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# IMPACTS OF CLIMATE CHANGE ON SHEEP GENETIC DIVERSITY: A REVIEW

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***Abstract***

*Native sheep breed act as reservoirs of local environment adapted genes. They are vital for food security as they are adapted to the extreme production environments.*

*Sheep farming is a potential profitable agricultural enterprise in lands unsuitable for other agricultural activities. However, climate change effects pose their existential challenge for it leads to genetic diversity within species. Available literature of implications of climate change effects on the genetic diversity of native sheep breeds is limited. In this study, therefore, we bridge this gap by discussing sheep selection for adaptation traits and its implication on genetic diversity.*

*This review discusses the climate change trends and projections, the history and importance of sheep, sheep farming systems, importance of genetic diversity in sheep and adaptation mechanisms highlighting their selection signatures. Further, we also discuss the use of genomic tools for selection for adaptation.*

*Finally, this paper highlights an effective way of maintaining genetic diversity and breeding for adaptation. The understanding of impacts of climate change on genetic diversity of native sheep breeds would help in developing directional breeding program encompassing adaptation traits, as well as trigger conservation efforts for already endangered sheep breeds.*

**Key words:** adaptation, climate change, genetic diversity, sheep

## INTRODUCTION

Global climate change (GCC) is one of the greatest concerns of today's world, varied climatic regions and impacting on the agricultural sector both directly and indirectly (Blackburn et al., 2017; Arora, 2019) thus affecting food value chains. The impacts of GCC are being manifested through increased surface temperatures, drought, floods, changing rain and snow patterns (Epstein et al., 1998; Deryng et al., 2014;) thereby affecting agricultural productivity.

Wreford and Topp, 2020, observe that agriculture is an essential economic sector providing food, fiber and fur and it is the most affected by GCC. Livestock being part of agriculture are the most exposed to vagaries of climate change. For instance, increased frequency of stressful events (e.g., hot days and heat waves) have affected agriculture, especially productivity of farm animals (Pasqui and Di Giuseppe, 2019).

According to Arora, 2019, anthropogenic activities have led to the average temperature rise by 0.9 ◦C since the 19th century and it is projected

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to increase by ~1.5 ◦C by the year 2050. Accordingly, Blackburn et al., 2017, recommend adoption of climate change resilient agricultural activities and livestock breeding programs to improve food security situation and to sustainably feed ever-increasing human population which is projected to be ~50 million by the year 2050 (Sawyer and Jitik Narayan, 2019). Expectedly, driven by population growth, urbanization and increasing income in developing economies, there would be an increase in demand of livestock products (Thornton, 2010). The author further indicates that, in the future, there will be a competition between food and feed production and that natural resources would not be adequate to meet their demand.

The impact of GCC on animals varies globally (Wreford and Topp, 2020), as a result of environmental heterogeneity, classified according to climatic zones (Peel et al., 2007). Environmental heterogeneity is believed to promote species diversity in ways stated by Stein et al., 2014. Thus, some authors have recommended alignment of farm animal species to forage, disease and heat stress caused by climate change (Blackburn et al., 2017). These calls for understanding of genetic and environment interplay. The question is how the relationship between genetics and environment will be understood without understanding the general combination of physiological, morphological, behavioral, and genetic base of livestock species of interest. In the case of small ruminants (sheep and goats), studies aver that they are tolerant to extreme, harsh environmental conditions by efficient and rapid combination of the above-mentioned mechanisms (Berihulay et al., 2019).

The primary purpose of this review is to bridge the existing literature gap by collating and synthesizing available literature and study results on climate and genetic diversity in native sheep (*Ovis aries*) breed and linking the selection signatures to genetic influence as an adaptation means.

A wide range of audience including and not limited to students, sheep farmers (large and small holders as well as pastoralists), research in the field of population and quantitative genetics, sheep breeding institutions and conservation organizations are expected to benefit from this study.

This paper is outlined as follows: section 2 gives a brief history of climate change including the trend and the projections for the future. Section 3 highlights history of sheep, evolution from wild species to domesticated ones, migratory episodes leading to habitation to varied ecological regions. Section 4 summarizes sheep farming systems while section 5 briefly focuses on the importance of genetic diversity and further gives a brief account of genetic diversity of native sheep breeds in some regions. Section 6 on the other hand will discuss main adaptation used by sheep and will briefly highlight on genes under selection affecting these mechanisms, inferring the importance of genetic composition in adaptation. Moreover, section 7 will summarize the use of molecular markers in selection for adaptation and Finally, we will conclude with section 8, in which we also suggest the ways of improving selection for adaptation.

