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The Importance of Breed Characterization and Conservation of Animal Genetic Resources for Climate Change.

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Abstract

Livestock production both contributes to and is affected by climate change. Indirect effects may be felt via ecosystem changes that alter the distribution of animal diseases or affect the supply of feed. Breeding goals may have to be adjusted to account for higher temperatures, lower quality diets and greater disease challenge. Species and breeds that are well adapted to such conditions may become more widely used. Climate change mitigation strategies, in combination with ever increasing demand for food, may also have an impact on breed and species utilization, driving a shift towards monogastric and breeds that are efficient converters of feed into meat, milk and eggs. This may lead to the neglect of the adaptation potential of local breeds in developing countries. Given the potential for significant future changes in production conditions and in the objectives of livestock production, it is essential that the value provided by animal genetic diversity is secured. This requires better characterization of breeds, production environments and associated knowledge; the compilation of more complete breed inventories; improved mechanisms to monitor and respond to threats to genetic diversity; more effective *in situ* and *ex situ* conservation measures; genetic improvement programmers targeting adaptive traits in high-output and performance traits in locally adapted breeds; increased support for developing countries in their management of animal genetic resources; and wider access to genetic resources and associated knowledge.

Keywords ;- Adaptation, Climate changes, Livestock breeds

INTRODUCTION

Animal genetic diversity is critical for food security and rural development. It allows farmers to select stock or develop new breeds in response to changing conditions, including climate change, new or resurgent disease threats, new knowledge of human nutritional requirements, and changing market conditions or societal needs. All of these are largely unpredictable. What is predictable is increased future human demand for food. The effects will be most acute in developing countries, where the increase in demand is expected to be greatest, will occur at a rate faster than increases in production and will occur where climate change is projected to have its greatest impact (Hoffmann, 2010).

The global livestock sector is characterized by a growing dichotomy between livestock kept by large numbers of smallholders and pastoralists in support of livelihoods and rural food security, and those kept in intensive commercial production systems. FAO's latest global assessment of breed diversity identifies 7040 local breeds (each reported by only one country) and 1051 transboundary breeds (each reported by several countries) (FAO, 2009a). A breed is a cultural rather than a biological or technical entity (Eding, 2008). A breed covers groups of animals having similar characteristics that depend on geographical area and origin. Local breeds are commonly used in grassland-based pastoral and small-scale mixed crop-livestock systems, where they deliver a wide range of products and services to the local community, with low to medium use of external inputs. They are usually not well characterized or described, and are seldom subject to structured breeding programmers to improve performance.

Climate change will affect the products and services provided by agricultural biodiversity. However, this biodiversity has not yet been properly integrated into strategies for adaptation to and mitigation of climate change

Consequently, breed-level predictions or bio-geographical models of the implications of climate change on livestock diversity are not possible with the current available data. Therefore, instead of trying to predict the survival or movement of specific breeds under climate change scenarios, this article aimed to shed light on the likely sensitivity of breed diversity to climate change and related drivers, the production and ecosystems that breeds depend upon, and the goods and services that they supply. Therefore, the objective of this paper is to review the Importance of breed Characterization and Conservation of Animal Genetic Resources for the future climate change

Livestock Adaptation Differences Relevant for Climate Change Adaptation

Genetic mechanisms influence fitness and adaptation. Barker (2009) defined adaption as the state of being adapted, the ability of breeds to produce and reproduce in a given set of environments, or the choice of particular breeds for specific environments. Adaptability is then a measure of potential or actual capacity to adapt, for example, if one breed is used in different environments. Adaptation traits are usually characterized by low heritability. In relatively stable environments, such traits have probably reached a selection limit; however, they are expected to respond to selection if the environment shifts, thus resulting in changing fitness profiles and increases in heterozygosity (Hill & Zhang 2009).

Physiological stress and thermoregulatory control

Heat stress is known to alter the physiology of livestock, reduce male and female reproduction and production, and increase mortality. Livestock water requirements increase with temperature. Heat stress suppresses appetite and feed intake; thus, feeding rations for high-performing animals need to be reformulated to account for the need to increase nutrient density. Body temperatures beyond 45–47 °C are lethal in most species. Heat stress is an important factor in determining specific production environments already today (Zwald et al. 2003). Temperature is predicted to increase globally, with reduced precipitation in many regions, particularly in already arid regions.

