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Perspectives

Biotechnology in livestock production: Overview of possibilities for Africa

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Livestock production is expected to grow tremendously in line with the projected demand for animal products. Therefore, the methods of livestock production must change to allow for efficiency and improvement in productivity. Biotechnology is important if the world is to respond to the pressure to produce more food from animals for the ever-growing human population. In general, biotechnology in livestock production can be categorised as the biological, chemical and physical techniques that influence animal health (survival), nutrition, breeding and reproduction. These techniques have been applied mostly in developed countries but their application in Africa is minimal due to reasons related to economic growth such as poor infrastructure, technical and educational capacity. However, Africa can still benefit from tailor-made technologies that simplify complex techniques into applicable form through strategic packaging. Public concerns on food safety, environment and ethics are issues that cannot be ignored.

Key words: Livestock production, biotechnology, Africa.

INTRODUCTION

Livestock and crops have received a lot of attention in the recent past following the success of the Green Revolution of the 1970s, which resulted in a sustained production of sufficient grain to meet global needs. However, currently livestock researchers have a special responsibility as all indicators reveal that the next food revolution will be a “Livestock Revolution” (Delgado et al., 1999). The world’s population is expected to grow to 7.5 billion people in 2020 with most of this growth occurring in developing countries (IFPRI, 2001). As a result, demand for animal products is expected to grow tremendously (Bradford, 1999). In view of this, the methods of livestock production must change to allow for efficiency and improvement in productivity.

Biotechnology (*Biotech*) is increasingly becoming a sustainable means of improving livestock production by directly influencing animal health, nutrition, reproduction, breeding and genetics (Bonneau and Laarveld, 1999). Biotechnology is simply the application of in-genuine biological principles in manipulating living organisms or their derivatives to either improve or multiply a product. The main impediment to the successful application of *biotech* relates to the cost of adoption and acceptability. This paper reviews *biotechs* in livestock production citing practical examples while focussing on possibilities for application in Africa.

OVERVIEW OF BIOTECHNOLOGIES

Livestock production is multifaceted requiring that animals be nursed, fed and bred in a sustainable manner to enable consistency in food production. In pre-industrialisation agriculture, production depended entirely on natural soil fertility and climatic conditions. However, the European industrial revolution in the 17th century that spread all over the world brought in new technologies for improving crop and animal agriculture (Bellaver and Bellaver, 1999). In this respect, industrialised countries are leading in the application of relevant *biotechs* probably because of the involvement of multinational

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agro-based companies that finance their development. Nonetheless, it is still widely believed that the major market for *biotechs* lies in developing countries where food security is an urgent priority (IFPRI, 2001; Bellaver and Bellaver, 1999; Bradford, 1999). It is rather difficult to rank the most urgent area of focus with respect to animal production in developing countries. However, nutrition, breeding and health have been cited as key areas that if improved will result in large scale economic impact (Cunningham, 1990; Doyle and Spradbrow, 1990). In general, *biotechs* in animal agriculture can be categorised as the biological, chemical and physical techniques that influence animal health (survival), nutrition, breeding, and reproduction.

Biotechnology in animal health and survival

The *biotechs* in animal health have been developed in a number of areas that include transgenesis, disease prevention, diagnosis, treatment and control (Bonneau and Laarveld, 1999; McKeever and Rege, 1999). Disease prevention is probably the most active faculty in animal heath technologies that has resulted in the development of vaccines. Although other methods of disease prevention and control such as vector control and quarantine are widely applied, vaccination still remains comparatively a sustainable means of providing health since the cost implication of vector control and quarantine is a limiting factor. In most cases, disease management requires the application of a combination of control measures.

The vaccines that are widely used are either attenuated or inactivated and have proved very efficient in establishing resistance. However, the main limitation with live attenuated vaccines is their stability, possibility of recombination with wild strains and the difficulty in differentiating vaccinated animals from their infected counterparts. In response, sub-unit vaccines developed under recombinant technology producing pure protective antigens for formulation with adjuvant (Doel et al., 1990; McKeever and Rege, 1999), pathogen attenuation by gene deletion (Brochier et al., 1991) and vectored vaccines (McGhee et al., 1992) have been developed to circumvent the limitations of traditional attenuated vaccines. Although vaccine vectoring has mostly been focused on viruses, an attenuated suicide bacteria has recently been constructed to deliver foreign antigen to microphages (Dietrich et al., 1998)

Disease diagnosis has also benefited from the application of *biotechs* to enhance speedy identification of disease at early stages to facilitate treatment. Earlier diagnostics relied heavily on specific antibody detection to yield information on sero-prevalence. Advances in *biotech* has enabled the application of enzyme-linked immunosorbent assay (ELISA) which now uses recombinant antigens - developed via gene cloning and sequencing – for detection of antibodies and provide information on responses to single epitopes or antibody recognition sites (van Vliet et al., 1996). Diagnostic tools have greatly been enhanced by the development of basic DNA detection techniques, the most significant of which arose from the development of polymerase chain reaction (PCR) methodology (Mullis et al., 1992). Antibody (monoclonal and polyclonal) and DNA/RNA probes are largely considered to offer efficient means of improving disease detection tests (Jackwood, 1994; Zarlenga, 1994). DNA-based disease diagnosis techniques have potential for development even though they are limited in their ability to detect previous exposure to infection and immune status (McKeever and Rege, 1999).

