Challenges and opportunities for beef production in developing countries of the southern hemisphere

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Abstract

Livestock production faces specific challenges due to a rise in population numbers, urbanization and economic development in the developing world. A substantial increase in demand for meat in these countries will offer larger market opportunities for livestock producers. Developing countries from the southern hemisphere are characterized by a highly dualistic beef cattle sector with communal, subsistence or small scale farmers and large commercial farmers co-existing. Whereas the off-take from the commercial sector is high, the off-take from the other sectors is still low in certain regions. Global warming is expected to have a negative effect on the beef production environments of these countries. By describing production environments it will be possible to identify genotypes that are adapted to the environment. Tools are needed to overlay geo-referenced data sets onto the different environments in order to quantify them. Gene or marker assisted selection may play an important role in selection for disease and parasite resistance or tolerance, since it is difficult to measure these traits directly. Strategies that utilize EBVs derived from genomic analyses (genomic EBVs), together with conventional mixed model methodology, may speed up the process of breeding animals with higher and more efficient production. Research into methane production will also have to be stimulated.

Keywords: Adaptation, animal improvement, animal recording, genomics, global warming, landscape genetics, methane production, production environment.

1.0 Introduction

Livestock production faces specific challenges due to increasing population, urbanization and economic development, especially in developing countries. These developments are expected to lead to a significant rise in demand for livestock products, referred to as the *Livestock Revolution* (Delgado *et al.*, 1999). The world demand for meat is expected to rise by more than 200% from 229 million ton in 1999 to 465 million ton in 2050 (Steinfeld *et al.*, 2006), with global numbers of meat animals that will have to increase to respond to the demand, which in turn will increase methane production from livestock. This substantial increase in demand for livestock products in developing countries (Delgado *et al.*, 1999), partly due to population increase and improved incomes, will offer much larger market opportunities for the livestock producers in these countries.

There is growing evidence that improving the productivity of farmers that are not currently operating on a commercialized level (subsistence, smallholder, emerging, etc.) has the potential to address poverty in agriculturally based economies (Hazell *et al.*, 2007) of developing countries in the southern hemisphere, while the more commercialized (industrialized) production systems remain in balance with the natural environment (Comprehensive Assessment of Water Management in Agriculture, 2007; UNEP, 2007).

Cattle are the most important livestock species in Africa and Latin America; the difference being that Africa is one of the centres of domestication (Bruford *et al.*, 2003; Hanotte *et al.*, 2002) and is richly endowed with a large number of indigenous breeds that have adapted to the continent's prevailing conditions (Scholtz, 1988, 2005; Scholtz and Theunissen, 2010), whereas the only domestic animals in Latin America at the time of the discovery of the Americas in 1454 were camelids such as llamas, alpacas, guinea pigs, etc. All other animals were imported, mainly from the Iberian Peninsula and North Africa and underwent approximately 500 years of natural selection in the diverse environments. From the end of the 19th century there were other imports from mainland Europe and zebu cattle from India (Primo, 2004).

The type of production strategy to be followed in these countries depends primarily on the environment and level of management (Scholtz and Theunissen, 2010). There is a need to match the environment with the correct genotype to ensure increased and sustainable production (McManus *et al.*, 2009). While beef production in Brazil is based primarily on *Bos indicus* (Zebu) breeds, Uruguay and Argentina base their beef cattle industry on traditional British breeds (Mariante *et al.*, 2008). Southern hemisphere Africa is dominated by indigenous Sanga breeds with some influence of Zebu, British and European breeds.

Major beef production in Latin American comes from Brazil, Argentina, and Uruguay, which are large net exporters of beef (over 35% of world trade in 2005 – Steiger, 2006), whereas southern hemisphere African counties, with the exception of Botswana and Namibia, are all net importers of beef, despite the huge and untapped potential of exceptionally good indigenous beef cattle breeds (Demeke, *et al.*, 2004; Scholtz and Theunissen, 2010; Rewe *et al.*, 2010 Wasike *et al.*, 2006).

This paper aims to discuss the challenges and opportunities for beef production in the developing countries of the southern hemisphere in relation to beef production levels, the challenges posed by global warming, enteric methane production, the role of recording and quantitative breeding technology, and genomics.

