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An Overview of Application of Animal Biotechnology in Africa: A Promising Approach for Life and Genetic Improvement of Farm Animals

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ABSTRACT

Biotechnology is defined as 'any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products and processes for specific use'. There is no doubt that technology had a major impact on rates of genetic improvement in dairy cattle and is just as important to the structure of animal breeding programs. The new techniques for understanding and modifying the genetics of living organisms have led to rapid adoption and large investments in biotechnology research and development. Most of this development is taking place in North America, Western Europe and East Asia, with the United States far ahead of the others. However, a diverse range of developing countries, from the technologically advanced like Brazil, China, India, Malaysia and South Africa to the technologically less advanced like Egypt, the Philippines and Vietnam are also investing a significant part of their total research and development resources on agro-biotechnology. But the least developed countries are lagging far behind, with the very modest investments that have been made in countries like Kenya, Tanzania and Uganda originating mostly from a few donor agencies. The techniques that are currently available to reach this end can be divided into two different groups. The first group includes all technologies that interfere with reproduction efficiency. The outcome of these technologies is an increased breeding accuracy, selection intensity and, in some cases, a shortened generation interval. The second group of applications is based on the molecular determination of genetic variability and the identification of genetically valuable traits and characteristics. Although; there is growing trend for genetic improvement and production of livestock especially in the dairy sector, African countries are the least investors in research and development of animal biotechnology. Artificial insemination is the first generation animal biotechnology introduced in cattle in the fifties and other reproductive animal biotechnologies are lagging behind to be practiced in the developing world. The growing dairy production observed from north, east and South African countries can be enhanced by capacity building, research and application of animal biotechnology options beyond artificial insemination.

Review

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INTRODUCTION

According to Sasson [1], the word 'biotechnology' was coined by Karl Ereky, a Hungarian engineer, in 1919 to refer to methods and techniques that allow the production of substances from raw materials with the aid of living organisms. A standard definition of biotechnology has been reached in the Convention on Biological Diversity (1992): 'any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products and processes for specific use'. This definition was agreed by 168 member nations and also accepted by the Food and Agricultural Organization of the United Nations (FAO) and the World Health Organization (WHO). Similarly; biotechnology can be broadly defined as the application of biological knowledge to practical needs. These technologies fall generally into two categories, reproductive and molecular. Not all of this is new. Artificial insemination was introduced in cattle in the fifties. There is no doubt that technology had a major impact on rates of genetic improvement in dairy cattle and is just as important to the structure of animal breeding programs [2]. Moreover; Biotechnologies are therefore a collection of techniques or processes using living organisms or their units to develop added-value products and services [1] and thus adding market value to local livestock breeds is a recognized strategy in conservation of AnGR [3], but the genetic improvement of breeds' traits is also a concrete option for increasing their profitability. Besides; the application of biotechnology techniques can be for production of knowledge goods and services for the betterment of human beings [4].

Livestock systems occupy about 30% of the planet's ice-free terrestrial surface area and this sector is increasingly organized in long market chains employing approximately 1.3 billion people globally and directly supporting the livelihoods of 600 million smallholding farmers in the developing countries [5]. In support of this task; the use of advanced tools such as genetic modification will undoubtedly have a profound impact on agriculture in the 21st century. The new techniques for understanding and modifying the genetics of living organisms have led to rapid adoption and large investments in biotechnology research and development (R&D). Most of this development is taking place in North America, Western Europe and East Asia, with the United States far ahead of the others. However, a diverse range of developing countries, from the technologically advanced like Brazil, China, India, Malaysia and South Africa to the technologically less advanced like Egypt, the Philippines and Vietnam are also investing a significant part of their total R&D resources on agro-biotechnology. But the least developed countries are lagging far behind, with the very modest investments that have been made in countries like Kenya, Tanzania and Uganda originating mostly from a few donor agencies [6]. Thus, the general objective of this review is to assess techniques and applications of biotechnology in livestock with emphasis to dairy sector of Africa and to address the following specific objectives:

- To review the available tools , techniques and applications of animal biotechnology as genetic improvement of livestock in Africa
- To review the role of animal biotechnology in bringing genetic improvement of livestock especially the dairy sector of Africa

