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The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.03
TPI 2018; 7(3): 345-350

www.thepharmajournal.com
Received: 01-01-2018
Accepted: 04-02-2018

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Heat adaptability in livestock in the tropics: A scenario

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Abstract
Globally, livestock play an important role in the economy of thousands of poor farmers who earn their livelihood by rearing them in different terrains and climatic conditions. However, livestock production both contributes to and is affected by climate change. In addition to the physiological effects of higher temperatures on individual animals, the consequences of climate change are likely to include increased risk that geographically restricted rare breed populations will be badly affected by disturbances. 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. In the objectives of livestock production, it is essential that the option value provided by animal genetic diversity be secured.

Keywords: climate change, adaptability, diversity, physiological stress, temperature-humidity index, heat tolerance index

1. Introduction

Livestock production both contributes to and is affected by climate change. In addition to the physiological effects of higher temperatures on individual animals, the consequences of climate change are likely to include increased risk that geographically restricted rare breed populations will be badly affected by disturbances. 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 monogastrics 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 option value provided by animal genetic diversity be 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 programmes 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.

Animal genetic diversity is critical for food security and rural development. It allows farmers to select stocks 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 changing societal needs – all of which 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, and occur at a rate faster than increases in production [1, 2], and where climate change is projected to have its greatest impact.

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 trans boundary breeds (each reported by several countries) [3]. A breed is a cultural rather than a biological or technical entity [4]. A breed covers groups of animals having similar characteristics that depend on geographical area and origin. Most European breeds are well defined, distinct and for a large part genetically isolated. In contrast, Asian and African breeds most often correspond to local populations that differ only gradually. About two-thirds of reported breeds are currently found in developing countries. 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 and described, and seldom subject to structured breeding programmes to improve performance. So-called "international trans boundary breeds" of the five major livestock species (cattle, sheep, goats, pigs, chickens), many of them high-output commercial breeds, have spread globally for use in large-scale, often landless, production systems, where they produce single products for the market (either milk, meat or eggs) with high levels of external inputs.

Most flows of genetic material occur among developed countries, most of which are without zoo sanitary restrictions, and involve animals suited to high-input production systems [5, 6]. More than 90% of exports originate from developed countries, and the share of trade in genetic material from developed to developing countries increased from 20% in 1995 to 30% in 2005 [7]. In many cases, the improved components of the high-input management systems needed to express the genetic potential of the high-output breeds have been transferred to developing countries. Industrial systems utilizing sophisticated technology and based on internationally sourced feed and animal genetics already produce 55% of pork, 68% of eggs and 74% of poultry meat globally [1, 8]. For 36% of breeds the risk status is unknown [3]. The loss of within-breed diversity is not known, although within commercial breeds, high selection pressure, particularly when combined with poor breeding programmes, leads to a narrowing genetic base. About 9% of reported breeds are extinct and 20% are currently classified as being at risk. The species involved in production and marketing systems with fast structural change show high proportions of breeds currently at-risk and already extinct. This includes 38% of chicken breeds, 35% of pig, 33% of horse, and 31% of cattle breeds [3]. Economic and market drivers also made up 28.5% of all responses in FAO's questionnaire survey on threats to animal genetic resources across the main species [9]. It can be expected that multifunctional local breeds continue to play a role in the livelihoods of poor people and in marginal areas.

Livestock production contributes to and will be affected by climate change. FAO has promoted discussion of the environmental impact of different livestock production systems. Consideration of the livestock sector is crucial for adaptation to, and mitigation of, climate change – because the sector is a large producer of greenhouse gases (GHG). Eighteen percent of global GHG emissions are attributed to livestock – via land use and land-use change (directly for grazing or indirectly through production of feed crops), manure management, and enteric fermentation [2, 10]. Climate change will affect the products and services provided by agricultural biodiversity. But this biodiversity has not yet been properly integrated into strategies for adaptation to and mitigation of climate change. Its role in the resilience of food systems still needs to be addressed. The Intergovernmental Panel on Climate Change (IPCC) report on biological diversity [11] and likewise the report of the Convention on Biological Diversity on climate change [12] contain little mention of agricultural biodiversity, and a recent literature review [13] largely ignores livestock diversity. In a survey on threats to livestock diversity [9], climate change was only mentioned as a minor factor in the context of extensive land-based production systems. The findings show that many stakeholders do not yet perceive climate change as a problem for the management and conservation of livestock biodiversity. In addition to the IPCC reports describing the predicted impact of climate change on ecosystems and agriculture [14], several papers provide a general overview of the expected impact of climate change on livestock production [15, 16]. Other papers model changes in production systems and species composition under climate change [17], poverty impact [18, 19] or projections of methane (CH4) emissions from African livestock [20, 21]. Provide an overview on the impact of climate change on animal diseases. The big mismatch between the low resolution of available data and the complexity of agricultural production systems makes it difficult to model the effects of climate change even for organisms with well-known environmental envelopes [19, 22]. Biogeographic models exist for the reaction of some well-described crop species to climate change. In the simplest case they project temperature and/or precipitation changes spatially and adjust the area under which a specific crop is able to produce. For some crop and forest species with known migration rates this allows the production of regional or national maps of projected species distribution [22, 23, 24]. For livestock, such projections are more complicated: Firstly, several species were domesticated in the same region, implying that they have similar environmental envelopes. Secondly today, many breeds of the major livestock species are globally distributed, implying that the geographic distribution of specific breeds is overlaid by different production systems. In addition, detailed data on most breeds' adaptation traits, including their thermal neutral zones and spatial distribution, are not available [25]. Consequently, breed-level predictions or bio-geographic models of the implications of climate change on livestock diversity are hardly possible with current data.