Treatment of animal diseases has for a long time been based on antibiotics extracted from various bacteria and fungi, however, other molecules extracted from the Ivermectine family have proved efficient in disease control (Bonneau and Laarveld, 1999). Passive immunization of farm animals using monoclonal antibodies offers a potential alternative for disease treatment which is costly. On-going work on cytokine therapy is yet to yield applicable results due to the over-dependence on timing of cytokine delivery in advance infection challenge (Babiuk et al., 1991). An alternative for cytokine therapy lies with the natural immune stimulants that evoke a more physiological cytokine cascade expected to enhance disease resistance in domestic animals (Yun et al., 1997).

Animal health is potentially the most important aspect of animal production and any development in the area of biotechnology will greatly benefit the industry. Nonetheless, there is currently little application of *biotechs* developed for disease treatment and diagnosis. Advance *biotech* could probably offer alternatives to replace the use of antibiotics or chemical therapy that are costly and have residual effects to the final consumer of animal products (Bonneau and Laarveld, 1999).

Biotechnology in animal nutrition

Animal nutrition has for a long time provided one of the greatest challenges to animal production with limitations arising from both quality and quantity. A large proportion of animal feeds are fibrous with varying levels of digestibility and nutritive values. Animal nutritionists have developed *biotechs* to improve nutritive value for feeds, enhance digestibility and acceptability and removal of anti-nutritive factors from feeds especially for ruminant animals (Kundu and Kumar, 1987). Apart from the *biotechs* targeted on feeds, the manipulation of rumen microbial population through alkali treatment, microbial balancing and genetic manipulations are probably the most reliable means of enhancing degradation of low-quality feeds. The methods currently used in the treatment of animal feeds to improve intake and digestibility are mainly mechanical, physical or chemical.

Lignin has been identified as the main cause of difficult digestion for fibrous material. A potent lignase enzyme produced by the soft-rot fungus (*Phanerochaete chrysosporium*) that causes a high degree of depolymerisation of lignin is now available (Tien and Kirk, 1983). Although the lignase levels produced by the fungi cannot meet the requirements for commercial treatments of straw, recombinant DNA technology has been tipped to have the potential to modify lignase genes and proteins to increase efficiency and stability considering that the lignin gene has already been cloned and sequenced from *P. chrysosporium* (Tien and Tu, 1987). Supplementation of roughage diets is basically the method of choice for many farmers in improving the nutritive value of animal feeds. However, removal of anti-nutritive factors has become a subject of great debate.

Anti-nutritive factors in plants such as protease inhibitors, tannins, phytohaemaglutinins and cynogens mainly in legumes have been tackled via plant breeding to either reduce or eliminate them. Inactivation as well as detoxification of anti-nutritive factors can also be done using transgenic bacteria given the success of experimental results of Jones and Megarrity (1986) using caprine rumen innoculum in cattle to detoxify a breakdown product of non-protein amino acid mimosine found in *Leucaena* forage. Similarly, conserved feeds also suffer the risk of being of low nutritive quality if poorly fermented. Sterile conditions are normally necessary to allow for rapid growth of lactic acid bacteria that influence the anaerobic fermentation of sugars. Additives such as chloroform, toluene and cresol are still being used to inhibit bacterial growth while appropriate pH levels are achieved through addition of acids e.g. sulphuric and hydrochloric acids and formic acid. Obviously, the hazardous nature of acids has intensified the search for alternative compounds for fermentation that include molasses, enzymes and innoculi of lactic acid bacteria. Extensive reviews on the use of enzymes to improve the nutritive value of animal feeds are available (Campbell and Bedford, 1992; Bedford, 1996).

Manipulation of digestive tract environments which includes mainly the rumen in ruminants and intestinal tract in monogastrics using prebiotics and probiotics has been reported to be beneficial and effective in increasing the availability of nutrients to the animal (Kelly et al., 1994; Salminen et al., 1998). The main focus in the rumen is the manipulation of microbial flora population and type. Although attempts have been made to introduce transgenic bacteria in the rumen environments to increase efficiency of rumen fermentation, the results have been unsatisfactory due to the complex nature of the rumen environment that include the internal competition of rumen microbes which limits availability of energy (Russel and Wilson, 1988; Flint et al., 1989). The manipulation of the rumen environment to improve the nutritive value of fibrous feedstuffs has been extensively reviewed in Mc Sweeney et al. (1999) with suggestions and limitations for the use of genetically modified organisms (GMOs)

Biotechnology in animal reproduction

The traditional methods utilised in animal reproduction may have been assumed as techniques that cannot be considered as *biotechs* for example, hand mating in small ruminants that relies on timely detection of heat. Artificial insemination (AI) and embryo transfer (ET) are probably the most popular methods that have been adopted in developed and developing livestock industries. The recent advances in biotechnology in reproduction include production of transgenic animals and cloning (Smidt and Niemann, 1999).