DISCUSSION

Overview of animal biotechnology tools and applications

Biotechnology is multidisciplinary in nature encompassing microbiology, chemistry, biochemistry, genetics, molecular biology, immunology, physiology and engineering. Biotechnology therefore has application in the fields of agriculture, medicine, food, industry, and environmental management [4] and the biotechnological application is used to improve the yield of crop and animal species and their product quality such as nutritional value and shelf life [7]. The common goal of all efforts undertaken in this field is genetic progress within a population, i.e. the improvement of the genetic resources and, ultimately, the phenotypic outcome [8].

According to Parawira and Khosa [4] report, biotechnology is the least developed in the sub-Saharan region outside South Africa and much of the biotechnology applied is mainly traditional biotechnology, particularly in agriculture and food. This is mainly because of lack of adequate public research capacity, that is, the portfolio of resources – human, physical and financial, available in the research system for performing and utilizing the research. These challenges, either directly or indirectly affects capacity building and retention of personnel. Nevertheless, Zimbabwe is employing various forms of biotechnological techniques in its agricultural, environmental, Industrial, medicine and food industry research. This trend in biotechnology research and development is important as the country recover, maintain and eventually expand resources needed for it to have a competitive position in regional and international markets and for sustainable development.

Techniques and applications of animal biotechnology

All factors of genetic progress (the accuracy of choosing candidates for breeding, the additive genetic variation within the population, the selection intensity (i.e. the proportion of the population selected for further breeding), and the generation interval (the age of breeding) can be influenced, to a varying extent, by modern biotechnology [8].

The techniques that are currently available to reach this end can be divided into two different groups [8]. The first group includes all technologies that interfere with reproduction efficiency: artificial insemination, embryo transfer (ET), embryo sexing, multiple ovulations, and ova pick-up and cloning, amongst others. The outcome of these technologies is an increased breeding accuracy, selection intensity and, in some cases, a shortened generation interval.

The second group of applications is based on the molecular determination of genetic variability and the identification of genetically valuable traits and characteristics. This includes the identification and characterization of quantitative trait loci (QTL) and the use of molecular markers for improved selection procedures. Furthermore, according to Bhagavan and Virgin [6] all of the modern biotechnology techniques can be used, and are being used, in the breeding of crops and livestock including molecular diagnostics and serology to aid crop and livestock production and protection, tissue culture , marker aided selection (MAS), genetic modification/genetic engineering , vaccine technology, functional genomics and bioinformatics.

Molecular animal biotechnology options

MAS programmes as a molecular animal biotechnology option. According to FAO [9] report, in a population, when the marker and gene are very close the physical characteristics of the animals will be statistically associated with the marker and will stay linked for generations of breeding. If this statistical relationship is detected, individuals can be selected when the desired form of the molecular marker is present, since its presence would be an indication of the desired trait under study. This is known as "Marker Assisted Selection". According to Coutinho [10] it was only after the discovery of the DNA structure by Watson and Crick in 1953 and of recombinant DNA technology in the 1970s that modern biotechnology has been designated for using of genetic information obtained directly from DNA. Moreover ; since the 1970s, the identification and genotyping of large numbers of genetic markers, the use of this technology to identify genomic regions that control variation in quantitative traits and to show how the resulting quantitative trait loci (QTL) could be used to enhance selection, have raised high expectations for the application of marker-assisted selection (MAS) in livestock.

The first reported map in livestock was for the chicken in 1992, which was quickly followed by publication of maps for cattle, pigs and sheep. Since then, the search for useful markers has continued and further species have been targeted, including the goat, horse, rabbit and turkey (see http://www.thearkdb.org) [11]. MAS can, in theory, be applied to any agriculturally important species, and active research programmes have been devoted to building molecular marker maps and to detecting QTLs for potential use in MAS programmes in a range of plant and animal species [11] in that biotechnology provides the production of goods and services by using of living organisms or their parts. For thousands of years, several human activities, such as fermented foods production (bread, wine, yogurt, beer, etc.) are examples of the use of biotechnology [10].