While substantial differences in thermal tolerance lie between species, there are also differences between breeds of a species. Ruminants generally have a higher degree of thermal tolerance than monogastric species, but species and breed environmental envelopes overlap. The ability to thermoregulate depends on complex interactions among anatomical and physiological factors. Factors such as properties of the skin and hair, sweating and respiration capacity, tissue insulation, the relationship between surface area per unit body weight or relative lung size, endocrinological profiles and metabolic heat production are known to influence heat loads, but the underlying physiological, behavioural or genetic mechanisms are largely unknown (Hall 2004; McManus et al. 2008). With increasing milk yield in dairy cattle, growth rates and leanness in pigs or poultry, metabolic heat production has increased and the capacity to tolerate elevated temperatures has declined (Zumbach et al. 2008; Dikmen & Hansen 2009). In the long term, single-trait selection for yields will therefore result in animals with lower heat tolerance.

On the other hand, many species and local breeds, particularly those from the Near East and Africa, are already adapted to high temperatures and harsh conditions (FAO, 2006b). The current distribution of some domesticated species is completely or mainly restricted to arid lands. Camelids are mostly found in arid areas, with the species differing in their adaptation to altitude and climatic zones. Yaks are adapted to very harsh high-altitude environments in the Asian drylands. More than 70% of breeds of ass, around 50% of sheep and goat breeds and 30% of cattle and horse breeds reported are adapted to arid areas (FAO, 2006b). Most local breeds are, however, not well characterized and their adaptation includes not only heat tolerance but also to their ability to survive, grow and reproduce in the presence of poor seasonal nutrition as well as parasites and diseases. Breeds adapted to these dry areas will more likely be affected by natural resource degradation linked to climate change rather than temperature or precipitation change per se.

Nutritional stress

Breed and species differences in diet selection in sheep and cattle have been observed, and linked to different metabolic profiles (Blench 1999; Jauregui et al. 2008; Fraser et al. 2009a,b). Hayes et al. (2009a) noted that there is more genetic variation in dairy cattle sensitivity to feeding level than to heat stress. Breeds differ with regard to their mobilization of body resources to cope with periodic underfeeding, and they also cease reproduction at different levels of body weight loss. In addition, rumen physiology, the ability to walk and reach scarce feed resources and to intake water and rehydrate, the ability to respond with increased night-time grazing to high afternoon temperatures, and even genetic aspects of diet selection also play a role (Hall 2004). The relationships between energy reserves, endocrinological parameters and breed reproduction performance need further attention.

In addition to diseases affecting the animal itself, a new range of pests and diseases will impinge on crop and forage species, thus affecting the quantity and quality of livestock feeds.

Disease stress

Climate affects vectors, pathogens, hosts and host-pathogen interactions from the level of cellular defence to that of the habitat. Hoberget al. (2008) provide an overview of predicted responses of complex host-pathogen systems to climate change. Climate change may affect the spatial distribution of disease outbreaks, and their timing and intensity (Epstein 2001). Outbreaks of African horse sickness, peste des petits ruminants, Rift Valley fever, bluetongue virus, facial eczema and anthrax are triggered by specific weather conditions and changes in seasonal rainfall profiles. The predicted reduction in the availability and quality of water will increase the risk of water-borne diseases for humans and livestock.

Climatic effects on host-vector and host-parasite population dynamics will further the geographical expansion of vector-borne infectious diseases (e.g. Rift Valley fever, bluetongue and tick-borne diseases) to higher elevations and higher latitudes and will affect the transmission and course of disease (Rogers & Randolph 2006). However, expansion of the range of a pathogen or vector does not necessarily result in wider disease transmission (de La Rocque et al. 2008).

Rapid spread of pathogens or even small spatial or seasonal changes in disease distribution may expose naïve livestock populations to new diseases. Such newly exposed host populations lack resistance or acquired immunity; this may result in more serious clinical disease. The expected increased and often novel disease pressure will favour genotypes that are resistant or tolerant to the diseases in question.FAO (2007a) lists breeds, mainly from developing countries, that are reported to be resistant or tolerant to trypanosomiasis, tick burden, tick-borne diseases, internal parasites, dermatophilosis or foot rot (59 cattle breeds, 33 sheep, 6 goat, 5 horse and 4 buffalo breeds). Again, many of these reports are based on anecdotal evidence rather than scientific studies, and the underlying physiological and genetic mechanisms are not well understood. Various studies have been undertaken to map genes (e.g. Regitano et al. 2008) and study gene expression (e.g. Berthier et al. 2008) in relation to these diseases, but no reports verifying causal mutations have been produced.