2.0 Discussion

2.1 Production levels

Cognisance should be taken of the fact that the cattle sector in these countries is highly dualistic with communal, subsistence or small scale farmers and large commercial farmers all co-existing. Whereas the off-take from the commercial sector is high, the off-take from the other sectors is still low in certain countries as a result of low fertility, high mortality, etc.

A survey undertaken in South Africa (Scholtz and Bester, 2009) demonstrated major differences in the different sectors regarding production levels (Table 1).

Table 1. Beef production information on the different sectors in South Africa.

Trait	Commercial sector	Emerging sector	Communal sector
% Adult females in herd	52	49	25
Calving percentage	62	48	35
Pre-weaning mortality (%)	3.1	3.3	30.7
Post weaning mortality (%)	2.7	2.2	4.7
% Off-take	32	25	6

Major discrepancies in production and throughput between the commercial, emerging and communal sectors in South Africa are demonstrated by Table 1, and clearly indicate that aspects such as pre-weaning mortality, herd composition and calving percentage in the communal sector should be urgently addressed to improve production from this sector.

Similar discrepancies in production were demonstrated in the Brazilian Pantanal (freshwater wetland). Table 2 demonstrates the effect of a four year monitoring period on production in the Pantanal (Abreu *et al.*, 2010). In harsh environments such as the Pantanal in Brazil, it had been shown that while Nellore cattle have a calving interval of almost two years the naturalized breeds such as Pantaneiro or Curraleiro calve once a year (McManus *et al.*, 2002).

Table 2. Beef cattle production in the Brazilian Pantanal following four years of monitoring.

Trait	Start of monitoring	After four years monitoring
Calving percentage	45-56	65-70
Pre-weaning mortality (%)	18-25	5-10
Post weaning mortality (%)	5	3

These examples illustrate the opportunities for increasing beef production in these regions, but specific actions need to be taken for this to happen. Farmers tend to be reluctant to address specific management problems, such as soil erosion, pasture quality or animal growth rates, preferring to open virgin forest to create temporary pastures, which are abandoned after use for a few years

The poor use of technology is emphasized when it is noted that meat off-take in Brazil is 22% and in the communal sector in South Africa 6%; compared to 26% in Argentina, 30% in Uruguay and 32% in the South African commercial sector. The United States have an off-take of up to 37%.

2.2 Global warming

Tropical and subtropical climates have both direct and indirect effects on livestock. Factors such as temperature, solar radiation, humidity and wind all have direct effects on animals, whereas factors such as digestibility of feed, intake, quality and quantity of grazing, pests and diseases, all have indirect effects on animals (Linington, 1990). It is predicted that climate change will have a more extreme effect on southern hemisphere continents than on other continents. Reports indicate that temperatures will rise by a minimum of 2.5° C in large parts of southern Africa, while the grazing capacity is expected to decline by more than 30% (Furstenburg and Scholtz, 2009). Romanini *et al.* (2008) predict that an increase of 5 ºC in air temperatures in Brazil may lead to a decrease in pasture capacity of up to approximately 50%. These changes in grazing capacity are substantial.

Ambient temperature is the factor that has the largest direct effect on livestock production. Most livestock performs at their best at temperatures between 4 and 24°C (McDowall, 1972). In the tropics and subtropics temperatures frequently rise above this comfort zone and it is therefore important that livestock are adapted to these higher temperatures (Linington, 1990). Maximum daily temperature is not the biggest problem, but if the minimum night temperature does not drop to below 20°C, un-adapted cattle will suffer from tropical degeneration (Bonsma, 1980). High temperatures and solar radiation decreases intake in order to reduce digestive heat production, and reduce grazing time (animals do not graze in hot midday hours), whereas sweating and water intake increases. Other factors involved in thermal comfort include the external coat of the animal (thickness, structure, thermo isolation, absorption and reflectivity) and body traits (shape, size and superficial area) (Bonsma, 1983; Silva, 2000).