**CLIMATE CHANDE TREND AND PROJECTIONS**

Animal production is highly dependent on weather conditions and climate (Gowane et al., 2017). For instance, without adequate rainfall and temperature, crops and pasture fail. On the other hand, extremely low and high temperatures and rainfall affects production of the same, animals get stressed, hence lowering productivity (Baumgard et al., 2012). According to Food and Agriculture Organization (FAO, 2019), there has been a continuous rise in global temperatures (Fig. 1).

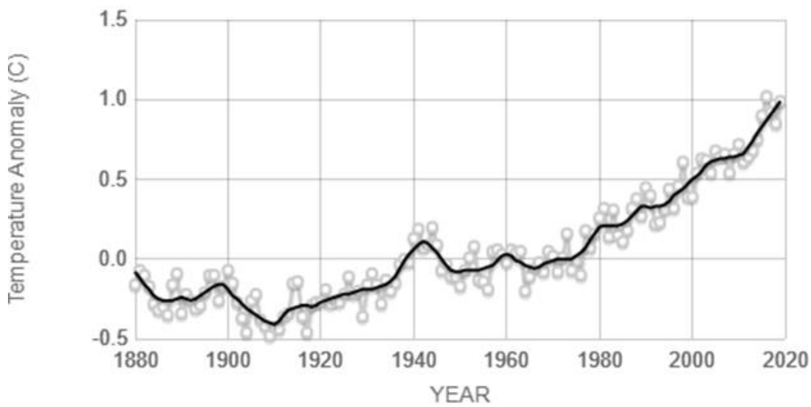



Fig. 1. Trend of temperature change between 1880 and 2020
Source: (NASA/GIS, 2019).

The organization claims that 1990s were 0.6 $^0$C warmer that in late 1890s and currently, temperatures are 0.9 $^0$C than the previous decade and is projected to be 1.5 $^0$C warmer in the 2050s (Meehl et al., 2007; Arora, 2019;). Generally, Meehl et al., 2007, in their global report avers that, while mean temperatures are expected to increase with more frequent and longer lasting warmer temperatures, mean precipitation is projected to increase in tropical regions (with possible floods), though, the report also projects droughts in mid continental regions.

Climate change and global warming are sometimes interchanged, but the latter is one effect of climate change and it drives other changes in the climate, e.g. changes in rainfall patterns and the frequency and distribution of weather events such as droughts, storms, floods and heat waves (Riedy, 2016). In general, climate change incorporates both global warming and other observed changes in climate. It is also projected that GCC will pose threat to existence of human civilization due to its widespread impact especially on agriculture sector. (Riedy, 2016).

Due to varied effects of climate change across the globe causing heterogeneous climatic conditions, exacerbated by projected climate change increase with an increasing human population, a balance between production to meet increased demand for animal proteins and environmental management must be met (Wiebe et al., 2015). This will be successful if the complicated impacts of climate change on livestock are well understood (Wiebe et al., 2015; Gonzalez-Rivas et al., 2020). Wiebe et al., 2015, asserts that several parameters both exogenous and endogenous affect animals' response to environmental stress, thus posing a question on which methods of estimating impacts of climate change to livestock species are reliable.

Climate change effects on agriculture can be mitigated by adjusting to adaptive agricultural production strategies for improved food security and sustainable environmental management. Heat stress is one of the major parameters of climate change which offers stressful events on animal agriculture (Xing et al., 2019; Gonzalez-Rivas et al., 2020; McManus, 2020;). Several scientific studies have indicated that, livestock are greatly affected by heat stress causing reduced production, reproduction and natural immunity endangering animal's survivability (Blackburn et al., 2017; Berihulay et al., 2019). Environmental stress, without adequate genetic adaptability of the species may lead to diversity loss which leads to species extinction in the long run (Mirkena et al., 2010). To evade this, it is advisable to maintain genetic diversity in livestock populations as well as indigenous genes well adapted to the local environmental conditions (Kusza et al., 2008).

To sustainably produce adequate animal proteins in an environmentally friendly manner, sheep would be an outstanding choice since they are adapted to thrive in a wide range of environments (Kijas et al., 2012; Berihulay et al., 2019).