Artificial insemination is by far the most widely used *biotech* in animal reproduction and has been reported to result in genetic progress that is four times better than natural mating (van Vleck, 1981). This is realistic considering the high selection intensity and accuracy arising from AI since only the top bulls are selected for use in producing numerous offspring in many herds. In most cases, the technology is restricted to cattle especially dairy cattle since beef cattle are managed extensively. Embryo transfer is also used although limited to highly commercialised livestock production systems and is also more popular with cattle than any other species. In small ruminants, the lack of an alternative to the present surgical procedures has prevented its use (Robinson and McEvoy, 1993). Supporting technologies that have increased the efficiency of AI and ET include micromanipulation of gametes and embryos for splitting, sexing, cloning, gene transfer, cryo-preservation of embryos, invitro maturation, fertilisation and culture (IVFMC) as well as genome analysis (Niemann and Riechelt, 1993; Smidt and Niemann, 1999).

Reproductive hormones have probably been the most rewarding for commercial livestock production. Progesterone and pregnant mare's serum gonadotropin (PMSG) treatments as well as immunisation against androstenedione have been reported to increase ovulation in sheep (Aboul-Naga et al., 1992). During ET procedures, embryo flushing from superior dams is entirely a function of exogenous oestrogen hormone. As expected, even endogenous hormones can be induced to increase the rate of oestrus by manipulating the environment of animals, for instance, exposing ewes to rams one week prior to mating (Aboul-Ela et al., 1988). Oestrus synchronisation is one of the most beneficial biotechnologies applied in reproduction especially for dairy cattle production.

Modern *biotechs* that increase reproductive efficiency but are marred with complexity in process and implementation such as production of transgenic animals and cloning will probably have low rates of adoption in both large scale and small scale farms even in future. This scenario may not only be as a result of cost implications

Table 1. Biotechnologies and their potential impact on livestock production.

Area of application	Biotechnologies[a]	Scale of impact	Potential of adoption	
			Developed countries	Developing countries
Animal health	SAD	Large	High	High
	ELISA	Large	High	Moderate
	DNA detection	Large	High	Low
	Vaccination	Large	High	High
	PCR	Large	High	Moderate
Animal nutrition	Enzyme degradation of fibrous feeds	Large	High	Low
	Rumen (GIT) manipulation	Large	High	Moderate
Animal reproduction	AI	Large	High	High
	MOET	Large	High	Moderate
	Embryo sexing	Large	High	Low
	Cloning	Large	Low	Low
Animal breeding	Nucleus Breeding	Large	High	Moderate
	Development of composite breeds	Large	High	Moderate
	MAS	Large	Moderate	Low

[a]SAD = specific antibody detection; ELISA = enzyme linked immuno-sorbent assay; DNA = dineucleic acid; PCR = polymerise chain reaction; GI T= gastro-intestinal tract; AI = artificial insemination; MOET = multiple ovulation embryo transfer; MAS = marker assisted selection. Modified from Cunningham (1990) and Doyle and Spradbrow (1990).

but ethical considerations as well that directly influence acceptability of products from animals produced under these technologies (Bonneau and Laarveld, 1999).

Biotechnology in animal breeding, genetics and conservation of genetic resources

Maintaining genetic diversity should always be the goal of animal breeding and genetics since this provides a cushion against environmental fluctuations and hence an avenue for utilising selection and mating systems to produce animals for various production environments. The *biotechs* applied in animal breeding and genetics are mainly geared towards increasing breeding efficiency of livestock - especially within organised breeding schemes - and conservation of animal genetic resources. Multiple ovulation and embryo transfer (MOET) which is a composite technology is one such technology that increases the utilisation of superior dams in a herd increasing the intensity for selection of females to further enhance genetic progress.

Breeding schemes in a number of ways can also be considered as a composite *biotech* useful for influencing the rate of genetic progress for a given species of livestock. By definition, a breeding scheme is an integration of biological and mathematical principles of genetic evaluation, selection and mating while strictly considering the socioeconomic aspects of target groups (farmers and markets) for purposes of genetic improvement and production of consumer products from livestock. In this respect, possible designs of breeding programme have been proposed that include centralised and decentralised setups.