Nutritional stress has the largest indirect effect on the grazing animal in the tropics and subtropics. In these environments, natural pasture has both lower nutritional value and lower tiller density than in temperate regions (Linington, 1990). These tropical grasses (C_4) have developed a different photosynthetic pathway to adapt to the climate. The C_4 refers to a 4 carbon compound compared to a 3 carbon compound (C_3) in temperate grasses. C_4 plants have a higher photosynthetic rate, which results in high fibre content, low stem to leaf ratio, reduced digestibility and intake (Leng, 1984). C_4 grasses also result in higher enteric methane production during fermentation than C_3 grasses.

Another consequence of climate change is altered patterns of diseases in animals, which may include the emergence of new disease syndromes and a change in the prevalence of existing diseases, particularly those spread by biting insects. Animals will therefore be exposed to different parasites and diseases (IPCC, 2007) as indicated from the predicted change in the distribution of, for example, Tsetse in Africa (Herrero, *et al.*, 2008); putting an even greater pressure on production and the survival of livestock breeds. Rift Valley Fever and East Coast fever are other diseases whose distribution may be effected.

Climate also plays a vital part in determining distribution of ticks, which are responsible for diseases such as Red Water, Gall Sickness, Heartwater, Corridor disease, and East Coast fever.

As a result of global warming, livestock in the developing countries of the southern hemisphere, will need to adapt to higher ambient temperatures, lower nutritional value of the grass in some cases, and expansion of diseases, especially ticks and tick borne diseases in Africa (Scholtz, *et al.*, 2009). Under such challenges balancing genotypes with production environments will become a crucial element requiring the utilization of diverse genetic resources with the appropriate genetic potential for growth, milk production, resistance to disease and prolificacy (Blackburn and Mezzadra, 2006). The question is how to measure adaptation and how to select for it.

2.3 Adaptation

Adaptability of an animal can be defined as the ability to survive and reproduce within a defined environment (Prayaga and Henshall, 2005) or the degree to which an organism, population or species can remain/become adapted to a wide range of environments by physiological or genetic means (Barker, 2009). An improved understanding of the adaptation of livestock to their production environments is important, but adaptation is complex and thus difficult to measure (Scholtz, *et al.* 2009). Extensive research has been conducted on the direct measurement of adaptation. This included direct measurements on the animal such as rectal body temperature, respiration rate, heart (pulse) rate, sweating rate (water loss), skin thickness and hair per cm^2. In addition, more sophisticated measurements investigated, included the heat tolerance test where the difference in body temperature was measured before and after exposure to extreme heat, and temperature change associated with exercising the animals (Bonsma, 1980; 1983; McManus, *et al.* 2009).

Several proxy-indicators for adaptation are available and have also been used (McManus, *et al.*, 2008). These include reproductive traits such as fertility, survival, birth rate and peri-natal mortality; production traits such as growth rate, milk production, low mortality and longevity; and health traits such as faecal egg counts and number of external parasites (Bonsma, 1980, 1983; Spickett *et al.*, 1989; Scholtz *et al.*, 1991; McManus *et al.*, 2008).

2.4 Description of production environments

Adaptation can also be characterized indirectly by describing the production environment in which a breed or population has been kept over a period of time and to which it has become adapted (Scholtz *et al.*, 2009). By describing production environments in more detail it would be possible to identify breeds or genotypes that may be adapted to the changed environment of an area (FAO/WAAP, 2008). It will thus be necessary to link animal performance with the production environment. Such information can then be factored during genetic evaluations either as part of the predictive model or as a "post breeding value prediction" calculation. This will require further research to identify and prioritize variables that can describe the genetics, management and climate of each herd more accurately.

Good quality environmental data describing production environments already exists (FAO/WAAP, 2008). Variables on temperature, relative humidity, precipitation (including variation in rainfall), day length and radiation are available through Geo-referenced Information Systems (GIS) layers. It is therefore important that GPS waypoints are recorded with the animal performance information. Likewise, levels of toxins (e.g. aflatoxins, phyto-toxins, excesses of some minerals, salts and tannins) can also be related to specific geo-morphological formations and geographical positions thus can be easily linked to the relative performance of animals.

2.5 Methane production

Methane makes up 16 % of total world gas emissions and is therefore the second most important greenhouse gas (GHG) (US-EPA, 2006). Despite the highest concentration being carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have a heating potential 23 and 296 times higher than CO_2, respectively, due to the higher atmospheric warming activity of these compounds (Clark *et al.*, 2001).

