Sustainable use and genetic improvement

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Summary

Sustainable use of animal genetic resources for agriculture and food production is proposed as the best strategy for maintaining their diversity. Achievement of sustainable use would continue to support livelihoods and minimize the long-term risk for survival of animal populations. The concept of sustainable use has economic, environmental and socio-cultural dimensions. Sustainable use of animal genetic resources also contributes to food security, rural development, increasing employment opportunities and improving standards of living of keepers of breeds. Supporting the rearing of breeds through better infrastructure, services, animal health care, marketing opportunities and other interventions would make a significant contribution to the sustainable use of animal genetic resources.

Sustainable use envisages the use and improvement of breeds that possess high levels of adaptive fitness to the prevailing environment. It also encompasses the deployment of sound genetic principles for sustainable development of the breeds and the sustainable intensification of the production systems themselves. Sustainable use and genetic improvement rely on access to a wide pool of genetic resources.

Genetic improvement programmes need to be considered in terms of national agriculture and livestock development objectives, suitability to local conditions and livelihood security as well as environmental sustainability. Genetic improvement can involve choice of appropriate breeds, choice of a suitable pure breeding or crossbreeding system and application of within-breed genetic improvement. The choice of appropriate breeds and crossbreeding systems in developed countries has been a major contributor to the large increases in productivity, and has benefited greatly from the fact that developed country animal genetic resources are well characterized and relatively freely exchanged. Where proper steps have been followed by careful assessment of demand, execution, delivery, impact and cost–benefit analyses, successful within-breed improvement has been realized within indigenous populations in developing countries. Breeding objectives and programmes for subsistence oriented and pastoralist systems are likely to be entirely different from conventional programmes. Crossbreeding has been most successful where it is followed by a rigorous selection programme involving livestock owners' participation and substantial public sector investment in the form of technical support. In any genetic improvement programme, inbreeding needs to be monitored and controlled.

Within-breed genetic improvement is normal practice in the developed world, and has become a highly technical enterprise, involving a range of reproduction, recording, computing and genomic technologies. Emerging genomic technologies promise the ability to identify better, use and improve developing world animal genetic resources in the foreseeable future. Useful systems can, however, be established without the need for application of advanced technology or processes.

Résumé

On propose une utilisation durable des ressources génétiques animales pour l'agriculture et l'alimentation comme meilleure stratégie pour la conservation de la diversité. Atteindre l'utilisation durable permettra d'améliorer la qualité de vie et diminuera le risque à long terme de la survie des populations animales. Le concept d'utilisation durable entraîne des mesures économiques, environnementales et socioculturelles. L'utilisation durable des ressources génétiques animales contribue aussi à la sécurité alimentaire, au développement rural, à l'augmentation des opportunités d'emploi et à l'amélioration des standards de vie des éleveurs. Soutenir l'amélioration des races à travers une meilleure infrastructure de services, de santé animale, d'opportunités de marché et d'autres interventions pourrait aider de façon significative à l'utilisation durable des ressources génétiques animales. L'utilisation durable comporte l'utilisation et amélioration des races qui possèdent des hauts niveaux d'adaptation physique aux principaux milieux. Cela comporte aussi l'application de principes génétiques adéquats au développement durable des races et à l'intensification durable des systèmes de production en soi. L'utilisation durable et l'amélioration génétique se basent sur l'accès à une large gamme de ressources génétiques.

Les programmes d'amélioration génétique doivent être considérés en termes d'agriculture nationale et développement des objectifs d'élevage, ainsi que compatible avec les conditions locales de moyens d'existence et d'environnement durable. L'amélioration génétique peut entraîner le choix de races plus appropiées, races plus pures adaptées ou un système de croisement de races et l'application de l'amélioration génétique à l'intérieur de la race elle-même. Le choix de la race et des systèmes de croisement de races dans les pays en développement a été un des facteurs qui a influencé le plus l'augmentation de la productivité et a bénéficier largement le fait que dans les pays développés les ressources génétiques animales soient bien caractérisées et puissent bénéficier d'un mouvement relativement libre. Là où les démarches appropriées ont été suivies à travers des évaluations correctes sur la demande, l'exécution, la remise, l'impact et l'analyse de coût-bénéfice, le succès de l'amélioration à l'intérieur de la race a tout de suite été atteint avec les population indigènes dans les pays en développement. Les objectifs d'amélioration et les programmes pour la subsistance et les systèmes de pâturage seront différents des programmes conventionnels. Les croisements de races ont eu plus de succès lorsqu'un programme de sélection rigoureux a été suivi et quand la participation des éleveurs et une partie du secteur public a été présente en forme d'investissement et appui technique. Dans tout programme d'amélioration génétique il est nécessaire de contrôler et faire un suivi de la consanguinité.

L'amélioration génétique de la race est une pratique normale dans le monde développé et est devenue une entreprise hautement technique qui met ensemble les domaines de la reproduction, le contrôle, l'identification et technologies du génome. Les nouvelles technologies du génome promettent dans un futur proche une meilleure capacité d'identification et l'utilisation et amélioration des ressources génétiques animales dans le monde en développement. Des systèmes utiles peuvent cependant être établis sans la nécessité d'appliquer des procédures ou des technologies à l'avant-garde.

Resumen

Se propone una utilización sostenible de los recursos zoogenéticos para la agricultura y la alimentación como mejor estrategia para el mantenimiento de su diversidad. Alcanzar el uso sostenible contribuirá a la mejora de la calidad de vida y minimizara el riesgo a largo plazo de la supervivencia de las poblaciones animales. El concepto de utilización sostenible conlleva dimensiones económicas, ambientales y socioculturales. La utilización sostenible de los recursos zoogenéticos también contribuye a la seguridad alimentaria, el desarrollo rural, el aumento de oportunidades de empleo y la mejora de los estándares de vida de los ganaderos. Apoyar la cría de razas a través de una mejor infraestructura, servicios, cuidados sanitarios de los animales, oportunidades de mercado y otras intervenciones contribuiría de forma significativa a la utilización sostenible de los recursos zoogenéticos.

La utilización sostenible comporta el uso y mejora de las razas que poseen altos niveles de adaptación de su forma física a los principales ambientes. También conlleva el despliegue de principios genéticos adecuados para el desarrollo sostenible de las razas y la intensificación sostenible de los sistemas de producción en sí mismos. La utilización sostenible y la mejora genética se basan en el acceso a un amplia gama de recursos genéticos.