The nucleus breeding scheme (NBS) is an example of a centralised system that has been recommended for developing livestock industries (Jasiorowski, 1990). The advantage of NBS over systems such as the decentralised progeny testing scheme is that more traits can be measured in more controlled and accessible herds. Breeding schemes offer opportunity for the application of *biotechs* such as the use of indicator traits (Blair et al., 1990) and application of marker-assisted selection (MAS) (Paterson et al., 1988). Genome mapping through the use of restriction fragment length polymorphism (RFLP) that uses amplifiers short DNA primers in PCR has been of great benefit in developing the DNA fingerprinting technique and genetic characterisation of a wide range of organisms (Southern, 1975; Jeffreys and Morton, 1987; Williams et al., 1990). Although a majority of these technologies are still work-in-progress, their potential adoption in livestock breeding schemes remains a subject of great debate.

APPLICATION OF BIOTECHNOLOGIES IN AFRICA

Table 1 presents the scale of impact and adoption potential of major biotechnologies in livestock production. In general, *biotechs* are expected to have moderate to high impact in the livestock production systems where they are applied. However, the level adoption limits the full-scale expression of their impact. Adoption levels are related to infrastructure and human capacity available in target countries. Developing countries, for a number of reasons, must improve local technological and human capacity for *biotech* research to enable steady adoption and development of relevant *biotechs*. One reason for this move is to enable the accommodation of commodeties considered unimportant by large multinationals due to their limited international use e.g. cassava, coconuts and indigenous livestock species. In contrast, these indigenous resources provide a vital source of livelihoods for millions of households in Africa and other developing countries. A strong local capacity in biotechnology will therefore be the backbone for the propagation and conservation of such indigenous crop and animal genetic resources.

In Africa, livestock are still being reared in natural pastures and environments that are acceptable by most consumers worldwide. The potential for Africa in the international livestock industry is therefore promising as demonstrated by the encouraging developments in stable countries in the south (Republic of South Africa), east (Kenya) and west (Ghana). In most cases, the limitations to livestock production are due to the lack of political will or worse still political instability that has increasingly sustained rural livestock keeping people in poverty and underdevelopment.

Animal health and survival

Disease prevention is a vital tool in animal survival as healthy animals can be used longer in various production systems. Vaccine development and vaccination is a *biotech* that is now well rooted in most African countries unlike vector control and quarantine that are logistically expensive requiring drugs and pesticides. Most livestock keepers in Africa are small to medium scale and thus find some of these technologies unaffordable. The few large scale commercial livestock keepers appreciate the technologies and have adapted them into their daily routines. The biggest risk to developing counties in the use of vaccines, drugs and pesticides is product dumping from manufacturing nations. Product dumping is unfortunately easy due to the lack of a strict monitoring mechanism and corruption. The livestock industries are still developing and are without organised structures to effect vaccine, drug and pesticide production and control as well as controlling product delivery to organised livestock keepers. In Kenya for instance, a reasonable level of organisation in vaccine development and control under the Kenya Veterinary Vaccine Production Initiative is commendable. The prospects for using sub-unit vaccines developed under recombinant technology, pathogen attenuation by gene deletion and vectored vaccines depends on the level of technological development and even more importantly, the packaging of the technology which directly influences its affordability.

Disease diagnosis being a traditional veterinary procedure is not an absolute challenge for developing livestock industries. Diagnostics in Africa may still be relying mostly on specific antibody detection to yield information on sero-prevalence. However, enzyme-linked immunosorbent assay (ELISA) has been achieved with reasonable levels of success. In most countries in Africa, disease diagnosis has been aided by donor support. Therefore, personnel and technological support in form of equipment and chemicals are available. The hope of utilisation of diagnostic tools based on basic DNA detection techniques and PCR methodology is therefore foreseeable. The use of monoclonal anti-bodies is increasing efficiency of disease diagnosis and has yielded encouraging results exemplified by the development of diagnostic tool for trypanosomosis (Nantulya and Lindqvist, 1989). Treatment of diseased animals is primarily through antibiotics extracted from various bacteria and fungi and to some extent, molecules extracted from the Iver-mectine family. Treatment using passive immunization of farm animals using monoclonal antibodies is limited by cost implications whereas cytokine therapy, as alluded to earlier, is still a work-in-progress even in developed countries.

Animal nutrition

Animal nutrition *biotechs* are steadily developing in Africa mostly through local technologies that ensure degradation of fibrous feedstuffs. However local technologies suffer one setback, they are mostly mechanical and thus tedious and impractical for implementation in large scale scenarios. The availability of lignase enzyme produced by the soft-rot fungus (*Phanerochaete chrysosporium*) that causes a high degree of depolymerisation of lignin (Tien and Kirk, 1983) should be embraced for application in large scale livestock production systems. As opposed to forage degradation, a more current problem is anti-nutritive factors that hinder acceptability and diminish the nutritive value of animal feeds. Although this constraint has been circumvented elsewhere through plant breeding and use of transgenic bacteria to eliminate, reduce or detoxify feeds, little has been done in Africa. Similarly, boosting the nutritive value of conserved feeds is of great concern in Africa due to seasonal variation in feed availability. The main treatment for silage is still primarily molasses as opposed to enzymes and innoculi of lactic acid bacteria. The absence of large scale production of silage for commercial purposes in most sub-Saharan countries has limited the use of additives such as chloroform, toluene and cresol to inhibit bacterial growth in order to facilitate fermentation by lactic acid bacteria.