Human-related activities producing methane include fossil fuel production, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning, and waste management. Natural sources of methane include wetlands, gas hydrates, permafrost, termites, oceans, freshwater bodies, non-wetland soils, wild ruminants (game) and other sources such as wild fires. It is estimated that more than 60 percent of global methane emissions are related to human activities (IPCC, 2007).

Enteric fermentation (animal digestive tract) is the main source of methane and is responsible for 28% of global CH_4 emissions, followed by natural gas (15%), waste management (13%) and rice cultivation (11%) (US-EPA, 2006). Factors that influence enteric methane production in livestock are level of feed intake, diet composition, digestibility and quality of roughage, forage or cultivar species, C_3 versus C_4 grasses, and variation between animals.

In ruminants, CH_4 is produced by a specific group of bacteria called methanogenics, (Moss, 1993), whereas CH_4 may also be produced by protozoa's, which may account for up to 20% of methanogenic microorganisms. As CH_4 cannot be metabolized by the animal or microorganisms, it is partly absorbed by the rumen wall and enters in the blood stream where it is eliminated in respiration. However, most is eliminated by eructation with CO_2 (Kozloski, 2002). From a nutritional point of view, methane represents a loss of energy by the animal of between 6 and 10% which is not converted to a product (meat, milk, wool, etc).

Greenhouse gas (GHG) emission from livestock is measured either in terms of kg CO_2 equivalent per kg of meat or milk available for consumption, or per area of land used. In the case of ruminants extensive systems are usually found to have a lower per-area footprint than intensive grain-fed systems but a higher footprint if expressed in terms of kg/product (Garnett, 2010).

Some studies have shown that the use of tanninferous legumes alone or in combination with grasses in pastures for ruminants, may reduce enteric methane emissions per unit of dry matter consumed (g CH_4/Kg DMC) without affecting production performance (Pinares-Patino *et al.*, 2003). However, most research has focused on manipulating animal diet in an effort to create a rumen environment unfavorable for methane production. Other options to combat enteric fermentation such as genetic engineering and the use of additives may be options (Beauchemin *et al.*, 2008), but further research and development is needed before such options can be employed.

A very important aspect is that the genetic improvement of livestock results in permanent and cumulative changes in animal performance (Wall *et al.*, 2009). Selection for productivity and efficiency will mitigate greenhouse gases in two ways: firstly, higher productivity leads to higher gross efficiency as a result of diluting the maintenance cost of animals; and secondly, a given level of production can be achieved with fewer higher yielding animals. Wall *et al.* (2009) reported variations between animals, between breeds, and across time, providing the potential for improvement through selection.

Nkrumah *et al.* (2006) reported that beef cattle with low residual feed intake produced up to 28% less methane than those with high residual feed intake. Residual feed intake is calculated as the difference between actual feed intake and the expected feed requirements for maintenance of body weight and a certain level of production (Hegarty *et al.*, 2007).The lower methane production was attributed to differences in rumen microbial population and Nkrumah *et al.* (2006) stated that the differences could be heritable.

Goopy and Hegarty (2004) found large variations in methane emissions between animals (Friesian Jersey crossbreds) at the same level of production and fed the same diet. "High" and "low" methane emitters were identified on identical feed and feed intakes. The reason for the reported differences is unclear, but they assumed that factors such as the rate of passage, microbial activity, fermentation conditions and grazing behavior could play a role.

2.6 Recording and improvement

Animal recording forms the backbone of any improvement programme. If traits are not measured and recorded no improvement is possible. Countries such as Argentina, Brazil, Namibia and South Africa have very well organized recording and improvement programmes in place. In South Africa the major improvement programme is the National Beef Recording and Improvement Scheme supported by government and managed by the ARC (Agricultural Research Council), whereas in Brazil, successful beef breeding schemes are run by private companies, together with universities and EMBRAPA (Brazilian Corporation for Agricultural Research).