Los programas de mejora genética necesitan ser considerados en términos de agricultura nacional y desarrollo de objetivos ganaderos, así como compatibilidad con las condiciones locales y seguridad de sustento y sostenibilidad ambientales. La mejora genética puede implicar la elección de las razas más apropiadas, la raza más pura adecuada o un sistema de cruce de razas y la aplicación de mejora genética dentro de la raza. La elección de la raza adecuada y de los sistemas de cruces de razas

en los países en vía de desarrollo ha sido uno de los factores que más ha influido en el incremento de la productividad, y se ha beneficiado ampliamente del hecho que en los países desarrollados los recursos zoogenéticos están bien caracterizados y gozan de un intercambio relativamente libre. Donde se han seguido los pasos adecuados con evaluaciones correctas sobre la demanda, ejecución, consigna, impacto y análisis de costo-beneficio, el éxito de la mejora dentro de la raza ha sido alcanzado con poblaciones indígenas en países en vía de desarrollo. Los objetivos de mejora y los programas para la subsistencia y sistemas pastorales serán mayormente distintos de los programas convencionales. Los cruces de razas han tenido mayor éxito donde se ha seguido un programa de selección riguroso que implique la participación de ganaderos y parte substancial del sector publico en forma de inversión y soporte técnico. En todo programa de mejora genética es necesario controlar y monitorear la consanguinidad.

La mejora genética dentro de la raza es una práctica normal en el mundo desarrollado y se ha convertido una empresa altamente técnica que cubre los campos de reproducción, control, computo y tecnologías de genoma. Las nuevas tecnologías de genoma prometen la capacidad para identificar mejor y la utilización y mejora de los recursos zoogenéticos del mundo en vía de desarrollo en un futuro próximo. Los sistemas útiles pueden sin embargo ser establecidos sin la necesidad de aplicar procedimientos o tecnologías de vanguardia.

Keywords: *Targeting breeds, Production systems, Market access, Adding value, Dissemination, Sustainable breeding programmes, Technology, Intellectual property.*

Introduction

Sustainable use "*is the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations*". This is the definition of "*sustainable use*" proposed in Article 2 of the Convention on Biodiversity (CBD). *The State of the World's Animal Genetic Resources for Food and Agriculture* (SoW-AnGR) (FAO, 2007) identified key elements of this concept as it applies to animal genetic resources. It reviewed existing concepts but did not attempt a comprehensive description of the state of the art. The general conclusions of the SOW-AnGR were that there is a need for the concept of "*sustainable use*" to be "*interpreted in the context of agricultural biodiversity, and for concrete management strategies to be developed for AnGR*". After the drafting of SOW-AnGR, FAO held an expert meeting that identified the guiding principles of sustainable use, made specific recommendations addressing relevant aspects of the concept and focused on work required to clarify and develop the concept further (FAO, 2006a; FAO, 2008). This paper describes the state of the art of scientific thinking on the key technical issues, options and opportunities in relation to sustainable use of AnGR.

Animals are reared in production systems, each with its unique geographical, environmental, cultural and socio-economic context. Sustainable use of animals for agriculture and food production in robust, ecologically compatible production systems is widely accepted to be the best strategy to maintain their diversity. Continued use of animal genetic resources within the environment in which they were developed provides a number of advantages, including maintenance of local knowledge about how best to manage the animal, maintenance of the production environment, and continued opportunities for the livestock to adapt to local production conditions and the needs of the society (FAO, 2006a). However, allowing movement of animal genetic resources to new locations and production and market systems is also a way of promoting their sustainability. Use of animal genetic resources inevitably includes development. Animal genetic resources are dynamic resources, changing with each generation in interaction with the physical environment and according to the selection criteria of their keepers (Wurzinger *et al*., 2006). The concept of sustainable use therefore encompasses genetic improvement.

Even in the most rapidly developing countries, there are striking inequities in access to the benefits of economic development. Many families continue to keep a few animals of traditional breeds, often with very low use of external inputs, to provide a wide variety of products and services for household consumption and for sale in local markets. The development of opportunities for most of these families to intensify production and participate in national or niche markets or to find more lucrative non-agricultural employment is not likely to occur in the near future. In the meantime, continued access to well-adapted, local animal genetic resources will remain important for them (FAO, 2006b). Support for sustainable use of animals in developing countries will thus contribute to the broader socio-economic goals of livelihood security and rural development, increasing employment opportunities and standards of living in rural areas and reducing migration to cities. Animal genetic resources play an important role in maintaining vital rural areas in developed countries also. In addition, in both developing and developed countries, animal genetic resources supply nutritious, protein-rich foods to people.

This paper discusses opportunities to enhance sustainable use of animal genetic resources, given the identified drivers of change articulated in the first paper in this series, mainly in agropastoral systems in marginal areas and crop–livestock systems in high potential areas. This focus is justified because industrial production systems using commercial breeds are already well developed, supported by heavy investment of capital, other resources and knowledge, and have efficient monitoring and corrective mechanisms in place if needed. The paper also presents the current scientific understanding in the area of genetic improvement and sustainable breeding programmes for development of animal genetic resources. The impact of revolutionary technologies in the field of genetic improvement and issues related to intellectual property rights are also discussed.

Facilitating sustainable use within production systems

Animal genetic resources form the basis of the livelihood and the cultural identity of a large number of farming and pastoral groups. Livestock have a critical role in maintaining sustainable agricultural systems, assuring food security and alleviating poverty. This role is especially important given the prospect of climate change or emerging diseases and the unpredicted rate and consequences of such change. It is expected that sustainable use would lead to the maintenance of vibrant and vigorous populations of breeds in their appropriate production systems. Increasing the profitability of rearing animals, particularly by increasing their market value, as well as enhancing their non-market values can maximize the probability of their continued use in the long term. Adaptive fitness and increased productivity can be achieved and maintained more effectively by improving inputs, environmental conditions and genetic resources concurrently. There is a range of alternatives and opportunities available for such facilitation including institutional strengthening. There are, however, also many examples where opportunities have been wasted or inadequately exploited due to inappropriate policies and lack of support in critical areas (Philipsson, Rege and Okeyo, 2006).

Targeting breeds that require interventions

In general, more effort to promote sustainable use needs to be directed to those breeds that are likely to become threatened without support. Another factor to be considered in the targeting of interventions is the specific characteristics of breeds that make them unique – for example, adaptive traits such as disease and heat-resistance or specific feeding behaviour. Other criteria might include a focus on breeds that are specific to restricted regions or are unique in terms of their genetic, morphological, functional or cultural characteristics or the products that they produce. Development of a breed is likely to be more successful where there is a local community that highly values the breed in question and has a long history of local knowledge and experience of working with the animals. Continuous monitoring of the status of breeds by periodic breed surveys and censuses would help to provide information on population trends and impending threats. Such data can inform decision-making and help in formulating sound development schemes. This aspect is dealt with more comprehensively in the companion paper on characterization.

Strengthening production systems

Breeds fit into specific production systems and agricultural landscapes. If particular production systems disappear, the associated animal populations may no longer continue to be used sustainably. Strengthening these production systems so that they are robust in the face of changing circumstances would support the sustainable use of animal genetic resources. Various ways of strengthening these systems are elaborated below.