Climate Change Adaptation of Livestock Production Systems

The IPCC has defined ‘Adaptation’ as ‘Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. There are many ways in which producers can adapt to climate change. Without judging possible differences in the efficiency of these measures, the article focuses on the utilization of animal genetic diversity as one option for climate change adaptation. Producers can adapt to climate change by adapting their animals’ genetics to the changed environment, or by adapting the production environment while maintaining the animal genetic portfolio. It is assumed that farmers will first use adaptation technologies that can be quickly deployed, and will only change their genetic resources portfolio when it becomes unavoidable.

Adaptation of husbandry practices

Frankham (2009) notes that the adaptation of high-output breeds to confined production environments is a recent phenomenon. The direct effects of climate change on housed livestock are expected to be small, as management can compensate for losses in animal fitness by modifying the environment. A variety of technologies can be used to deal with the effects of short-term heat waves, including shading or sprinkling to reduce excessive heat loads (Marcillac-Embertson et al. 2009). Access to these technologies and to capital will determine the ability of producers to protect their herds from the physiological stress of climate change. Intensive livestock production systems have more potential for adaptation through technological change, and this may make them relatively insensitive to climate change and allow high-output breeds to be retained (Adams et al. 1998). Freitas et al. (2006), for example, found that effects of heat stress were smaller in larger herds, which were more likely to afford high-efficiency cooling devices.

The widespread adoption of such technologies will also depend on the availability and prices of energy and water. The question is: How long can the production environment of high-output breeds be maintained in view of expected increases in feed, energy and water prices? In extensive or pastoral systems, where the rate of technology adoption is generally low, or in regions that already today have a limited capacity to adapt (e.g. sub-Saharan Africa), the risk of breed displacement or loss may increase. However, local breeds under traditional management are generally more resilient to environmental changes than are high-output breeds.

Species and breed shifts

Shifts attributable to agro-ecosystem changes

The use of multi-species and multi-breed herds is one strategy that many traditional livestock farmers use to maintain high diversity in on-farm niches and to buffer against climatic and economic adversities (Hoffmann 2003; FAO, 2009b). Such traditional diversification practices are useful for adaptation to climate change. Seo & Mendelsohn (2007, 2008) modelled that small farms in developing countries were more climate change resilient because of their more diverse species portfolios, the ease with which they can shift between species and diversify, and their reliance on goats and sheep. On the contrary, commercial dairy and beef operations were more vulnerable than small farms, because their specialized nature makes it difficult for them to switch to other species.

Several livestock species-level models (Herrero et al. 2008; Seo & Mendelsohn 2008) that take into account the direct effects of climate change together with changes in agro-ecological conditions and production systems indicate that farmers will switch from cattle and chickens towards goats and sheep as temperature rises. The models agree that in Africa, livestock in semi-arid rangelands will expand at the expense of humid and temperate/tropical highland systems. However, they differ in the relative share of these shifts. Seo & Mendelsohn (2008) predict that ruminant numbers in rangelands will increase as long as there is sufficient precipitation to support vegetation growth .

Species substitution because of climate and vegetation changes has already been observed in the Sahel, where dromedaries have replaced cattle, and goats have replaced sheep, following the droughts of the 1980s. In countries such as Niger and Mauritania, and in northern Nigeria, camel rearing is now a common activity. Unlike cattle and sheep, which largely feed on herbaceous vegetation, camels browse on shrubs and trees, while goats use both strata. The use of browsing species has several advantages: the browse strata cannot easily be used by other species, it tends to offer green forage during the dry season, and browse is increasing in some environments as a result of overuse of the herbaceous layer. While species and breed displacement from the arid and semi-arid to the sub-humid zones in West Africa has been observed, extension into the humid zones, where disease pressure is high, is still limited (Gouro et al. 2008; Seo & Mendelsohn 2008).

Environmental degradation may exacerbate the impacts of climate change and raise the costs of climate change adaptation. The recent restriction imposed on grazing in provinces of Western China with the objective of reducing rangeland degradation (Zhang & Hong 2009) is an example that may affect local breeds of ruminants.