Biotechnology approaches used to identify genes. Five biotechnology approaches used to identify genes of interest: QTL mapping, candidate genes approach, DNA and mRNA sequencing, including gene expression, genome scan approach, fine mapping.

Quantitative trait loci (QTL) mapping. QTL mapping is based on the identification of chromosomal regions associated with the genetic variation of traits of economic interest. This identification is dependent both on the development of genetic maps saturated with polymorphic molecular markers and on a population structure that shows segregation for the trait of interest [10].

Table 1. QTL mapping for some economically important traits

No.	QTL	Species of LS	Trait affected (Milk Production)	Source
1	BM143	Cattle	Milk yield, protein yield, protein percentage, fat yield, fat percentage	[12]
2	Diacilglicerol O-Acetiltransferase (DGAT1)	Cattle	Milk composition and production	[13]
3	Myostatin	Cattle	Muscle development	
5	Calpastatin gene	Cattle	Tenderization of meat.	[14]
6	Myostatin F94L	Cattle	Double-muscling	[15]
7	Diacylglycerol Acyltransferase (DGAT)	Cattle	Muscle fat content	[16]

QTL= quantitative trait loci; LS= Livestock

Candidate genes approach

The candidate gene approach studies the relationship between the traits and known genes that may be associated with the physiological pathways underlying the trait [17]. In other words, this approach assumes that a gene involved in the physiology of the trait could harbor a mutation causing variation in the trait. The gene or part of gene, are sequenced in a number of different animals, and any variation found in the DNA sequences, is tested for association with variation in the phenotypic trait. This approach has had some success [18]. For example a mutation was discovered in the estrogen receptor locus (ESR) which results increased litter size in pig.

Table 2. Candidate genes for some economically important traits

No	Candidate genes	Trait Meat quality of farm animals	Species of LS	Source
1	Halothane and RN genes	Meat quality	Pigs	[19]
2	Myostatin gene	Double-muscling	Cattle	[20]
3	Calpain and calpastatin	Meat tenderness	Cattle	[21]
5	Extracellular fatty acid binding protein (EX-ABP) gene	Abdominal fat Traits	Chicken	[22]
6	Liver fatty acid-binding protein (L-FABP) gene	Abdominal fat weight and percentage of abdominal fat	Chicken	[23]
7	Calpastatin (CAST) gene	Raw firmness scores and average tenderness, juiciness, and chewiness	Pig	[24]

LS= Livestock; CAST= Calpastatin gene; RN gene= Napole gene

Reproductive animal biotechnology option

Artificial insemination (AI) in cattle. Genetic progress in cattle can be increased up to 50% through the application of AI, the first generation biotechnology, using either extended semen that has been preserved in liquid form (fresh, or cooled to 5ºC), or deep-frozen [25]. During the past 50 years, the development and application of cattle AI with preserved (either chilled or frozen) semen have been growing exponentially on a global scale [26]. The number of produced semen doses is >250 million worldwide [27] and this technique can enable a single bull to be used for fertilization simultaneously in several countries for up to 100 000 inseminations a year [8].

Embryo transfer. Although not economically feasible for commercial use on small farms at present [28], the embryo transfer (ET) methodology is a suitable, more integrated approach for genetic distribution than AI, leading to improvement of genetic basis within 5 years [29] and embryo technology can greatly contribute to research and genetic improvement in local breeds [28]. Moreover, as for AI, allows movement of material worldwide and reduces the risk of transmitting specific diseases, provided the embryos are free from contamination [29].

There are two procedures presently available for the production of embryos from donor females [28]. One consists of super ovulation using a range of hormone implants and treatments, followed by AI and then flushing of the uterus to gather the embryos. The other, called *in vitro* fertilization (IVF) consists of recovery of eggs from the ovaries with the aid of the ultrasound-guided transvaginal oocyte pick-up (OPU) technique. When heifers reach puberty at 11-12 months of age, their oocytes may be retrieved weekly or even twice a week. These are matured and fertilized *in vitro* and kept until they are ready for implantation into foster females. In this way, high-value female calves can be used for breeding long before they reach their normal breeding age. IVF facilitates recovery of a large number of embryos from a single female at a reduced cost, thus making ET techniques economically feasible on a large scale.