Manipulation of the digestive tract environment, especially rumen microbial flora population and type is an efficient means of ensuring nutrient availability to animals. There seems to be an over concentration on treatment of feeds to ease digestibility, acceptability and improvement of nutritive value as opposed to preparation of the animal's system to uptake nutrients. The suggestions and limitation for the use of genetically modified organisms (GMOs) (Flint et al., 1989; Mc Sweeney et al., 1999) should be studied carefully to fully establish how well the digestive tract of animals, the rumen in particular, can be manipulated to increase availability of ingested nutrients to the animal.

Animal reproduction

Artificial insemination is the most widely used *biotech* in animal reproduction in some countries in Africa operating under semi-organised structures. The purpose initially was to upgrade indigenous livestock but in the advent of establishment of vibrant industries, the technology is now used to increase efficiency of reproduction. The utilisation of ET in Africa is mainly an issue of cost benefit analysis and infrastructure. The majority of farmers are small-holder and have found that returns do not measure to the investment in ET technology considering that ET involves cryo-preservation of embryos as well as in-vitro maturation, fertilisation and culture, which are expensive. The transport systems and technological capacity is still too poor in some countries in Africa to sustain the spread of reproductive biotechnologies. This means that the utilisation of transgenic animals, micromanipulation of gametes and embryos for splitting, sexing, cloning and gene transfer is not foreseeable in the near future.

Animal breeding and genetics

Animal breeding and genetics aims at improving genetic gains in traits of economic importance. This means offspring expected in the next generation are always those from selected animals. In many livestock systems in Africa, sire selection is still the main mode of influencing genetic improvement. Multiple ovulation and embryo transfer is a technology that allows for superior females to also have an effect in effecting genetic change. However, this technology has been only beneficial to cattle where low reproductive rates and long generation intervals make it economically viable. Limitations in utilisation of AI and MOET in Africa are attributable to the absence of organised breeding schemes as a result poor infrastructure among other reasons (Jasiorowski, 1970; Cunningham, 1990). The use of indicator traits and application of MAS are more effective if used within structured breeding schemes where the benefits can be shared by many farmers. Genome mapping and DNA fingerprinting techniques are important for genetic characterisation that could be applied in animal genetic resource conservation. Unfortunately, this objective though noble, is not of immediate priority within African livestock keepers where food security is still the main concern.

IMMERGING ISSUES

Public concerns

The main concerns of the public in general are related to food and the environment (Bonneau and Laarveld, 1999). Acceptability of products from *biotech* is varied with sharp opposition coming from consumer watch organisations that have attributed these technologies to prevalent human diseases. These claims are in some cases justified, for instance, animal products have been noted to be affected by animal genetics and feeding technique that influence quality changes e.g. red meat associated with cardiovascular problems or meat that causes the infamous Bovine Spongiform Encephalopathy (BSE) or the mad cow disease (Bellaver and Bellaver, 1999).

Environmental concerns are related to resultant responses from both social structures and agricultural management due to rapid technological changes (Bonneau and Laarveld, 1999). Animal welfare which entails how animals are reared in relation to housing, feeding and management is a subject of great debate especially in affluent societies where animal production is increasingly becoming intensive. Vegetation patterns can also be affected by plant breeding and manipulation to the extent that some indigenous plant types disappear entirely. Genetic death even for animals is unacceptable thus the need to strengthen programmes for conservation of genetic resources.

Ethical concerns

Genetic engineering which has led to the development of cloning techniques and transgenic products as food for humans remains a subject of great conflict. The fact that animals are closer to humans than plants, genetic manipulations in animals creates fear since it suggests possibilities of interference with the human genome, which in unacceptable for many religious organisations.

Industry concerns

The question, who is the beneficiary of the *biotech* must strictly be answered to allow for wholesome acceptance of technologies. Caution is required when applying *biotechs* especially those related to product quality and quantity as this in most cases results in one-sided benefits for the industry with little or no benefits to the general public that form the consumer base (Bonneau and Laarveld, 1999).