Shifts attributed to climate change mitigation measures

Despite the livestock sector contributing only 25% to GHG emissions (FAO, 2006a), public discussion focuses on enteric methane (CH4) fermentation in ruminants. Reducing livestock numbers, increasing individual animal resource use efficiency and optimization of feed rations and feed additives or other technologies may be primarily used to reduce CH4 excretion in ruminants. In general, CH4 output increases with the higher dry matter intake that is linked to high performance. However, the production pathways of different animal products differ in their GHG emissions and this may influence the future emphasis given to different production systems – and their related breeds. For beef cattle, intensive feedlot systems give rise to less CH4 per unit of meat produced than do extensive grazing systems, because CH4 decreases as the proportion of concentrate in the diet increases, and because of faster growth rate and shorter time to market. Milk protein can be produced with less CH4 emission than beef (Williams et al. 2006); CH4 emission per kg of milk declines as production increases, but with a diminishing rate. In a life-cycle-assessment of global GHG emissions per kg of fat and protein corrected milk (FPCM), Gerber & Vellinga (2009) found that intensive and mixed farming dairy production had lower emissions than grassland-based systems. Moreover, industrialized countries have lower emissions than developing regions per kg FPCM. Improved genetic potential of the cattle, increased feed quality and manure management will reduce emissions from extensive systems. In an intermediate GHG reduction scenario, dairying might become the major focus of cattle production, and beef may become a by-product of dairying. Dual-purpose breeds and crossbreeding may gain importance (Flachowsky & Brade 2007).

Local ruminant breeds, with their relatively lower output and higher GHG emission per kg of single food product, are considered unproductive. However, the productivity equation should take into account the multiple products and services provided by livestock in most smallholder and pastoral production systems (Ayalew et al. 2003). When considering GHG emissions from enteric fermentation, account should be taken not only of the gross efficiency of converting feed inputs to human food, but also of differences in species' ability to use forages that cannot otherwise be used by humans. Historical and alternative herbivores (e.g. wild ungulates) and C-sequestration in grasslands may partially offset GHG emissions from other components of the production process. Improved pasture management (e.g. restoring soil organic matter, reducing erosion, decreasing biomass losses resulting from burning and overgrazing) has positive environmental effects (soil C-sequestration, biodiversity) and a favourable impact on livestock productivity (Smith et al. 2007). Gill & Smith (2008) propose using 'human edible return' as another indicator to assess livestock efficiency. This would favour the return of herbivore livestock species to forage-based feeding and land-based production systems and result in a different breed portfolio than the intensive production pathway.

Breeding for Climate Change Adaptation and Mitigation

Although the direct effects of climate change on the animals are likely to be small as long as temperature increases do not exceed 3 °C (Easterling et al. 2007), projections suggest that further selection for breeds with effective thermoregulatory control will be needed. This calls for the inclusion of traits associated with thermal tolerance in breeding indices, and more consideration of genotype-by-environment interactions (G × E) to identify animals most adapted to specific conditions.

Breeding for climate change adaptation or mitigation will not be fundamentally different from existing breeding programmes; however, the problems related to measuring the phenotypes relevant to adaptation must be overcome. In the past decade, breeding goals in many commercial breeding programmes have broadened through changes in selection indices and aim to improve production, longevity and functional traits simultaneously – for example, in dairy cattle, pigs and layer chickens (Wall et al. 2008). As a result, correlations between breeding values with broader indexes that include functional traits are lower than those with production traits only (Mulder et al. 2006).

Correlations between the performance of genotypes in different environments are less than unity because of G × E, differences in trait definitions, and differences in data collection and analysis procedures (Zwald et al. 2003). Such correlations between breeding values are lower in high temperature countries, suggesting that heat stress plays an important role in G × E (Zwald et al. 2003). Biologically important G × E is assumed if the correlations between the performance of the same genotype in different environments are below 0.8 (Robertson 1959). A single breeding programme with progeny testing of sires in different environments and applying index selection to simultaneously improve performance in those environments is recommended for genetic correlations between environments higher than 0.6. At lower genetic correlations between environments, environment-specific breeding programmes are necessary to breed for special adaptability (Mulder et al. 2006).