- Opportunities for small changes in farming systems. Small changes in farming systems, designed according to the prevailing climate, resource profile and agricultural practices, can make livestock rearing more profitable and beneficial to the farming system and thus more sustainable. One example is to use novel ways of integrating crop farming and livestock rearing such as ley farming. Another example of an alternative model of farming using livestock is growing grass/leguminous forage on marginal, rainfed lands and rearing livestock instead of sowing grain crops that usually do not yield any grain because of inadequate rainfall.

- Provision of technical services. In some cases, technical improvements to animal nutrition, management and health may improve the economic viability of animal populations. The sustainability of animal genetic resources in existing production systems could be improved substantially by provision of basic veterinary services, including disease prevention measures such as vaccination. Improvements in management and genetics go together in reality as changes in one create new opportunities for the other. Provision of credit to purchase animals and for capital expenditure and a reliable supply of feed resources can provide significant impetus to the rearing of endangered breeds. These services may have to be tailored to specific needs – for example, they need to be mobile for nomadic herding. Other improvements to rural and agricultural infrastructure would also encourage livestock rearing in addition to other general benefits, for example by improving market access through provision of market information and objective pricing structures.
- Ensuring continued resource availability to livestock keepers. Sustainable use of animal genetic resources is closely linked to the continued availability of adequate grazing and water. Pastoralist production systems are increasingly under threat worldwide. The reasons for this are numerous:
  - deterioration of natural pastures as a result of droughts, inappropriate management of grazing and soil erosion;
  - curtailed access of livestock to common property resources;
  - diversion of grazing lands to other uses such as irrigated crop-farming, establishment of industries, urbanization or creation of national parks;
  - increasing difficulties in migration owing to increased cross-border disease-related controls, and traffic and highway codes that restrict livestock movement along and across major highways.

There are also other increasing demands, such as for biofuel production, on common property resources and government lands in almost all countries. A pragmatic approach would be to take into account the vital role of animal genetic resources in diverse spheres, from production of much-demanded animal protein to maintenance of fertility of farmlands and creation of space for animal genetic resources in land-use plans (Köhler-Rollefson and LIFE Network, 2007).

- Capacity building. Training will help to inform livestock keepers of the latest scientific developments applicable to their livestock, such as availability of new vaccines, and will help to protect them from inappropriate advice (Malmfors *et al*., 2002). Training should build upon existing local knowledge of the production system and enable livestock keepers to make informed decisions.
- Improving the status of animal genetic resources by raising awareness among policy- and decision-makers. Sustainable use of animal genetic resources has not achieved a high priority in the strategies of many governments or national and international funding agencies. In the Consultative Group on International Agricultural Research (CGIAR), institutional capacity and availability of funds are generally skewed heavily towards the plant sector (FAO, 2006b). Animal husbandry usually gets a raw deal compared to crop farming in governmental financial allocations because of inadequate awareness of policy-makers of the importance of livestock. It is therefore necessary to raise the awareness of the contribution of livestock to national economies and to the well-being of large numbers of families to give a higher profile and status to livestock rearing. Raising awareness will help in encouraging policy-makers to develop sound policies that are beneficial for sustainable use of animal genetic resources rather than policies that may have an adverse impact on livestock rearing. For example, supportive public policy and long-term technical support systems are largely responsible for the success of the dairy subsector in India (Kumar, Birthal and Joshi, 2003).
- Promoting "*organizations*" of livestock keepers. A key aspect to promoting sustainable use is creating or strengthening structures to organize the keepers of animals and help motivate communal efforts (Kosgey & Okeyo, 2007). Organizations are stronger than individuals and can safeguard group interests better, by advocacy with authorities. In the longer term, building these structures may serve a capacity-building role – allowing livestock

keepers better access to information, strengthening their position in relation to extension services, facilitating the organization of training and improving bargaining power when marketing products. In Europe, there are strong farmer cooperatives and breeding organizations that go back a century and have also received much public support over the years.

Improving market access and promoting novel uses of animal genetic resources

Developing markets for livestock breeds, their products and services

The value of animal production can be increased by marketing products more effectively. Ease of marketing and lucrative prices for animals and their products can provide the biggest boost for continued use of animal genetic resources (Boxes 1 and 2).

Development of niche markets is also important from the perspective of promoting sustainable utilization. Niche markets rely on creating perceived value regarding the conditions of production, product quality or a combination of these. Consumers that particularly value food quality or specific production methods are the most likely to purchase specialized niche products such as Parmigiano Reggiano cheese produced from Regianna cattle in Italy, high-value cured pork products from Iberian pigs reared in oak-forest production environments in Spain and meat from the black boned chicken breed in Viet Nam, known for its medicinal value. One of the ways to create demand for products of breeds reared in pastoralist systems with no chemical inputs is to market them as "*range-fed*" or "*fed on natural vegetation*". Such products could also benefit from "geographical indication" recognition.

In almost all areas of India, a niche market for local breed chickens and eggs, perceived to be "*high-quality*" and therefore more expensive, exists side by side with broiler chicken and commercial layer hen eggs. Similarly, in Malaysia, meat from the Kampong chicken is considered to be better tasting than the commercial breeds. In the United Kingdom, a ready market was developed for beef from Angus cattle as high-quality beef (with high marbling), which served to increase the Angus population. The measures adopted for this included promoting Angus beef through a restaurant chain. The fragility of some such niche markets is, however, demonstrated by the collapse of the restaurant chain following the outbreak of mad cow disease.

Novel uses for animals and animal products

New uses have been developed for animals and their products with desirable consequences for continued maintenance of animal genetic resources. The unique immune system enhancement properties of Panchagavya (a mixture of milk, curd, ghee, urine and dung of indigenous cows prepared according to a recipe from ancient Ayurveda [Sushruta Samhita, 1985]), identified by new research (Chauhan *et al*., 2004) have led to new marketing possibilities in India and Sri Lanka. A non-governmental organization (NGO) in Rajasthan, India, has successfully introduced camel milk ice cream (desert dessert) as part of a comprehensive strategy to make camel rearing more profitable. Research in the United States of America on "*aversive conditioning*" using boluses with lithium chloride (Mueller, Poore and Skroch, 1999) shows that sheep can be trained to bypass the tender shoots of grapevines and trees for the weeds sprouting underneath.

Promoting use of animals in landscape conservation

Use of traditional grazing livestock for landscape heritage and biodiversity maintenance and for nurturing more complete ecosystems is a growing management practice in many developed countries. In the United Kingdom and Europe, and specifically the Balkans, the role of grazing livestock has been recognized as critical in the maintenance of wildlife and native plant biodiversity in many high nature value ecosystems. In the Mediterranean, grazing for shrub control helps to reduce forest fires. Cultural tourism associated with the unique culture of rearing local breeds has been expanding rapidly in Europe and also in South America where camelids are great attractions at parks and tourist sites. Similar approaches are needed in other developing countries, since here too particular breeds have shaped certain landscapes. Functioning pastoralist systems also have value as tourist attractions, besides contributing to ecosystem health.