In vitro embryo production (IVP). Methods for *in vitro* maturation (IVM), fertilization (IVF) and culture (IVC) are available for cattle, proved by the birth of innumerable calves' worldwide [30]. *In vitro* fertilization (IVF), the process of fertilizing and growing cattle embryos in the lab, is not a new technology. Briefly, eggs (or oocytes) are harvested from cows: 1) through the use of a transvaginal ultrasound-guided needle (mostly used in cows with high genetic value – more expensive method); or 2) straight from the ovaries of cows sent to the slaughterhouse (a much cheaper method). Once harvested, these oocytes are brought to the lab and placed in solutions that mimic the uterine environment. This allows sperm to fertilize the eggs and the formed embryos to grow until transferred to recipient cows, roughly one week after oocytes were harvested from the ovaries [31].

Embryo splitting, bisection and reproductive cloning by nuclear transfer. Cloning, as a multiplication technique, has been used in small ruminants since the late 1970´s. Splitting of cattle embryos can be used to increase the number of embryos available from selected females and to produce genetically identical animals for biomedical research. Both separation of blastomeres in 2-4 cell-embryos and embryo (morula or blastocyst) bisection have proven efficient to yield monocygotic twins after quick laparoscopic transfer to recipient cows.

Pregnancy rates achieved were similar to when transferring whole embryos and twinning reached 50% after pair transfer. The overall efficiency of cow embryo splitting (number of calves born per embryos bisected and transferred) can reach almost 60 % [32].

Embryo sexing. Technologies for rapid and reliable sexing of embryos allow the generation of the desired sex at specific points in a genetic improvement programme, markedly reducing the number of animals required and enabling increased breeding progress. A number of approaches to the sexing of semen have been attempted; however, the only method of semen sexing that has shown any promise has been the sorting of spermatozoa according to the DNA content by means of flow cytometry [33]. Embryo sexing has been attempted by a variety of methods, including cytogenetic analysis, assays for X-linked enzyme activity, analysis of differential development rates, detection of male-specific antigens, and the use of Y-chromosome specific DNA sequences [8].

Factors for limited applications of biotechnology

As biotechnology industries are knowledge- and resource-intensive, two of the major drivers of its growth are effective and sustainable research and development and innovations [34].

Dairy production: a potential sector for animal biotechnology to be applied on:

World milk production is derived from cows, buffaloes, goats, sheep and camels [35]. Moreover; As in Sub-Saharan Africa (SSA) in general, cow milk production is predominant in Eastern Africa, followed by goat milk, sheep milk and camel milk [36]. The milk production has doubled from 1996 to 2013 reaching 40 million MT and in volume terms the major growth has been in the countries in North Africa and in Kenya and South Africa. The other countries in Sub-Sahara Africa have all experienced high relatively growth but from an extremely low level, the milk production in Africa accounts only for 5% of the world milk production [35,37] and it is not foreseen to be able to cover the demand in the coming decades [37]. The largest milk-producing countries are Egypt, Kenya, South Africa and Sudan [35], the top five African milk producing countries in terms of milk volume being Sudan, Egypt, Kenya, South Africa and Algeria. Meanwhile, the first four countries alone produce 52% of total African milk [37].