Heat tolerance

Finocchiaro et al. (2005) proposed the use of heat-resistant individuals in a sheep breeding programme as a main strategy to improve animal welfare and productivity in hot climates. Various physiological and blood parameters differ between local and exotic cattle breeds in Brazil (McManus et al. 2008). Several Latin American cattle breeds with very short, sleek hair coats were observed to maintain lower rectal temperatures, and research in the major 'slick hair' gene, which is dominant in inheritance and located on Bovine Chromosome 20, is ongoing (Olson et al. 2003; Dikmen et al. 2008). Collier et al. (2008) suggest that there is some opportunity to improve heat tolerance through manipulation of genetic mechanisms at a cellular level.

Selection for heat tolerance in high-output breeds based on rectal temperature measurements and inclusion of a temperature–humidity index (THI) in genetic evaluation models are promising. Different parameters, such as THI or dry-bulb temperature measurements, are used as indicators for heat stress (Finocchiaro et al. 2005; Bohmanova et al. 2007; Dikmen & Hansen 2009). Different THI definitions were found to be preferable in the USA, depending on the extent of natural and artificial evaporative cooling (Freitas et al. 2006; Bohmanovaet al. 2007). The genetic variance caused by heat stress was substantial at high THI (Ravagnolo & Misztal 2002).

Productivity and feed efficiency

Increasing productivity is a condition sine qua non for all production systems because of the need to make efficient use of the available inputs and to reduce the livestock sector's environmental footprint. In addition to selection for increased production per se, any selection that reduces mortality and increases early maturity, fertility and longevity tends to contribute to reducing GHG emissions per unit of output. Breeding for high performance and improved FCR, and reduced mortality resulting from better hygienic management, have significantly reduced the amount of feed (and land needed to produce this feed) per unit of product – more in monogastrics and in dairy cattle than in beef cattle or sheep (Flock & Preisinger 2002; Capper et al. 2009). The largest contributions in broilers came from improved FCR, and in pigs from improvements to growth rate and fertility. Genetic gain in milk performance has considerably reduced the environmental impact of dairy production in the USA (Capper et al. 2009). Future options for selection in ruminants lie in the host components of rumen function, post-absorption nutrient utilization, and disease resistance. In pigs and poultry, the genetic variation in digestion parameters can be exploited (Warkup 2007).

In addition to the potential for fertility improvements in ruminants – for example decreasing the age of first-calving in indicine cattle – there is sufficient genetic variability in feed intake, independent of liveweight and daily gain (Flachowsky & Brade 2007), to permit selection for this trait. Assuming that future dairy systems may become more reliant on pasture than grain feeding, Hayes et al. (2009a) proposed to select sires whose daughters will cope better with low feeding levels and higher heat stress. They identified markers associated with sensitivity of milk production to feeding level and sensitivity of milk production to THI in Jersey and Holstein. Because feed-efficient animals are also more cost-effective and productive, the Australian beef industry now includes net feed efficiency as an integral part of its breeding programme (Beef CRC).

Disease resistance

Experiments in domestic species have shown that there are often genetic differences in responses to disease challenge (Bishop et al.2002). Some of this variation is caused by single genes and some by multiple genes each with small effect. There is potential for genetic improvement of disease resistance, and various commercial breeding programmes already include resistance to helminthosis, ticks, mastitis, Escherichia coli or scrapie. Extensive research on the genetics and breeding for worm resistance has been carried out in Australia, New Zealand and recently also in South Africa (de Greef 2009). Breeding for disease resistance depends very much on the type of disease and the hosts' resistance or tolerance mechanisms, the availability and costs of alternative treatment (e.g. vaccines, drugs) and the antimicrobial resistance of pathogens. In any case, the importance of molecular markers and marker assisted selection in such breeding programmes will increase (Bishop et al. 2002; Prayaga et al. 2006).

Challenges

The speed of artificial selection depends on many genetic factors, and on reproductive technology, selection procedures and on the accuracy of phenotyping, amongst other factors. Breeding for improved performance has become a high-tech exercise; the technologies and skills required present a bias towards certain breeds and production systems. Similarly, while G × E is the measure of choice for assessing variability of breed performance and adaptation across different environments, there are several caveats related to its wide application:

1. **Limited breeds:** On a routine basis, publicly accessible G × E across countries is only estimated for sires within six international dairy cattle breeds, through the international genetic evaluations performed by Interbull that treat sire's multiple trait performance in each country as a different trait. Routine G × E assessments are not available for other cattle breeds or species.