However, performance recording in many developing countries is difficult since the breeding objective may include many traits, some of which can not be easily measured or quantified. Furthermore, organizational and institutional bottlenecks, including inadequate funding and staffing lead to inconsistencies in systems where governments are in charge of official performance and pedigree recording. Uganda and Kenya offer good, yet contrasting examples of where the public sector support livestock recording, but with little success or impact being realized to the former (personal observation). Through private farmer initiatives and building of strategic partnership with international organizations such as ILRI, Kenya's beef recording is now picked up from a near collapse a few years ago. Although data can easily be recorded at ranch or farm levels, adequate computing/processing facilities are not always available leading to delays or total lack of feedbacks to the farmers, thus rendering such recording exercises almost useless (Kosgey *et al.*, 2010).

Opportunities of using the modern information technologies such as mobile phones, to relay raw data to central data processing centres exist, but are yet exploited. Other constrains include rigid rules on recording, even when such rules do not add much value. For example, in some countries, breed societies, which are may be exclusive clubs actually hinder livestock recording, by not accepting own recorded farm data, and insisting on some form of inspection, and by-laws on breed standards and registration. By insisting that only officially registered animals can be recorded, opportunities to exploit the huge genetic variation in the population are lost.

Wurzinger *et al.* (2009) and Kugonza (2009) examined the ranking or scoring of animals for a trait rather than measuring the trait directly, even for traits that are easy to measure. They concluded that if animals can be ranked reasonable accurately for a trait of economic value, direct measurements may not be necessary. It also appeared that ranking is more accurate than scoring.

There are large differences between breeding cattle for the subtropics / tropics and temperate areas, the main difference being in trait definition. Cattle in subtropical and tropical environments are subjected to numerous stressors (Prayaga *et al.*, 2006), e.g. parasites (tick and tick borne diseases, internal parasites, flies), seasonally poor nutrition, high temperatures or high daily temperature variation, humidity (both high and low) and temperament (exaggerated by extensive production systems).

In these cases management interventions may be possible, but they are difficult and expensive to implement, particularly in poorly adapted cattle. The best method of ameliorating the effects of these environmental stressors to improve productivity and animal welfare is to breed cattle that are productive in their presence, without the need of managerial interventions.

Statistical science continues to support animal breeding and improvement, and very sophisticated, high-dimensional, models have been applied in this field (Gianola, 2006). The challenge now is to identify fixed and random effects, in respect of quantitative breeding technology, that account for spatial and temporal variation in production environments for use in genetic evaluations (Scholtz, *et al.*, 2009). Further research is needed to identify and prioritize variables that can describe the genetics and management levels of each herd more accurately (Neser *et al.*, 2008). The estimation of separate breeding values (EBV's) for different production environments may even be necessary in extreme cases.

As mentioned earlier, proxy-indicators are available to use in selection for adaptation. Unfortunately it is only in the case of growth traits that quantitative breeding technology has succeeded in the prediction of breeding values that are not problematic. Traits linked to fertility and/or survival (days to calving, calving interval, stayability, calving tempo) are all influenced significantly by management or arbitrary decisions taken by breeders or scientists (Scholtz, *et al.*, 2009). The appropriate quantitative breeding technology to properly handle these traits still needs to be developed.

With respect to parasite resistance adequate quantitative breeding technology exists and heritability for such resistance seems to be high (Scholtz *et al.*, 1989). Parameters such as levels of parasites in the blood etc. are additional information that can easily be measured and included in evaluation programs.

Efficient recording is also necessary to keep inbreeding under control. Globalization of breeding programs and semen sales have led to a limited number of elite sires being used for insemination, leading to increased inbreeding with a reduction in fitness (Falconer and Mackay, 1996), and a decrease in survival and reproductive performance in cows (Smith *et al.*, 1998). A classical example is the Holstein-Friesian which represents more than 90% of all dairy cattle in USA and more than 60% in Europe. The effective population size for the Holstein-Friesian breed has been estimated at only 60 animals (Hansen, 2006).

Computer programs that enable assigning of breeding mates in such a way that inbreeding is minimized without compromising on the expected genetic gains have been developed (Bergh, 2010; Kinghorn and Kinghorn, 2009), however, for such programs to be useful, accurate pedigree records must be kept and used.

2.7 Genomics

Twenty years ago the first studies to identify, characterize and use molecular markers to characterize genetic resources and generate tools for animal breeding and management were carried out. Over the last 20 years the technologies to generate molecular data went through several innovation cycles, including Restriction Fragment Length Polymorphisms (RFLP) and Single Sequence Repeats (SSR). The first genome wide genetic maps in domestic animals were built using microsatelite markers (Guerin *et al.*, 2003).