2. Role of livestock in Indian economy

Livestock plays an important role in Indian economy. About 20.5 million people depend upon livestock for their livelihood. Livestock contributed 16% to the income of small farm households as against an average of 14% for all rural households. Livestock provides livelihood to two-third of rural community. It also provides employment to about 8.8 % of the population in India. India has vast livestock resources. Livestock sector contributes 4.11% GDP and 25.6% of total Agriculture GDP.

The livestock plays an important role in the economy of farmers. The farmers in India maintain mixed farming system i.e. a combination of crop and livestock where the output of one enterprise becomes the input of another enterprise thereby realize the resource efficiency. The livestock serve the farmers in different ways. Livestock is a source of subsidiary income for many families in India especially the resource poor who maintain few heads of animals. Cows and buffaloes if in milk will provide regular income to the livestock farmers through sale of milk. Animals like sheep and goat serve as sources of income during emergencies to meet exigencies like marriages, treatment of sick persons, children education, repair of houses etc. The animals also serve as moving banks and assets which provide economic security to the owners. A large number of people in India being less literate and unskilled depend upon agriculture for their livelihoods. But agriculture being seasonal in nature could provide employment for a maximum of 180 days in a year. The land less and less land people depend upon livestock for utilizing their labour during lean agricultural season.

3. Differences in livestock adaptation relevant for climate change

Genetic mechanisms influence fitness and adaptation [26]. Defined adaptedness 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, resulting in change of fitness profiles and increase in heterozygosity [27].

4. 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's 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 [28]. 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 thermo regulate 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 [29, 30]. 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 [31, 32]. In the long term, single-trait selection for yields will therefore result in animals with lower heat tolerance.

Measurement of the effects of heat and other stressors is difficult. The effect of heat stress on milk yield at specific test days is more immediate and easier to measure than on growth [31]. After research on heat resistance of different species in the 1970s and 1980s, there is still today a lack of experimentation and simulation of livestock physiology and adaptation to climate change, which makes it difficult to predict impacts or develop adaptation strategies. In addition to standard physiological measures of heat stress, such as rectal temperature or heart and respiratory rates, measurements of net radiation and convection are required to evaluate the implications of heat stress in extensive grazing systems [33]. Heat tolerance tests will give misleading results unless modifying factors such as age, nutrition, state of health, reproduction and emotion, physical activity, level of production, acclimatization and management are taken into consideration [34]. However, research into behavioural or metabolic breed differences is in its infancy.

A wealth of literature is available on adaptation differences between zebu and taurine cattle [35-38]. *Bos indicus* is generally more heat resistant than *Bos taurus* [37], with zebu cattle maintaining lower rectal temperatures, lower respiration rates and lower water requirements than taurine breeds [36]. However, research is biased towards few breeds. Many of these studies involved international transboundary cattle breeds, dairy more than beef. There are fewer breed-level studies of local breeds within the taurine or zebu cattle groups, and even fewer in other livestock species. In general, the high-output breeds originating from temperate regions that provide the bulk of market production today are not well adapted to heat stress. Milk production, fertility and longevity, in Holstein Friesian cattle for example, decline as temperature increases [39, 40]. Large White sows are less heat tolerant than Creole sows [41, 42]. 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 [43]. The 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 [43]. 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 resources degradation linked to climate change rather than temperature or precipitation change per se.