2. **Limited countries:** Interbull's customers are mainly based in developed countries; South Africa is the only developing country customer. G × E effects are more pronounced if tropical countries are considered (Ojango & Pollott 2002).
3. **Limited production systems:** Current AI bull evaluations are mainly based on daughters producing in high-input production systems and often do not differentiate between environments within countries (Zwald et al. 2003). Even within the US dairy industry, G × E exists between husbandry systems and climatic zones, e.g. between grazing and confined dairy herds, especially those in extensive, hot areas (Kearney et al. 2004).
4. **Demanding data quality and analysis:** Only a small percentage of national herds are usually used for progeny testing. Electronic data capture, which increasingly forms the basis of genetic evaluation, is mostly prevalent in large herds; in future even fewer herds will be needed for progeny testing. Adaptive traits are more difficult to study and to record, have lower heritability, higher levels of non-additive genetic variation and phenotypic variance, and are more susceptible to G × E than production traits (Frankham 2009). Even in dairy cattle populations in some developed countries, female reproduction traits are incompletely recorded (Goddard 2009) – not to mention other functional or adaptation traits.
5. **Economic constraints:** Although the genetic correlations between performance in developed and developing countries are probably lower than 0.75 (Ojango & Pollott 2002) – a threshold above which it is genetically reasonable to import semen from large breeding programmes (Mulder et al. 2006) – there are no breeding programmes in developed countries that target developing country environments. As only a relatively small amount of genetic material is sold to developing countries (Gollin et al.2008), commercial breeders find it hard to justify specific breeding programmers for such environments.

The majority of developing countries import genetic progress in production traits rather than developing it in their local breeds, as was highlighted in the low number of breeding programmers reported in the FAO State of the World report (FAO, 2007a). Gollin et al. (2008)found that the more economically advanced developing countries are importers of genetic material, while the poorest countries are not engaged in any international trade in animal genetic resources

Genomic selection may exacerbate these trends through the related requirements of reference populations for phenotyping. The accuracy of genomic breeding value estimation depends on the number of animals with phenotypes and genotypes in the reference population from which the SNP effects are estimated. Genomic selection is being applied in dairy breeding where consortia of main breeding companies are forming to assure the availability of the high numbers of progeny-tested bulls needed in the reference population. However, it is more difficult to implement in beef cattle or other ruminant species because of their dispersed breeding structure. In poultry, genomic selection is being tested across populations within companies (Avendano 2009).

Genomic selection is promising but not yet transferable to developing countries, where structured phenotyping and performance recording are largely missing, and reference populations would be difficult to establish even if the genotyping could be sourced out. To be transferable across breeds or crossbreds, very high density SNP panels need to be developed and reference populations should include at least some individuals from all target breeds.

Conservation and Exchange

Conservation

Conservation measures for threatened breeds have already been established in some countries (FAO, 2007a) and are a priority of the Global Plan of Action for Animal Genetic Resources (FAO, 2007b). The IPCC predicts an increase in disturbance and catastrophic weather events. Loss of animals as a result of droughts and floods, or disease epidemics related to climate change may thus increase (FAO, 2008a). If breeds are geographically isolated (endemic), as is the case for some local and rare breeds, there is a risk of their being lost in localized disasters (Carson et al. 2009). To secure against such disasters, it is necessary to characterize animal genetic resources and subsequently to build inventories, including information on the spatial distribution of breeds and valuable breeding stocks. This may include precautionary cryo-conservation of genetic material, or other measures to ensure genetic recovery following a disaster.

In the field of nature conservation and conservation of crop wild relatives it is now argued that in situ strategies must account for the fact that conditions in species' historic ranges will change, and indeed are already changing (McCarty 2001; Jarvis et al. 2008). These researchers advocate the facilitation of species migration and maximization of adaptation opportunities through the maintenance of intact ecosystems. However, recognizing that climate change may quickly affect our food system, the authors stress the urgent need to identify priority core species for collection and inclusion in gene banks.

Similarly, in animal genetic resource conservation, the focus may shift from in vivo to in vitro conservation. Most conservation programmers are based in developed countries with strong collaborations between gene banks and the animal breeding industry (FAO, 2007a). In developing countries, few breeds of the five major species are covered by conservation programmers, and programmers are of variable quality; the focus is typically on in vivo conservation (FAO, 2007a).