## HISTORY AND IMPORTANCE OF SHEEP

Sheep, descendants of wild Asian mouflon in Southwest Asia (Larson and Burger, 2013; Ciani et al., 2020) were the first animals to be domesticated and differentiated according to "retrotyope" and morphological traits (Chessa et al., 2009) before dispersing across Eurasia and Africa via separate migratory episodes (Chessa et al., 2009). Using the current molecular tools like autosomal and mitochondrial DNA (mtDNA) and microsatellites, studies have been contacted to infer origin and migratory episodes of sheep in the past 12,000-10,000 years (Demirci et al., 2013; Lv et al., 2014; Zhao et al., 2017; Deng et al., 2020). Currently, the small ruminants have colonized several regions experiencing different and extreme climatic conditions exhibiting varied morphological traits. On this basis, they have been thought to be resilient to extreme weather conditions (Berihulay et al., 2019).

Since the first agrarian revolution (Neolithic), sheep has become an essential part of livestock producing milk, meat and fur as well contributing greatly to gross domestic product (GDP) both in developing and developed economies (Rochus et al., 2018; Ciani et al., 2020). Due to their importance (Hassan et al., 1998), various studies and reviews have been made addressing an array of knowledge on climate change and small ruminants ranging from implications of climate change on species metapopulation to quality and quantity of the products (Epps et al., 2004; Marai et al., 2007; Rose and Wall, 2011; Sejian, 2013; Stein et al., 2014; Berihulay et al., 2019). More research is now emerging on the use of molecular options like using genome wide sequencing, evaluating genes under selection in a population as a factor contributing to the animal's tolerance to prevailing climatic conditions (Kijas et al., 2009, 2012; Fan et al., 2011; Gurgul et al., 2014: Blackburn et al., 2017; Ciani et al., 2020; Eydivandi et al., 2020). However, little information is available on implications of climate change on the genetic diversity of this vital species.

The potential of small ruminants is high, but due to inadequate utilization of the interaction between gene and environment, their productivity is still low (Skapetas and Kalaitzidou, 2013). The gene-environment interaction is defined as "expression of a trait that results from the interplay between genes and the environment" (Wakchaure et al., 2016). Some traits are significantly influenced by the gene while others are influenced by the environment. However, most traits are influenced by one or more genes, interacting in a complex way with the environment (Wakchaure et al., 2016).

With the vagaries of climate change, sheep production efficiency and adaptability mechanisms, sheep farming is now considered as a primary meat industry in the future (Gowane et al., 2017). It is reported that more than 50% of global sheep population are in arid regions, indicating their adaptability and future suitability to increasing temperatures (Gowane et al., 2017). Sheep production is also considered as one of the main ways of reducing global warming since they mainly graze in ranches, wastelands and pasturelands and by doing so, they also increase fertility of the grazing land (Gowane et al., 2017). In most parts of the globe, the hardy breeds of this livestock species are indigenous type. This could be because they have adapted to extreme local environment, which includes heat stress. They can grow, survive and reproduce in the presence of poor seasonal nutrition besides parasites and diseases (Hoffmann, 2013).

Global sheep population registered an increase of 12 % during the period of 2000 - 2018 (Table 1). Sheep numbers are projected to increase even further (Terril, 1985; Thornton, 2010). Africa registered the highest increase (34 %) while Oceania, Australia and New Zealand registered the highest decline (- 65 %). The highest increment in Africa could be due to the presence of many local environments' adapted breeds (Turner, 1991) as compared to regions with decrease which rear pure-bred or highly admixture breeds compromising tolerance to climate change effects.

*Table 1*

Sheep population change between 2000 to 2018

| Region | Sheep population (heads) | | % change |
|---|---|---|---|
| | 2000 | 2018 | |
| Africa | 253 069 651 | 383 954 675 | 34 |
| Americas | 90 014 007 | 82 421 347 | -9 |
| Asia | 413 523 701 | 514 986 624 | 20 |
| Australia and New Zealand | 160 812 000 | 97 363 065 | -65 |
| Europe | 148 942 604 | 130 703 609 | -14 |
| Oceania | 160 828 340 | 97 400 824 | -65 |
| World | 1 066 378 303 | 1 209 467 079 | 12 |

Data source, FAOSTAT, 2020

Notwithstanding effects of GCC, human population would increase, as well as demand for food. But with shrinking productivity resulting from climate change effects, challenges of meeting food demands are posed. United Nations projects a 10 billion human population by the year 2050 (Sawyer and Jitik Narayan, 2019). The question is, how will these people be fed? Sawyer and Jitik Narayan, 2019, suggests that, graziers, farmers and pastoralists are the ones charged with feeding this population growth. With changing demographics and rising purchasing power in developing countries, demand for quality animal proteins is projected to increase (Grigg, 1995). Hence, it is necessary for livestock farmers to not only concentrate on meeting market demands, but also environmental management. This can be achieved by applying sustainable agriculture practices within this changing climate (Sawyer and Jitik Narayan, 2019) era, thus indigenous sheep production not only helps farmers meet market demand and maintain the environment but also are environmental stress tolerant.