Box 1. Adding value to Nguni cattle

The Nguni of South Africa is an African taurine breed with a slight admixture of zebu blood that reached the region together with southward migrating pastoralists in about 300 AD. After white settlers arrived with exotic cattle, the Nguni cattle were long perceived as inferior because of smaller carcass size, non-uniform colour pattern and lack of information on their production potential. Even the people who had originally kept this breed started crossbreeding or keeping exotic cattle. Research in the 1980s then revealed that the Nguni breed is very tick-tolerant, can maintain its condition during seasonal food shortages, can obtain optimal nutritional value from the available forage, is a good walker and very docile. Its adaptation to harsh extensive production systems offers many advantages to smallholders. The Animal Improvement Institute has therefore initiated a project to supply selected Nguni bulls to smallholders together with training and infrastructural support. Nguni cattle have a wide range of colours. The colour variation indicates the cultural heritage of the breed, which has been raised by African stockmen for centuries. Colour variation frequently had a ceremonial and symbolic importance. The colourful Nguni hides are much in demand these days for pelts that are tanned with the hair on, for use as rugs, clothing and home furnishings. Being able to predict and generate specific colours has taken on a new economic aspect as these uses have recently increased. In addition, certain colours or pigmentation patterns (such as pigmented skin beneath white hair) can be helpful in adaptation of animals to harsh conditions of high solar radiation. All three of these factors (tradition, utility, adaptation) combine to make colour important for Nguni breeders, and unravelling the details of colour genetics can be useful for them (Köhler-Rollefson, 2004; Sponenberg, 2007).

Box 2. Value-adding to peri-urban dairy farming in Latin America

Straddling the border of Peru and Bolivia, the Altiplano – a high-altitude plain at 4 000m above sea level – is one of the poorest regions in the world. At such high altitudes, the environment is unforgiving: drought and extreme cold are common. The region supports six million people, who mostly depend on agriculture. Potato is the staple but crop failure is a regular occurrence and many families live in extreme poverty. However, for some Altiplano farming families living close to urban centres, nutritional and income stability is not completely unattainable. Milk production is growing in importance in the region and a pilot project, under the ALTAGRO initiative of the International Potato Center (CIP) and its partners, has created a market in several large towns for cheese made from local cows' milk. Most households in the area earn around US$1 per day. With this initiative, dairy producers have more than doubled their income, with some now earning up to US$850 per year. The ALTAGRO project, financed by the Canadian Government, has supported the construction of two small dairies in Atuncolla-Illpa, a Peruvian town with a population of 10 000 people. A training plant set up at the experimental station of the Instituto Nacional de Investigación Agraria (INIA, Peru's National Agricultural Research Institute) is providing technical assistance to farmers and processors in how to transport the milk and process it into cheese (*www.new-ag.info/07/04/focuson/focuson1.php*).

Research and dissemination of research results

Public-funded applied research needs to focus on improving livestock rearing as an integral part of production systems and finding innovative solutions to real problems rather than on obscure theoretical topics. Successes as well as failures need to be published in order to capitalize on experiences. Research on the beneficial interrelationships between livestock and their environment and the necessity of livestock to maintain the sustainability of the landscapes they use is likely to provide enlightening results (Lewis, 2003). It is important to publish research results in accessible sources to ensure wider dissemination.

Promoting sustainability as the main objective

The supporting interventions should be such that they create an enabling environment to make livestock rearing self-sustained in the long term rather than dependent on outside support. If support is withdrawn due to a change in the macroeconomic situation or in the government, the livestock rearing system it has strengthened should not collapse. In fact, consequences of interventions could be tested against the potentiality that the support may be terminated.

Appropriate strategies for sustainable use will differ from country to country or among groups of countries because of the large differences among areas of the world, especially in terms of gross national product and available technology (Gandini and Oldenbroek, 2007).

Genetic improvement and sustainable breeding programmes

Introduction

The concept of sustainable use encompasses the development of animal genetic resources, ensuring that they remain a functional part of production systems, and the sustainable intensification of these production systems. Genetic improvement is the systematic exploitation of genetic variation in important traits among individuals within or between breeds. Breeding programmes for animal genetic resources are generally undertaken in order to improve their productivity and the quality of food and products derived from them and to ensure the availability of such food/products at affordable prices. Genetic improvement of livestock has made and will continue to make major contributions to agricultural development, food security, sustainability and livelihoods. In high-input production systems, which are common in the developed world, modern chicken and pig hybrids consume less than half the feed per kilogram of meat produced than the strains of 50 years ago. Such genotypes cannot, however, stand the harsh rigours (disease challenge, poor-quality feed, high temperature) of the low-input, livelihood-focused systems in most of the developing countries. The high feed conversion efficiency has allowed the demand for meat of affluent societies to be met from a greatly reduced land area, thus releasing large areas of agricultural land that would otherwise have been required to produce poultry and pig feed. The importation of these improved genetics along with their associated production systems into developing countries has benefited consumers through availability of cheap broiler meat and pork and has also brought profits to farmers, although some other farmers were crowded out of markets because of these developments. There are other examples of benefits (with some qualifications) in the developing world. For example, the use of improved dairy genotypes has allowed the development of a large informal milk market that has dramatically improved smallholder livelihoods and human nutrition in the densely populated highlands of Kenya. A recent study has, however, shown that these animals are of higher milk potential than tropical climates and feed resources can support. In some situations, this resulted in drastic reductions in farmers' profits (King *et al.*, 2006).

Genetic improvement can take many forms, but generally and logically follows an ordered hierarchy of events. This starts with understanding of the production and marketing systems, choice of appropriate breeds or strains (sometimes resulting in replacement of existing breeds), establishment of an effective pure breeding or crossbreeding system, and then further improvement through selection of superior genotypes within populations that best suit the production and market conditions. The past 50 years have seen a drastic change in breed use. As a consequence, genetic improvement in the developed world is now primarily based on a few breeds and within-breed improvement. Almost all pigs in developed country markets are, however, crossbred and some strategic crossbreeding is being undertaken increasingly in cattle and sheep. In the developing world, most genetic change is taking place through change of breeds via crossbreeding programmes aimed at "*grading up*" of indigenous breeds towards exotics from the developed world. Systematic within-breed improvement is much less prevalent, although livestock keepers themselves continuously make decisions to keep and cull animals according to criteria they consider important. However, apart from a few cases, most of the structured breeding programmes have seen limited success, mainly because of inadequate understanding of the prevailing agro-ecological and marketing conditions.