PERSPECTIVES

In all circumstances, *biotech* development and use requires the involvement of stakeholders in a systematic design to enhance research and development as well as transfer of the *biotech* to target groups. Figure 1 presents a systematic design of stakeholders against a variety of *biotech* options. Government and National Agricultural Research Systems (NARS) are responsible for a majority of the processes required to successfully develop and

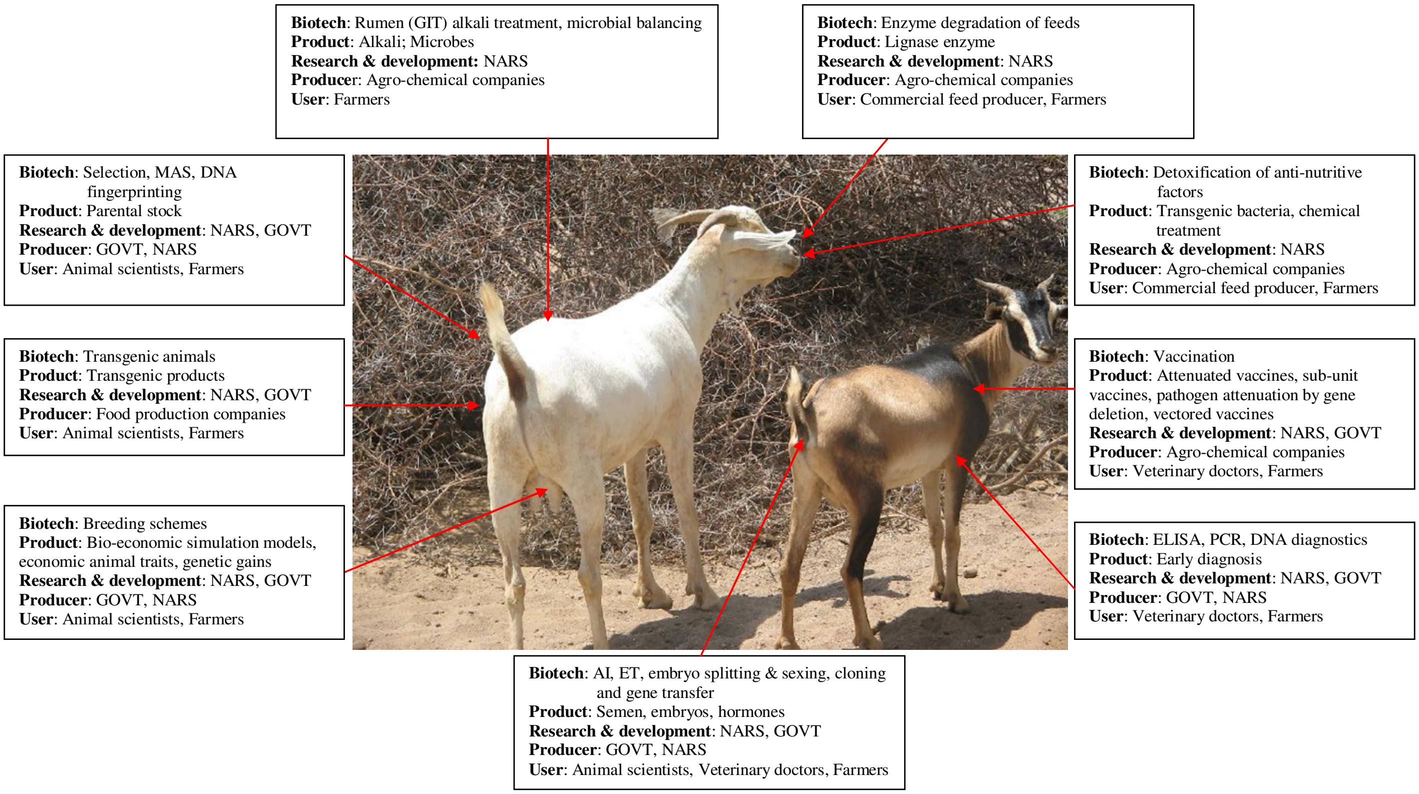

Figure 1. An outlay of development and usage of biotechnologies in Livestock production. NARS = National Agricultural Research Systems; GOVT = Government; ELISA = Enzyme Linked Immuno-sorbent Assay; PCR = Polymerase Chain Reaction; MAS = Marker Assisted Selection.

transfer relevant biotechnologies. To deliver *biotechs* for use by target groups, there is need for cooperation between Government, NARS and agro-chemical companies.

In Africa, use of *biotech* can be greatly enhanced through strategic partnerships with developed economies where such technologies are well established. However, *biotech* development and adoption requires a high level of commitment to research and development. Therefore, there is need to develop scientific capacity through local universities and research institutions for development of own technologies and dealing with technologies offered by the developed countries.

The ease with which some technologies have been adopted in Africa is attributable to the mode of packaging. Technologies that require expensive equipments, heavy machines, expensive chemicals as well as high level of technological expertise e.g. molecular *biotechs*, have the slowest rate of adoption in Africa. Technologies such as ET have been reported to be unaffected by fancy equipment indicating that simple ice or alcohol baths can be used for freezing embryos thus reducing the cost of the technology (Seidel and Seidel, 1992).