Exchange

Most livestock production systems depend on species originally domesticated elsewhere and breeds developed in other countries and regions, making most countries highly interdependent with respect to animal genetic resources (FAO 2007a,b). Climate change will increase the need to maintain wide access to animal genetic resources in the interests of future food security.

Livestock breeding and production systems are complex and knowledge intensive. New species or breeds may replace the current ones as single new components in a production system or they may be changed together with other components of a system, including knowledge components. In human-managed systems, 'establishment' of new species or breeds depends on how many components of the old production system can be transferred to the new area/system and on the socio-economic conditions. Blackburn & Gollin (2008) emphasize that successful introduction of new breeds into the USA has been based on several production traits and the interest and acceptance of the private sector, while introduction to take advantage of single traits has not proved sustainable, especially when other economically important traits were compromised. In any case, such replacement processes may involve considerable costs and substantial investments in learning and gaining experience.

Although specific traits of tropical breeds may become important, it remains to be seen whether the impact of climate change will lead to a reassessment of the value of local breeds. The arguments Hill & Zhang (2009) make to explain why little use is made of conserved lines or breeds of developed countries to increase adaptation in commercial populations equally apply for local populations of developing countries: the production performance differentials between commercial, intensively selected breeds and any local breeds are so huge that selection for improved adaptation within those breeds offers far more opportunity than crossing or introgression of adapted genes.

Only if climate change exceeds the adaptive capacity of the currently used genetic portfolio, would countries need to depend on better-adapted genetic resources from other countries to adapt their food and agriculture systems. In this case, increased strategic crossbreeding with better-adapted breeds or insertion of specific genes through the use of biotechnology may occur (McManus et al. 2008). The importance and value of specific genetics would thus increase. Such changes in the species or breed mix may potentially lead to a reverse in the current flow of genetics. Countries that happen to host sought-after resources may then try to take advantage of their scarcity and control access to what will have become crucial genetic resources. The need for improved exchange mechanisms for animal genetic resources and the associated knowledge would thus also increase.

CONCLUSION

Climate change is one additional factor affecting the already highly dynamic livestock sector. However, because of its slow but long-term effect and more pressing current needs such as increasing demand for animal products, climate change is not yet fully on the radar screen of the livestock community. It will increase the need for resource-efficient livestock production and may thus intensify current trends, with a growing dichotomy between livestock kept for livelihoods by smallholders and pastoralists and those kept for commercial production. The direct effects of climate change depend very much on the production and housing system, resulting in a buffered effect for the high-output breeds in confined systems.

Climate change mitigation measures in conjunction with the ‘traditional’ economic drivers may have implications for the breed portfolio. Measures that reduce the land area previously used for grazing may add to the threats to local ruminant breeds and affect the livelihoods of their keepers. Changes in the land area devoted to cropping (including fodder) relative to rangeland and their relative productivity will influence the balance between non-ruminant and ruminant production, as will GHG reduction targets. In general, superior FCR will grant monogastrics a comparative advantage over cereal-fed ruminants. Efficiency differences between breeds will influence the proportion of commercial vs. local breeds. High-output breeds of all species selected for improved FCR and high yield will dominate the production of milk, eggs and meat. These breeds will continue to out-compete local breeds.

Although many existing technologies in animal genetic resource characterization, conservation and breeding will be crucial for climate change adaptation and mitigation, research gaps do exist, especially with regard to the physiology and genetics of adaptation. There is need for long-term comprehensive breed characterization studies to shed light on the biological basis of adaptive traits.

At the current state of knowledge, it is not predictable whether climate change will be faster than natural or artificial selection. Developed and developing countries differ with regard to their portfolios of genetic resources and the management of these resources. Most tropically adapted breeds reside in developing countries and are largely uncharacterized and without structured breeding or conservation programmers. On the other hand, most high-output breeds are selected in addition, the performance differentials between local breeds and high-output breeds, the long-term commitment required for genetic improvement, and the ease of genetic material imports, may discourage developing countries from initiating their own breeding programmes. However, for the optimal utilization of the adaptation traits harbored in all breeds, research into genetic characterization and understanding adaptation in stressful environments needs to be strengthened. In view of the uncertainty for future developments, the use and non-use values of animal genetic resources should be maintained.

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