Within-breed improvement

Within-breed genetic improvement programmes are routine for all the breeds and strains of livestock used in the dominant livestock production systems of the developed world. The genetic improvement typically accounts for 40 to 60 percent of the annual productivity gains in these systems. In the developing world, however, within-breed improvement to improve productivity is not common and has not often been sustainable. The relative lack of effort is partly due to the perception that greater genetic change is possible through the choice of specialized and improved exotic breeds and strains and crossbreeding systems. However, inadequately planned crossbreeding programmes have seen as much failure, if not more, as within-breed improvement programmes. Lack of suitable infrastructure, expertise and sustained government support has also hampered the establishment of within-breed improvement programmes in developing countries. Many factors have contributed to the lack of success in existing programmes – inadequate initial characterization of local populations, lack of participation of smallholder beneficiaries, inadequate dissemination mechanisms, inadequate or unsustainable infrastructure and expertise and/or rapid evolution of production systems (such as breed replacement), apparently eliminating the need or demand for the improved stock. Successful application of within-breed improvement is undoubtedly attainable in the developing world, but requires more careful assessment of demand, execution, delivery, impact and cost–benefit analyses.

Within-breed improvement presents a particular challenge in subsistence-oriented systems. It has to be based on adequate knowledge of the breeds in question and of the production system. Serious consideration has to be given to social, economic and environmental sustainability in this situation. Potential strategies for breed development appropriate to the local conditions and in keeping with the country's overall livestock development objectives should then be identified, assessed and prioritized (Box 3).

Generally, breeding objectives have focused on increasing productivity, often measured at the individual animal level. However, breed improvement should take into account the full range of attributes that make production systems sustainable. Selective breeding efforts can vary in scope from highly organized breeding programmes through to simple culling decisions based on individual phenotypic information under less controlled environments. The choice of methods will depend on the objectives of the breeding programme, their acceptability to the whole spectrum of stakeholders, access to improved genetic resources and the technology and infrastructure available.

In harsh mountainous or arid rangelands and pastoral systems where the environment and markets are unlikely to change in the medium to long term and where existing genotypes are well adapted, simple within-breed selection programmes focusing on as few traits as possible provide the best approach. The traits to be included need to be easily recorded for the animals to be selected and depend on the primary use of a breed. They will be multiple for multipurpose breeds. While natural selection will take care of many adaptive traits, fertility of male animals needs to be considered based on the results of a first mating season. When the environment and market requirements are changing, then more planning, better designs and institutional integration/coordination are required.

Where proper steps have been followed, successful within-breed improvement has been realized, even within indigenous populations in developing countries. The improved Boran cattle in Kenya, the Nguni cattle in South Africa, the Tuli cattle of Zimbabwe and the Murrah buffalo programme of India (with some limitations) are success stories in regions where many programmes have failed. What is unique about all these examples is that the production, policy and market environments were well understood, the locally available genetic resources/breeds were well

Box 3. Community sheep breeding programme in Peru

In the highlands of the Sierra Central in Peru (an isolated high mountain range environment at an altitude of about 4 000 metres above sea level), dual purpose Corriedale sheep and native-type sheep with different levels of exotic upgrading are kept in an extensive pastoral system. A survey conducted in 1996 identified three types of sheep production systems: individual family flocks, communal flocks belonging to villages and multicommunal flocks managed by cooperatives often involving several villages in a region. The survey identified two major requests of farmers related to breeding: the need for suitable rams and the need for training in breeding techniques. After extensive discussions, an interesting breeding structure based on the open nucleus concept was established and made functional. The land and labour necessary to run the nucleus were provided by the communities based on a series of arrangements and technical support was provided by the university. The nucleus was established by mating imported and locally produced top rams with 50 "*best*" females of each of nine communal and multicommunal flocks. Half of the ewes were returned pregnant to the suppliers and the other half were used for starting a central nucleus providing improved rams to communal and regional flocks, which in turn also provided rams to family flocks. Incidentally, the progeny of local rams proved to be better suited to the local market conditions than the progeny of imported rams. Farmer organization and farmer training are the backbone of this successful community-based sheep breeding programme, which is still in operation (Mueller, Flores and Gutierrez, 2002).

evaluated and simple selection criteria agreed upon and implemented.

Intensive selective breeding will inevitably result in some reduction in genetic diversity within the breed. Systems for allocating breeding males to females based on the relative genetic contributions of parents have been developed to optimize genetic improvement while minimizing the rate of inbreeding (e.g. Sonesson and Meuwissen, 2000). These are used in commercial breeding and can be applied to local breeds if animals are appropriately identified and their pedigrees recorded accurately.

Choice of breeds and cross-breeding

The matching of appropriate breeds to evolving production systems has been a major contributor to growth in productivity and improvement of product quality in the developed world. This has been possible because developed world breeds and strains are relatively well characterized and are easily accessible through established processes such as genetic evaluation rankings and semen and breeding male distribution schemes. In the developing world, most animal genetic resources are inadequately characterized and access to animal genetic resources from other developing countries is often difficult or impossible. In fact it is ironic that recently developed well-intentioned instruments such as the Convention on Biodiversity may hamper the sharing of breeds across countries even if it appears to be the most technically logical option and would actually contribute to the maintenance of agricultural biodiversity. Unless livestock genetic resources of the developing world are better characterized and made more accessible, it is inevitable that the choice of breeds and strains for breed replacement and crossbreeding will be dominated by those of the developed world. This is evident, given the strong marketing strategies of the improved livestock genetics companies from the high-input systems of some developed countries. This may severely restrict the options of developing countries to develop their local breeds to meet goals for agricultural and economic development, sustainability and improvement of livelihoods.

With now widely predicted climate changes through direct and indirect effects (i.e. reduced number of growing days, hence herbage yields, increased disease outbreaks and challenges), the developing regions of the world's production systems are likely to be severely affected. Therefore, the need to source appropriate (those that best match the predicted future scenarios) breeds and genes from one developing country to another would be the most logical option. For example, if, as a result of global climate change, most of the sub-Saharan regions receive less rainfall and have hotter climates than currently is the case, then instead of embarking on long-term within-breed improvement of local breeds to match the predicted future environments in the affected areas, it would be better to access and move breeds. For example, Kenana and Butana cattle breeds of the Sudan that are already naturally adapted and reasonably productive under a harsh environment could be moved to those areas where harsher conditions are expected in future. Such realities add a new dimension to the potential utility of indigenous breeds.

In pastoral systems, and when market opportunities for improved milk and meat production exist but where large erratic environmental changes such as droughts are common, livestock keepers may maintain a range of diverse genotypes, some of which can survive drought conditions. Traditionally, pastoralists may keep a mix of species and breeds in their herds to maximize the advantages of good seasons and to reduce risk during bad seasons. For example, crossbred animals generated by crossing locally adapted females to an improved "*exotic*" breed male may be more profitable than their local purebred mothers when conditions are good, but may be the first to die when there is a bad drought. Farmers may use some indigenous breed sires and some exotic sires on parts of their herds/flocks while practising within-breed selection in part of the herd/flock. A good example is the Ankole cattle breed in the African Great Lakes region, where many keepers of large herds adopt a strategy of splitting their herds in this manner (Wurzinger *et al*., 2006). Better planning is then necessary to find a balance between high-profit/high-risk and low-profit/low-risk and to ensure a good bio-economic balance.