Biotechnological possibilities for Africa have great potential to improve food security. In this respect, careful interpretation of relevant biotechnologies in livestock production is important. Even though technological advances and adoption of new technologies require complimentary development in society in relation to education, research and economic development, Africa can benefit from tailor-made technologies that simplify complex techniques into applicable form through strategic packaging. This packaging must involve local knowledge to ease acceptance and sustainability of technology utilisation. It is important therefore for Africa to build capacity in all aspects of livestock research as a response to changing technologies and new discoveries to ensure food security for the ever-growing population.

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REFERENCES

Aboul-Ela MB, El-Nakhla SM, Gabr MG, Hassan FA, Aboul-Naga AM, Hanrahan JP (1988). Effect of active immunization against androstenedione on ovulation rate and fecundity in fat-tailed rahmania and Finnish landrace x Rahmani crossbred ewes. In: Proceedings of the 11th International Congress on Animal Reproduction and Artificial Insemination, University College Dublin, Ireland, 26-30 June 1988. Volume 4. University College Dublin, Dublin, Irish Republic. pp 487.

Aboul-Naga AM, Aboul-Ela MB, Hassan F (1992). Manipulation of reproductive activity in subtropical sheep. Small Rum. Res. 7: 151-160.

Babiuk LA, Sordillo LM, Campos M, Hughes HPA, Rossi-Campos A, Harland R (1991). Application of interferons in the control of infectious diseases of cattle. J. Dairy Sci. 74: 4385-4398.

Bedford MR (1996). The effect of enzymes on digestion. J. Appl. Poultry Res. 5: 370-378.

Bellaver C, Bellaver IH (1999). Livestock production and quality of societies' life in transition economics. Livest. Prod. Sci. 59: 125-135.

Blair HT, McCutcheon SN, Mackenzie DDS (1990). Components of the somatotropic axis as predictors of genetic merit for growth. 4th WCGALP. XVI: 246-255.

Bonneau M, Laarveld B (1999). Biotechnology in animal nutrition, physiology and health. Livest. Prod. Sci. 59: 223-241.

Bradford GE (1999). Contributions of animal agriculture in meeting global human food demand. Livest. Prod. Sci. 59: 95-112.

Brochier B, Kieny MP, Costy F, Coppens P, Bauduin B, Languet B, Chappus G, Desmettre P, Afiademanyo K, Libois R, Pstoret PP (1991). Large scale eradication of rabies using recombinant vaccinia-rabies vaccine. Nature. 354: 520-522.

Campbell GL, Bedford MR (1992). Enzyme applications for monogastrics feeds: a review. Can. J. Anim. Sci. 71: 449-456.

Cunningham EP (1990). Animal production. In: Persley GJ (ed), Agricultural Biotechnology: Opportunities for International Development. CAB (Commonwealth Agricultural Bureaux) International, Wallingford, UK. pp. 169-175.

Delgado C Rosegrant M, Steinfeld H, Ehui S, Courbois C (1999). Livestock to 2020: The Next Food Revolution. Discussion Paper 20. IFPRI, Washington D. C., USA.

Dietrich G, Bubert A, Gentschev I, Sokolovic Z, Simm A, Caltic A, Kaufmann SHE, Hess J, Szalay AA, Goebell W (1998). Delivery of antigen-encoding plasmid DNA into the cytosol of macrophages by attenuated suicide Listeria monocytogens. Nat. Biotechnol. 16: 181-185.

Doel TR, Gale C, Do Amaral CMCF, Mulcahy G, Dimarchi R (1990). Heterotypic protection induced by synthetic peptides corresponding to three serotypes of foot-and-mouth disease. J. Virol. 64: 2260-2264.

Doyle JJ, Spradbrow PB (1990). Animal Health. Animal production. In: Persley GJ (ed), Agricultural Biotechnology: Opportunities for International Development. CAB (Commonwealth Agricultural Bureaux) International, Wallingford, UK, pp. 176-186.

Flint HJ, Bisset J, Webb T (1989). Use of antibiotic-resistance mutations to tract strains of obligate anaerobic bacteria introduced into the rumen of sheep. J. Appl. Bacteriol. 67: 117-183.

IFPRI (2001). 2020 Global Food Outlook: Trends, alternatives and choices. Food Policy Report. IFPRI, Washington D. C., USA.

Jackwood MW (1994). Biotechnology and the development of diagnostic test in veterinary medicine. J. Am. Vet. Med. Assoc. 204: 1603-1605.

Jasiorowski HA (1990). Open nucleus breeding schemes – new challenges for the developing countries. In: Zurkowski M (ed), Proceedings of a Conference on Open Nucleus Breeding Systems, Biatobrzegi, Poland, 1 – 19 January 1989. FAO (Food and Agriculture Organisation of the United Nations), Rome, Italy. pp. 7-12.

Jeffreys AJ, Morton DB (1987). DNA fingerprints of dogs and cats. Anim. Genet. 18: 1-15.