5. Temperature Humidity Index (THI)

[44] Proposed the use of heat-resistant individuals in a sheep breeding program 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 [30]. Several Latin American cattle breeds with very short, sleek hair coat 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 [45, 46, 47] suggest that there is some opportunity to improve heat tolerance through manipulation of genetic mechanisms at 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 [32, 44, 48]. Different THI definitions were found prefable in the US, depending on the extent of natural and artificial evaporative cooling [48, 49]. The genetic variance due to heat stress was substantial at high THI [50]. However, in the dairy sector it may be difficult to combine the traits desirable for adaptation to high temperature environments with high production potential, because there seem to be different physiological and metabolic processes controlling heat tolerance and milk yield on the one hand, and heat tolerance and reproductive performance on the other [48, 50, 51]. In beef cattle, the genetic antagonisms between adaptation to high temperature environments with high production potential seem to be more limited than in dairy, and improved characterization of adaptive traits, use of reproductive technologies and molecular markers, and strategic crossbreeding are being incorporated into programmes, for example in the Australian beef Cooperative Research Centre [38].

The magnitude of heat stress, defined here as the sum of forces external to the animal that act to displace body temperature from set point, is caused by the combined effects of dry bulb temperature (Tdb), humidity, solar radiation, and wind speed (WS). A variety of indices were used to estimate the degree of heat stress affecting cattle and other animals. The most common of these, the temperature-humidity index (THI), uses Tdb and wet bulb temperature (Twb) to estimate the magnitude of heat stress [52]. Other THI were formulated empirically and often without reference to body temperatures of cattle. Nonetheless, the original THI and several variations of it have been used extensively to estimate the degree of heat stress in dairy and beef cattle [48, 53, 54]. Despite not being formulated using cow data, THI are related to body temperatures of cattle exposed to heat stress [55-57]. Recently, [48] showed that various THI were predictive of milk yield in cows in the southeastern United States.

Estimating the severity of heat stress in livestock and poultry is being formulated using both ambient temperature and relative humidity, termed as the temperature–humidity index (THI) [58] THI can be used as a tool for formulation of thermal comfort zone for dairy goats [59]. When temperature is measured (◦F), the equation to determine THI is as follows [58]:

$THI = db\,{}^{\circ}F - \{(0.55 - 0.55\,RH)(db\,{}^{\circ}F - 58)\}$, where db ◦F is the dry bulb temperature and RH is the relative humidity (RH%)/100, for goats. The obtained values indicate the following: values <82 = absence of heat stress; 82 to <84 = moderate heat stress; 84 to <86 = severe heat stress and over 86 = extreme severe heat stress [58]. When temperature is expressed in ◦C, the equation changes as follows [60]:

$THI = 0.8 \times AT + (RH\,(\%)/100) \times [(AT - 14.4) + 46.4]$, where AT= is the air temperature (◦C) and RH is the relative humidity (RH%).

The Globe Temperature and Humidity Index (GTHI) is a physical index used for characterization of thermal comfort rate for the most diverse animal species. Higher value of the index indicates thermal discomfort. This condition results in imbalance in the thermo neutral zone of the animals [60].

$GTHI = TBG + 0.36^{*}\,Tdp - 330$, where TBG is the thermometer temperature of black globe (°C); TDP is the temperature of the dew point (°C); 330 is the constant.

6. Heat Tolerance Index

Environmental factors such as the climate can interfere with the animal performance, reducing the food consumption and weight gain of animals. High temperatures and strong sunlight predominate during almost the whole year in arid regions and semi-arid region of Northeastern Brazil and may lead the animals to the caloric stress causing decline in production due to the drop in consumption of dry matter, as shown by several studies with sheep, even with animals of Santa Inês breed.

In tropical conditions, environmental factors are generally not compatible with the ideal range of thermal comfort efficiency for optimal animal performance. It would be ideal that determining the adaptability of an animal to a given environment had high correlation with the yield or growth performance. Adaptive characteristics are very important in the process of adjustment of the animal to the adverse weather conditions, and among them stands out the coat color that determines the amount of thermal radiation that the animal reflects and absorbs, which may change their caloric balance.

Heat tolerance index (HTI) was determined according to Iberia heat tolerance test (RHOAD, 1944) with a minor modification. The following formula was used: $HTI = 100 - (ART - 39)$, where ART is the average rectal temperature before and after 4 hours exposure to solar radiation for 3 consecutive days and 39 is the average normal rectal temperature of goats [61].

Heat adaptability of an animal reflects its ability to balance metabolic heat production against environmental heat gains and heat losses. Consequently, traditional heat tolerance indices have been based on the stability or thermal, water and protein balances. But the methods used have neither been reproduced nor com: lated with growth and productive perlonnanee of animals.

7. Conclusion

Climate change is one additional factor affecting the already highly dynamic livestock sector. However, due to 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.

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