The use of crossbreeding has also made major contributions to productivity and product quality in the developed world. Structured cross-breeding systems, such as "*terminal crossing*" where first generation cross-bred (F1) animals are slaughtered or where specialized crossbred dam lines are used, are common. Cross-breeding may also be used for gradual breed replacement with upgrading or the controlled maintenance of various proportions of exotics leading to formation of composites. The need to maintain pure breeds for the production of crossbred animals or commercial production is either managed by farmers or by commercial companies. Farmers have had extensive support and training and now understand the need to maintain a balance of breeds to make the system sustainable in the long term.

There are also examples of successful crossbreeding programmes in developing countries. In some situations, carefully conceived and executed crossbreeding programmes have merit as a rapid method of introducing desirable traits into local well-adapted breeds. The development of the Dorper sheep is one of the most successful programmes of composite breed development for a low-input production environment (de Waal and Combrinck, 2000). The breed was developed in South Africa by crossing Dorset Horn sheep with the fat-rumped, black-headed Persian sheep, a local Somali breed. Other successful crossbreeding programmes include the formation of the Sunandini synthetic dairy cattle in Kerala State, India (Box 4), the Boer goat of South Africa (Malan, 2000) and the Brazilian Milking Hybrid (MLB) cattle (Madalena, 2005). Crossbreeding has been most successful where it was followed by a rigorous selection programme involving livestock owners' participation and substantial public sector investment in the form of technical support.

However, very often, crossbreeding has been indiscriminate and the local breeds that underpin the crossbreeding programme have been lost because of a lack of understanding by the authorities, companies and/or farmers involved that these pure breeds must be maintained to support the system. The strategic use of crossbreeding as a way out of a narrowed genetic base in commercial breeds is also considered important. It is gaining acceptance, for example, for fixing the increasing adverse trends in reproductive traits in commercial dairy cattle in North America. Such strategic crossbreeding is desirable to prevent long-term reduction of genetic diversity.

Finally, it should be recognized that large, highly variable and rich genetic pools of crosses

Box 4. The Sunandini cow in Kerala, India

Conditions in the State of Kerala in southern India are generally not conducive to classical dairy farming. These conditions are: the year round hot and humid climate, relentless pressure on land for human needs, acute scarcity of fodder, high rainfall and consequent mineral depletion of the soil. However, the Kerala dairy development programme, implemented over four decades (1964–65 to 2000–01), increased the State's average yield per cow per day from less than a litre to nearly 7 litres and milk production from 200 000 to 2.6 million tonnes per year. It has provided livelihood support to over one million smallholder households. The phenomenal growth in milk production can be attributed to a planned effort to develop the cattle genetically for milk production, supported by an extension programme for fodder development and a well-organized milk collection, processing and marketing system. A new composite breed, called "*Sunandini*" has been established by crossbreeding local cattle and further selection among the crosses. During the process, however, almost 80 percent of the local cattle have been converted to Sunandini and the local Vechur breed of cattle has almost been lost. The composite has a wide genetic base of exotic donor breeds – Brown Swiss, Jersey and Holstein Friesian and, to a lesser extent, the Indian donor breeds Sahiwal, Gir, Rathi and Kankrej. The Sunandini breed combines the positive qualities of local cattle such as adaptability, resistance to disease and strong hooves with the high production potential of the exotics. The level of exotic inheritance is limited to 50 percent. Its overall average lactation milk yield is 3 400 kg with a milk fat percentage of 4.0 (KLDB, 2004).

between exotic and indigenous breeds exist in developing countries today. Such populations would serve as a quick foundation for synthetic breed formation; especially given the surviving individuals have the combination of genes that best fit the prevailing environments. Strategic use of such crosses to develop breeds for specific production systems is prudent and timely. For example, in trypanosomiasis endemic areas, it would make good sense to combine N'dama crosses that have survived and are productive with purebreds or crosses of equally tolerant cattle breeds such as the Orma Boran of Kenya and Sheko of Ethiopia (which is at risk). This underlines the importance of sorting out the problem of cross-country access to such genetics.

Applications of technology in genetic improvement

Current use of technology

Breeding programmes in the industrial production systems are complex and have evolved over many years of technical inputs in terms of design, determination of breeding objectives, calculation of economic weights, genetic evaluation methods, breeding strategies and delivery of services, as well as structures and techniques for dissemination of improved genetics. They involve the extensive use of technologies for data recording and storage, advanced computing and statistical analysis, reproduction, genetics and genomics. For example, dairy cattle improvement generally involves automatic milk recording of several hundred thousand cows each year, compositional quality assessment, data download to a central database, large computers and advanced computer algorithms that estimate the genetic merit of millions of animals simultaneously, artificial insemination of millions of cows and embryo transfer of several thousand cows, laboratory assays to determine parentage and, increasingly, molecular genetic testing to determine which animals carry particularly desirable sets of genes.

In the developing world, advanced technologies are more difficult to implement because of high cost, lack of expertise and infrastructure and are consequently not widely used. A contrasting situation, however, exists in some developing countries (such as India) where several top research institutes pursue the use of mainly molecular technologies for their glamour rather than for supporting a practical breeding programme.

Research involving use of technologies is preferred over more tedious field research, which is perceived to be less rewarding. It is therefore necessary to ensure that simple breeding programmes based on proven genetic principles are not abandoned in favour of molecular genetic technologies that, in turn, need the existence of sound breeding programmes to be used effectively (see Box 5 for an example of effective use of advanced technology in a breeding programme in a developing country.) An example of effective use is that reproductive technologies, such as frozen semen or embryos, are used in several species to transfer germplasm between countries and sometimes to expand and/or disseminate rapidly an imported population. In addition to greater efficiency and reduced cost achieved, the use of such technologies greatly reduces the risk of disease transmission compared with importation of live animals.

Progress with simple technology

The low level of use of advanced technologies in most aspects of genetic improvement in the developing world need not prevent effective improvement being achieved (Box 6). For example, a well designed improvement programme, based on selection of the best animals assessed on their own performance, with no other information or analysis, can achieve from 40 to 70 percent of the maximum possible rate of genetic improvement when compared with the use of all advanced technologies. The use of advanced technologies in the developed world is driven by the intense competition among breeding groups or companies and the desire to improve characteristics that are not easily or accurately recorded for every animal. In the absence of such intense competition in developing countries, there is no immediate need to introduce expensive, advanced technologies. A lower rate of genetic progress using simple cost-effective techniques is preferable and certainly better than no selection.