Jones RJ, Megarrity RG (1986). Successful transfer of DHP degrading bacteria from Hawaiian goats to Australian ruminants to overcome the toxicity of Leucaena. Austr. Vet. J. 63: 259-262.

Kelly D, Bergbie R, King TP (1994). Nutritional influences on interactions between bacteria and the small intestinal mucosa. Nutr. Res. Rev. 7: 233-257.

Kundu SS, Kumar V (1987). Biotechnological processes to convert crop residues to quality feeds for livestock. Ind. Dairyman. 39: 113-114.

McGhee JR, Mestecky J, Dertzbaugh MT, Eldridge JH, Hirasawa M, Kiyono H (1992). The mucosal immune system: from fundamental concepts to vaccine development. Vaccine. 10: 75-88.

McKeever DJ, Rege JEO (1999). Vaccines and diagnostic tools for animal health: the influence of biotechnology. Livest. Prod. Sci. 59: 257-264.

Mc Sweeney CS, Dalrimple BP, Gobius KS, Kennedy PM, Krause DO, Merckie RI, Xue GP (1999). The application of rumen biotechnology to improve the nutritive value of fibrous feedstuffs: pre- and post ingestion. Livest. Prod. Sci. 59: 265-283.

Mullis K, Faloona F, Sharf S, Saiki R, Horn G, Erlich H (1992). Specific enzymatic amplification of DNA in vitro: the polymerase chain reaction. Biotechnology. 24: 17-27.

Nantulya VM, Lindqvist KJ (1989). Antigen-detection anzyme immunoassay for the diagnosis of Trypanosome vivax, T. congolense and T. brucei infections in cattle. Trop. Med. Parasitol. 40: 267-272.

Niemann H, Riechelt B (1993). Manipulating early pig embryos. J. Repr. Fert. Suppl. 48: 75-94.

Paterson AH, Lander ES, Hewitt JD, Peterson S Lincoln SE, Tanksley S D (1988). Resolution of quantitative traits into Mendelian factors using a complete linkage map of restriction fragment length polymorphisms. Nature. 335: 721-728.

Robinson JJ, McEnvoy TG (1993). Biotechnology – the possibilities. Anim. Prod. 57: 335-352.

Russel JB, Wilson DB (1988). Potential opportunities and problems for genetically altered rumen microorganisms. J. Nutr. 118: 271-279.

Salminen S, Bouley C, Boutron-Ruault MC, Cummings JH, Franck A, Gobson GR, Isolauri E, Moreau MC, Roberfroid M, Rowland I (1998). Functional food science and gastrointestinal physiology and function. Br. J. Nutr. 80(1): 147-171.

Seidel GE, Seidel SM (1992). Analysis of applications of emryo transfer in developing countries. In: Niemann H, Franzen H, Smidt D (eds), Potential and limitations of Biotechnology in Livestock Production in Developing Countries, Proceedings of a Symposium, Mariensee, Germany, May 1992. Part I. ATSAF (Council for Tropical and Subtropical Agricultural Research), Bonn, Germany. pp. 68-80.

Smidt D, Niemann H (1999). Biotechnology in genetics and reproduction. Livest. Prod. Sci. 59: 207-221.

Southern EM (1975). Detection of specific sequencing among DNA fragments separated by gel electrophoresis. J. Mol. Biol. 95: 503-517.

Tien M, Kirk KT (1983). Lignin degrading enzyme from the Hymenomycete Phanerochaete chrysosporium burds. Science. 221: 661-663.

Tien M, Tu CPD (1987). Cloning and sequencing of a cDNA for a ligninase from Phanerochaete chrysosporium. Nature (London). 326: 520-523.

Van Vleck LD (1981). Potential genetic impact of artificial insemination, sex selection, embryo transfer, cloning and selfing in dairy cattle. In: Brackett BG, Seidel GE, Siedel SM (eds), New Technologies in Animal Breeding. Academic Press, New York, USA. pp. 221-242.

Van Vliet AH, van der Zeijst BA, Camus E, Mahan SM, Martinez D, Jongejan F (1996). Recombiant expression and use in serology of a specific fragment from the Cowdria ruminantium MAP1 protein. Annals of the National Academy of Science - Ann. National. Acad. Sci. 791: 35-45.

Williams JG, Kublelik AR, Livak KJC, Rafalski JA, Tingey MSV (1990). DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. Nucl. Acids Res. 18(22): 6531-6535.

Yun CH, Estrada A, Van Kessel AG, Gajadhar AA, Redmond MJ, Laarveld B (1997). ß-(1→3, 1→4) oat glucan enhances resistance to Elmeria vermiformis infection in immunosuppressed mice. Int. J. Parasitol. 27: 329-337.

Zarlenga DS (1994). Advances in parasite control through biotechnology. J. Am. Vet. Med. Assoc. 204: 1616-1621.