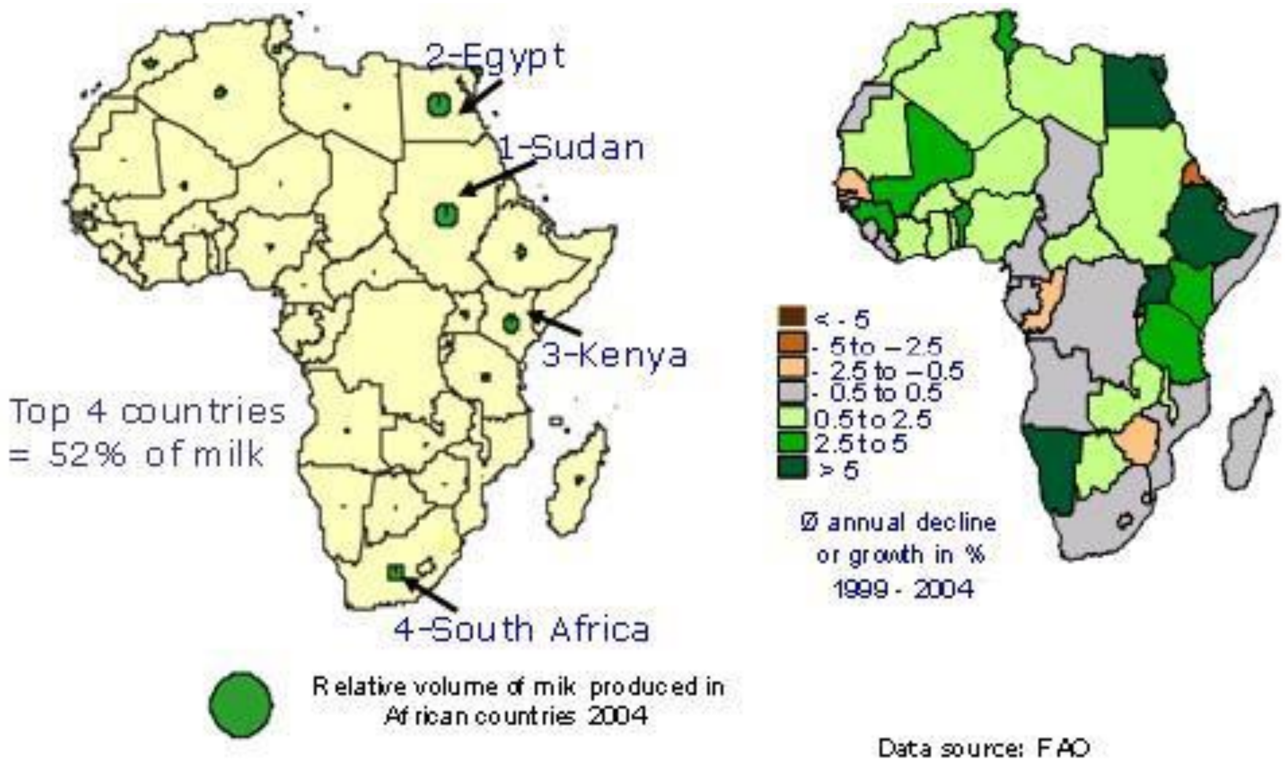

Figure 1. Milk production structure in Africa

Moreover, Eastern Africa is the leading first milk-producing region in Africa, representing 68% of the continent's milk output [38]. Ethiopia, Kenya and Tanzania are among the biggest dairy producers in Africa. The dairy sector is one of the fastest growing agricultural sub-sectors in Eastern African countries, which has generated significant economic returns and employment opportunities along dairy value chains. In Rwanda, according to the 2013 National Dairy Strategy (NDS), milk production has been rising rapidly, from 51.5 million (m) litres (l) in 2000 to 445 m l in 2012 and continued rapid growth is expected. This rapid rise in milk production has been attributed to a favorable policy and institutional environment and important investments by the Government and development partners [39].

Table 3. Dairy production in Eastern Africa in 2011

Country	Milk (million t) 2011	Milk (% of growth rate, 2000-11)	Butter (1000 t)	Cheese (1000 t)
Ethiopia	4.4	14.2	17.6	5.8
Kenya	4.3	5.5	14.7	0.3
Rwanda	0.2	5.3	0.7	n/a
Tanzania	1.8	7.8	13.0	13.0
Uganda	1.2	8.0	n/a	n/a

Source: FAO STAT, 2014

CONCLUSION AND RECOMMENDATIONS

AI is the first generation animal biotechnology in practice for the dairy sector starting in the fifties and other reproductive animal biotechnologies are lagging behind to be practiced in the developing world. Although, there is growing trend for genetic improvement and production of livestock especially in the dairy sector, developing countries including Africa are the least investors in research and development of animal biotechnology. The growing dairy production observed from north, east and South African countries can be enhanced by capacity building, research and application of animal biotechnology options beyond artificial insemination.

Competing interests

The authors declare that they have no competing interests.

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