with the highest potential returns.

With land relatively abundant and with an expanding feed resource base, Latin America will significantly step up production, productivity and exports of livestock products. Of particular importance is thereby the careful use of less exploitative forms of livestock production. Latin America holds a large share of the world’s bio-diversity, which is being threatened by habitat loss, partially driven by land lost to livestock operations. Markets are being liberalized and related infrastructure developed, forming the prerequisite for export-oriented production and processing and for the utilization of biotechnology options as they become commercially available. The region will benefit from genetic gain, mainly for feed conversion efficiency, enhanced by biotechnology interventions. This is expected to happen particularly rapidly in species with short generation intervals - poultry, pigs (and potentially small ruminants). Improvements are likely to be rapidly taken on board in South America, where the industrialisation of the sector is much advanced with technical coefficients of production, e.g. in poultry being close to those achieved in developed countries. Reduction and transformation of livestock waste is another area, where biotechnology is likely to offer major benefits.

Poverty, diseases and agricultural pest problems prevail at a continental scale in Africa. Animal agriculture is largely traditional, with modern commercial operations developing at different scales and intensities depending on specific local circumstances. Over the past decades there have been significant increases in the volume of small ruminant production, particularly goats, but low productivity levels persist. Livestock production is much complicated by the prevalence of diseases. Commercial beef ranching exists in some places and also modern poultry and dairy develops mainly around urban centres. There is potential for significant development of both crop and livestock production provided favourable policy frameworks are put in place.

In sub-Saharan Africa (SSA) diseases are estimated to cause losses of between 20 and 25% of the livestock sector output. Although monogastrics are growing in importance, in 2015 they are expected to only contribute around 25% of meat production, most meat coming from grassland and mixed rainfed systems. For SSA, therefore, utilization of biotechnology appears to offer most prospects in the field of the control of major diseases and parasites of ruminants to support intensification of production. SSA has very limited capacities for biotechnology generation, adaptation and extension, however. Without substantial public and international investment in these areas, the productivity and technology gap with other regions will further increase and small-scale livestock producers will benefit little from modern biotechnology.

In West Asia and North Africa the situation for poultry, the main growth sector in the region, is similar to that in Latin America. However, climate being harsher in most of the region, breeding poultry for better heat tolerance and tolerance to other environmental stressors may bring additional advantages. For small ruminants, the situation appears similar to SSA, with enhanced disease control probably offering the most immediate returns. Biotechnology inputs in support of these areas may thus primarily be forthcoming.
III. Risks and Ethical Concerns, Policy Considerations

There are substantial public concerns expressed on potential negative consequences of biotechnology in general and on genetic engineering products and processes in particular on human and animal health, and on the socio-economic and the bio-physical environment. These concerns also relate to ethical dimensions of the relationship of mankind with nature.

Most of the biotechnology R&D activities (>80%; Persley and Lantin, 2000) are conducted by large private companies for commercial exploitation and are designed to meet the requirements of developed markets. They are thus unlikely to be very suitable for the conditions of small-scale farmers in tropical regions of the world and this may lead to increasing inequality of income and wealth within countries (large vs. small farmers) and between countries (developed vs. developing). Legal registration requirements can serve as barriers to commercial product introduction, giving relative advantage to large, mostly international corporations that have sufficient institutional infrastructure and financial resources to meet intensive registration requirements.

The gap between the industrialised and developing countries in technical expertise and relevant research capacity is becoming wider and contributing to brain drain in the profession. Out of 152 laboratories involved in veterinary biotechnology in 1991, only 26 were located in developing countries (Rege 1996).

With the establishment of WTO in 1995 members are bound by the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS), stipulating the granting of patents for inventions in all fields of technology. Most processes and many products of biotechnology are patentable. Increasingly, public concerns about animal welfare when applying biotechnology, and about ownership of genetic material, particularly with respect to patents on life, and general misgivings about ‘tampering’ with nature, require politically and culturally careful procedures of analysis, evaluation, information and arbitration.

In 1991 the FAO Council endorsed a request from the Commission on Plant Genetic resources to draft a Code of Conduct for Biotechnology as It Affects the Conservation and Use of Plant Genetic Resources. The further development of the code was decided to be stalled, pending the revision of the Undertaking on Plant Genetic Resources expected to be concluded in late 2000. In the interim, FAO has prepared a statement on biotechnology in general where the Organisation states its support of a science-based evaluation system that would objectively determine benefits and risks of each individual genetically modified organism or process; this statement implies a call for a cautious case-by-case approach to address legitimate concerns for the biosafety of each product or process prior to its release. FAO thus supports the general application of the increasingly accepted precautionary principle in assessing biotechnological products and processes. Careful monitoring of the post-release effects of these products and processes is also considered essential to ensure their continued safety to human beings, animals and the environment. The Codex Alimentarius Committee (CAC) is considering the development of a standard which would apply basic food safety and control disciplines to foods derived through biotechnology.

Agricultural problems are multidisciplinary in their nature and biotechnology in isolation is unlikely to solve them. Agricultural technology is only one tool in addressing poverty and food security. Ultimately the reduction of poverty and associated malnutrition and hunger requires political solutions. Technology application by developing country farmers is often hampered by limited access to delivery systems, extension services, productive resources and
markets as well as by poorly developed rural infrastructure. Biotechnology is no ‘quick fix’ for the infrastructural, political and institutional constraints in many developing countries and policies that facilitate the incorporation of smallholders into commercial production are required. This implies the revision of policies that tend to favour large-scale, industrial livestock production through artificial economies of scale and externalization of negative environmental impacts. Linking small-scale producers vertically with larger-scale marketers and processors would combine the environmental and poverty-alleviation benefits of small-scale livestock production with the economies of scale that derive from larger-scale processing. Regulatory systems compatible with international best practices to ensure compliance with agreed bio-safety standards are required for consumer protection.

References

Cunningham, E.P., 1999. Recent developments in biotechnology as they relate to animal genetic resources for food and agriculture. Background Study Paper No. 10. Commission on Genetic Resources for Food and Agriculture, FAO, Rome