The level of sophistication in terms of breeding strategies to be adopted in order to ensure sustainability and effectiveness needs to be carefully considered. It will depend on the state of the local infrastructure, the product market and available supportive technical expertise and institutional arrangements. An example of unsustainable levels of sophistication is the Kenyan National Dairy Cattle Breeding Programme, with sophisticated progeny testing comprising multibreed centralized milk and butter fat recording and data processing systems involving several institutions. The programme was modelled along a European type of system without considering the local infrastructure and institutional limitations. The result is an ineffective system in which an unacceptably low (five or less) number of bulls per breed are recruited each year, with up to 11 years before the test results are completed, leading to a

Box 5. Marker-assisted introgression/gene introduction in India

A good example of a clear gene effect successfully implemented in a marker-assisted introgression (MAI) programme is found in India. The Booroola gene is being introgressed from the small Garole breed into the local Deccani breed that is suitable for meat production but has a limited reproductive performance. The Booroola gene has tremendous economic effects in this production system, increasing the weaning rate by nearly 50 percent. The breeding programme is undertaken by a research institute, but there are clear strategies and activities to ensure that the improved stock finds its way to shepherd flocks. Evaluation of the results in these shepherd flocks is an explicit part of the project, and initial results look very promising. Long-term impact, however, needs to be assessed. Early results also indicate that the litter size of Booroola carriers has a direct correlation with feed availability during mating/pregnancy. This means shepherds would be able to reap the benefits of the higher litter size during "*good*" years while the flock's average litter size would not be unsustainably high during "*bad*" years. Shepherds may also like to keep a mixed flock of Booroola carrier and non-carrier animals as a risk insurance. MAI should not be ruled out for breeding programmes in developing countries, but should be assessed based on the merit of each case (van der Werf, 2007).

near-zero genetic gain. In this situation, a simpler nucleus-herd-based young bull scheme would have been more effective and sustainable, given the very limited number of herds actually contributing to genetic improvement. Location and management of the nucleus and recorded herds should ensure that production conditions in such herds match or mimic those of the smallholder and/or commercial farms under which most of the progenies of the bulls are raised.

Emerging technology applications

Reproduction, data and statistical analysis technologies continue to show regular incremental improvements and are expected to benefit but not fundamentally change the current design and operation of genetic improvement programmes. After decades of research and development, sexed semen has recently become available on a commercial basis (Johnson *et al*., 1987, Weigel, 2004). The use of sexed semen could be especially beneficial in countries such as India where religious beliefs preclude the consumption of beef. In such countries, the male animals are neglected and are a wasted resource. Technologies for management of female reproduction, such as synchronization of oestrus and (non) pregnancy diagnosis, can contribute to faster genetic improvement by decreasing the intervals between successive parturitions and increasing the number of candidates for selection.

Some technologies, such as the Livestock Identification and Trace-Back System (LITS) implemented in Botswana as a deterrent to cattle thefts (*http://practicalaction.org/?id=peace5_cattle_tracking_botswana*), could have huge potential for a genetic improvement programme where lack of individual identification is one of the main hurdles. The digital identification system uses radio frequency identification technology, is safe, environmentally friendly and tamperproof, and is used to identify individual livestock throughout the country. Other than managing cattle records and deterring cattle thefts, the system would also potentially open up access to important livestock markets such as the European Union (EU). The EU beef market regulation requires that imported beef be traceable from the export slaughter facilities to the individual animal that the meat came from.

Genomic technologies that have emerged from the human genome project are rapidly being developed for livestock. For example, in the past two years the ability to detect variations in the genetic code of individual cattle has risen from testing two or three variations in a single test to 50 000 variations in a single test, and the cost of testing has dropped more than a hundredfold (see companion paper on characterization). Such technology developments are truly revolutionary and provide prospects for radical changes in

Box 6. Simplifying phenotypic measurement of performance

The marginal gain obtained by increasing the precision of information on phenotypic traits is subject to the law of diminishing returns. For this reason, developing countries that are attempting to implement an open nucleus breeding scheme may be advised to begin by collecting "*low tech*", simple measurements of phenotypes from more animals and farms, rather than asking a few farmers to record complicated measures. For example, recording of milk yield could be bi-monthly or quarterly, rather than monthly. Lactation milk yield estimates based on only two test-days have been shown in some studies to have a correlation of greater than 0.85 with estimates based on ten test-days (Vasconcelos *et al*., 2004). Measurements of heart girth can serve as a proxy for body weight when scales are not available, as the traits are both highly heritable and highly correlated genetically (Janssens and Vandepitte, 2004). For traits such as overall likeability, temperament and general disease resistance that would be difficult or expensive to measure objectively, farmers can be asked to assign simple, ordered categorical scores for phenotypes.

genetic characterization and improvement. Several groups have already demonstrated that using such tests it is possible to determine the genetic merit of individual animals for most commercially important characteristics, without the need for any prior phenotypic information on the animal (Meuwissen, Hayes and Goddard, 2001). Huge quantities of molecular level data are, however, needed. The ramifications of this are still being explored, but it is clear that radical changes in design and operation of genetic improvement in the developed world could emerge. The ability to apply such technologies for routine genetic improvement in the developing world will require substantial reductions in cost, which seem likely to be achieved but cannot be guaranteed. However, it is already clear that these new technologies can be applied to achieve a much greater understanding of the functional genetic variation of developing and developed world animal genetic resources, which can then be used indirectly to better target genetic improvement globally.

Intellectual property issues

Virtually all the processes of relevant reproduction, data capture, statistical analysis and computing technology are in the public domain. Proprietary software is either readily available at reasonable cost or can easily be duplicated without infringement of proprietary rights. A small number of commercially valuable molecular genetic tests have been patented. In most cases these patents have not been registered in developing countries and therefore provide little or no restriction on use in developing countries. Coupled with the fact that such existing patents are for inventions with little practical value in the developing world, the willingness of patent owners to provide free or low-cost access to the developing world does not appear to have been tested. The recent development of high-throughput tests for genetic variants has led to several applications for patents for simultaneous use of large numbers of genetic polymorphisms. It is understood that in recent months the United States Patent Office has ruled that such patents are not valid and that the test for each polymorphism must be patented separately. The most likely consequence of this is that inventors will seek to protect such intellectual property (IP) by maintaining commercial secrecy rather than applying for thousands of separate patents. This will mean that the technology will be available to competing companies or countries, but the exchange of information will be hindered. It may also mean more difficulties for inventors to share IP with others, even where no commercial competition exists. This is because of the risk that key information might be leaked, thereby devaluing the IP. This situation is likely to be more damaging to technology use in the developing world where resources are less likely to be available to duplicate discoveries that have been protected by commercial secrecy.

Conclusions

Enhanced use and development of animal genetic resources in all relevant production systems play key roles in achieving food security and alleviating poverty. Ongoing utilization is also regarded as an effective means of maintaining diversity and ensuring the availability of resources for the future. Utilization is likely to continue if the breeds are perceived to provide genuine benefits – whether these are private benefits for the livestock keeper or public benefits for which society is willing to pay.

Continued increases in animal production and productivity will be necessary to enhance food security and provide critical income, products and services to hundreds of millions of poor families. Strategies involving incremental improvements in the production potential and productivity of traditional breeds, and corresponding gradual improvements in management and access to veterinary services, supplemental feeds and markets, appear most promising. The continued use of traditional breeds is likely to remain the most effective strategy for resource-poor farmers in many of the least-developed countries. However, opportunities may exist both to improve local breeds and for carefully managed and limited introductions of exotic breeds in areas of greatest production potential. These opportunities must be seized when genuinely available.