With respect to gene or marker assisted selection beef cattle breeders have been promised for years that it will change the way they breed livestock. However, currently only a few of such tests are available for production traits.

Recent research has indicated that the inclusion of information from DNA analysis in the genetic evaluations or estimation of breeding values may result in substantial increases in genetic gain at reduced cost (Meuwissen *et al.*, 2001; VanRaden, 2008; VanRaden *et al.*, 2009). Strategies that utilizes EBVs derived from DNA information (genomic EBVs), together with conventional mixed model methodology, may speed up the process of breeding animals that are adapted to the newly created environment as a result of climate change.

The developments in Quantitative Trait Loci (QTL) (Williams, 2005), and high-throughput SNP's or gene chips (genomic selection based on Single Nucleotide Polymorphisms) may enhance the detection and fine mapping of many genes and QTLs, that for example affect tick resistance. It is foreseen that the utilization of marker assisted selection will play a major role in selection for disease and parasite resistance or tolerance.

Marker assisted selection and proteomics may also be valuable in selection for secondary traits linked to adaptation, such as the gene(s) for high levels of blood urea (N) and ruminal NH_3 in certain genotypes, associated with adaptation to low quality C_4 grasses (Scholtz, *et al.*, 2009).

The most recent innovations include methods to identify and genotype SNP (Single Nucleotide Polymorphism) markers in large scale. High density DNA chips were generated to genotype from tens of thousands to hundreds of thousands of SNPs in a single assay. These new technologies will lead to the development of new applications such as methods to genetically evaluate and select animals (Hayes *et al.*, 2009) based on their Genomic Estimated Breeding Value (GEBV). The first bull summary for the Holstein breed with GEBVs for milk production and quality traits was released in January 2009.

The development of a high-throughput SNP or gene chip may enhance the implementation of marker assisted and genomic selection. A 50k SNP chip is currently on the market for bovines and can make a major contribution towards selection for adaptability. An important prerequisite is the establishment of resource (reference) populations (Meuwissen *et al.*, 2001; VanRaden, 2008; VanRaden *et al.*, 2009) for different environments, which may be costly.

Landscape genomics is also a new field and is a combination of landscape ecology and population genetics aiming at providing information about the interaction between landscape features and micro-evolutionary processes, such as gene flow, genetic drift and selection (Manel *et al.*, 2003). The development of landscape genomics is based on the integration between landscape ecology [such as high-quality remote sensing techniques and geographical information systems (GIS)] and molecular data, as well spatial statistics designed to detect discontinuities in geographical space (Guillot *et al.*, 2005; Kidd & Ritchie, 2006).

Sub-Saharan Africa is characterized by extremely variable environments and is home to many indigenous cattle breeds and combinations of breeds; the latter as a result of both planned and unplanned crossbreeding with exotic beef breeds. The application of landscape genomics offer tremendous opportunities for the better understanding of the different types and complex nature of gene actions and interactions. If properly analyzed, the results can reveal attributes such as genetic adaptation to specific environmental stress causing factors such as diseases, parasites and extreme heat, humidity or lack of water or combinations of thereof.

3.0 Conclusion

Challenges facing beef production in the developing counties of the southern hemisphere include variable and low production levels, the effect of climate change, enteric methane production and low levels of animal recording.

Several new technologies offer opportunities for beef production in developing countries in next few years. These include genomic evaluation methods, together with the development of statistical, bio-informatics, computational and geographical information system techniques.

There is a demand for overlapping research programmes that use molecular tools to empirically evaluate the geographical context of biodiversity patterns by linking genetics, environment and biogeography. In this way, developing countries can be prepared for challenges and make optimum of the use these opportunities as they materialize with changes in environmental and political status in regions and countries. To fully benefit from these technologies, performance and pedigree recorded herds of local breeds in developing countries, especially sub-Saharan Africa countries have to participate in on-going SNP genotyping and sequencing so as to allow for appropriate calibration and development of the appropriate chips that contain adequate information for the local breeds, breed combinations and production systems.

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