List of references

Chauhan, R.S., Singh D.D., Singhal, L.K. & Kumar, R. 2004. Effect of cow urine on interleukin-1 and 2. Journal of Immunology and Immunopathology, 6(1): 38–39.

de Waal, H.O. & Combrinck, W.J. 2000. The development of the Dorper, its nutrition and a perspective of the grazing ruminant on veld. Small Ruminant Research, 36(2): 103–117.

FAO. 2006a. Report on an expert meeting on sustainable utilization. Commission on Genetic Resources for Food and Agriculture. Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture. Fourth session. 13–15 December 2006. Rome.

FAO. 2006b. A strategic approach for conservation and continued use of animal genetic resources. Commission on Genetic Resources for Food and Agriculture. Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture. Fourth session. 13-15 December 2006. Rome.

FAO. 2007. The State of the World's Animal Genetic Resources for Food and Agriculture, edited by B. Rischkowsky & D. Pilling. Rome.

FAO. 2008. Report of the FAO/WAAP Expert Meeting on Sustainable Utilization of Animal Genetic Resources, Ferentillo, Italy, 2–4 July 2006, by D. Weary, D. Pilling & B. Rischkowsky. Rome. (Forthcoming – full proceedings including presented papers).

Gandini, G. & Oldenbroek, K. 2007. Strategies for moving from conservation to utilization. In K. Oldenbroek, (Ed.). Utilization and conservation of farm animal genetic resources, Wageningen, Netherlands, Wageningen Academic Publishers, pp. 29–54.

Janssens, S. & Vandepitte, W. 2004. Genetic parameters for body measurements and linear type traits in Belgian Bleu du Maine, Suffolk and Texel sheep. Small Ruminant Research, 54: 13–24.

Johnson, L.A., Flook, J.P., Look, M.V. & Pinkel, D. 1987. Flow sorting of X and Y chromosome-bearing spermatozoa into two populations. Gamete Research, 16: 1–9.

King, J.M., Parsons, D.J., Turnpenny, J.R., Nyangaga, J., Bakari, P. & Wathes, C.M. 2006. Modelling energy metabolism of Friesians in Kenya smallholdings shows how heat stress and energy deficit constrain milk yield and cow replacement rate. Animal Science, 82(5): 705–716.

KLDB (Kerala Livestock Development Board). 2004. Capitalization of experiences in Kerala Livestock Development Board. Kerala, India. pp. 158.

Köhler-Rollefson, I. 2004. Farm animal genetic resources. Safeguarding national assets for food security and trade. GTZ, FAO, CTA, pp. 60.

Köhler-Rollefson, I. & LIFE Network. 2007. Keepers of genes: the interdependence between pastoralists, breeds, access to the commons, and livelihoods. Sadri, Rajasthan, India, LIFE Network. pp. 57.

Kosgey, I.S. & Okeyo, A.M. 2007. Genetic improvement of small ruminants in low input, smallholder production systems: technical and infrastructural issues. Small Ruminant Research, 70: 76–88.

Kumar, A., Birthal, P.S. & Joshi, P.K. 2003. Research on crossbreeding in cattle: an analysis of its economic and social impact in India. Agricultural Economics Research Review, 16(2): 91-102.

Lewis, M. 2003. Cattle and conservation at Bharatpur: a case study in science and advocacy. Conservation and Society, 1: 1–21.

Madalena, F.E. 2005. Considerations on the management of animal genetic resources in Latin America. Proceedings of EAAP/SLU/FAO/ICAR Workshop on Sustainable Management of Animal Genetic Resources: Linking perspectives globally. 2 June 2005, Uppsala, Sweden, pp. 10.

Malan, S.W. 2000. The improved Boer goat. Small Ruminant Research, 36(2): 165–170.

Malmfors, B.M., Smalley, M., Philipsson, J., Ibrahim, H., Anderson-Eklund, L., Mwai, O., Mpofu, N. & Rege, J.E.O. 2002. Capacity building for sustainable use of animal genetic resources in developing countries- A new approach. 7th World Congress on Genetics Applied to Livestock Production. 19-23 August 2002, Montpellier, France. CD-ROM Communication No.29-04.

Meuwissen, T.H.E., Hayes, B.J. & Goddard, M.E. 2001. Prediction of total genetic value using genome wide dense marker maps. Genetics, 157: 1819–1829.

Mueller, J.P., Flores, E.R. & Gutierrez, G.A. 2002. Experiences with a large scale sheep genetic improvement project in the Peruvian highlands.

7th World Congress on Genetics Applied to Livestock Production. 19–23 August 2002, Montpellier, France. CD-ROM Communication No. 25-12.

Mueller, J.P., Poore, M.H. & Skroch, W.A. 1999. Damage assessment in Christmas tree plantations following vegetation control with sheep and geese. Southern Journal of Applied Forestry, 23: 11–15.

Philipsson, J., Rege, J.E.O & Okeyo, A.M. 2006. Sustainable breeding programs for tropical farming systems. In J.M. Ojango, B. Malmfors, & A.M. Okeyo, (Eds). Animal genetics training resources. CD-ROM, Version 2. Nairobi, International Livestock Research Institute and Uppsala, Sweden, Swedish University of Agricultural Sciences.

Sonesson, A.K. & Meuwissen, T.H. 2000. Mating schemes for optimum contribution selection with constrained rates of inbreeding. Genetics Selection Evolution, 32: 231–248.

Sponenberg, D. P. 2007. Rainbow livestock: Nguni cattle, Damara sheep, and indigenous goat types. South African Studbreeder. Issue 17. South African Studbook Authority.

Sushruta Samhita. 1985. The medical science of ancient Aryans, 2nd ed., edited and translated by A.C. Bandyopadhyaya. Calcutta, India.

van der Werf, J.H.J. 2007. Marker-assisted selection in sheep and goats. In E. Guimaraes, J. Ruane, B. Scherf, A. Sonnino & J. Dargie (Eds). Marker-assisted selection: current status and future perspectives in crops, livestock, forestry and fish. Rome, FAO.

Vasconcelos, J., Martins, A., Petim-Batista, M.F., Colaço, J., Blake, R.W. & Carvalheira, J. 2004. Prediction of daily and lactation yields of milk, fat, and protein using an autoregressive repeatability test day model. Journal of Dairy Science, 87: 2591-2598.

Weigel, K.A. 2004. Exploring the role of sexed semen in dairy production systems. Journal of Dairy Science, 87: E120–E130.

Wurzinger, M., Ndumu, D., Baumung, R., Drucker, A., Okeyo, A.M., Semambo, D.K., Byamungu, N. & Sölkner, J. 2006. Comparison of production systems and selection criteria of Ankole cattle by breeders in Burundi, Rwanda, Tanzania and Uganda. Tropical Animal Health and Production, 38: 571–581.