## SHEEP FARMING SYSTEMS

Globally, sheep farming is characterized by a dichotomy of farming systems depending on prevailing local conditions. Extensive sheep farming system is practiced by pastoralists and small holder farmers who rear sheep for livelihood, cultural and local food security. This system allows animals to interact with the natural environment undergoing forces of natural selection in addition to unstructured human selection (Hoffmann, 2013).

Extensive sheep farming systems are predominated by indigenous sheep breeds which harbors traits that are adapted to the local conditions. Extensive systems are generally used in grassland based pastoral and small holder mixed crop-livestock systems where they produce wide range of products to the local community with minimal external inputs and with low or no structured breeding program to improve performance (Hoffmann, 2013).

Native sheep breeds also have better ability to utilize low quality forage as compared to pure-bred breeds (Ates et al., 2015) inferring genotype variation in utilization of feed of varying quality (Souza et al., 2013). According to Bruinsma, 2003, local breeds play a crucial role in meeting essential human food and nutritional needs.

Failure of properly utilizing local breeds leads to extinction, i.e., high levels of selection for economic traits disregarding adaptation traits or indiscriminatory crossbreeding in the efforts of improving production traits leads to loss of important alleles for adaptation. There are approximately 8,800 domestic animal breeds globally, of which 7 % are extinct and 24 % are at risk of extinction.

The second sheep farming system is intensive sheep production system which is practiced by large scale farmers using modern technology to improve performance, principally, this kind of production system is done in controlled environment evading extreme impacts of climate change (Hoffmann, 2013).

## IMPORTANCE OF GENETIC DIVERSITY IN SHEEP POPULATIONS

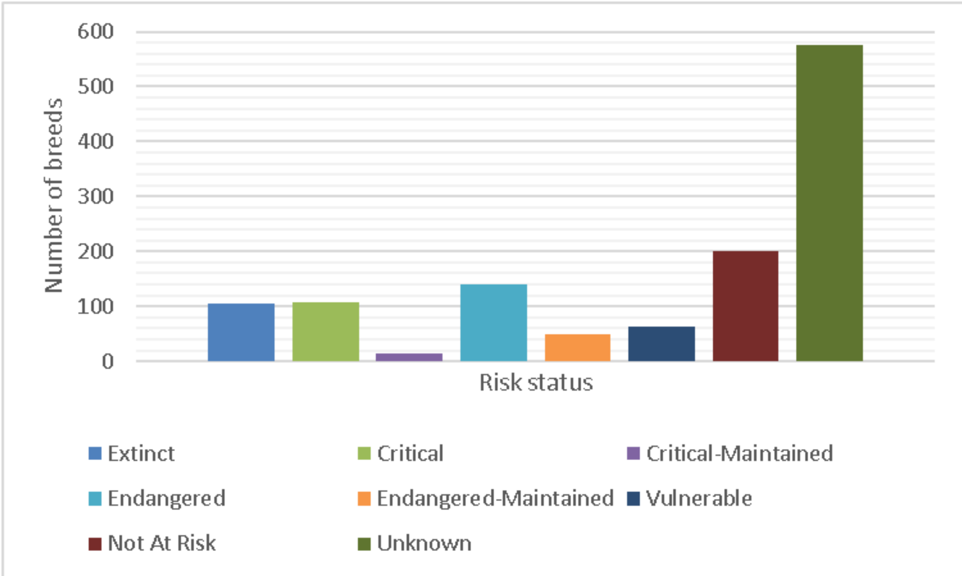
Genetic diversity refers to naturally occurring variations among individuals of the same species. These variations provide a base for survival of a population in the face of changing environmental circumstances (Pauls et al., 2013). Markert et al., 2010, states that decrease in genetic diversity means that numerous alleles are lost from the population increasing individuals with homozygous alleles hence reducing individual fitness to the changing climatic aspects, whereas in the long term, moderate allelic losses may also lead to heterozygous loss thereby reducing capacity of populations to adapt to altered environment.

Research on adaptation of livestock species to environmental stressors have been conducted. However, there are knowledge gaps on the influence of genetic makeup on adaptation traits, as well as footprints of climate change on genetic heterozygosity of livestock species, in this case native sheep breeds, which are presumed to have developed an efficient adaptive mechanism to environmental stressors. Adaptation to harsh environments include ability to produce, grow, reproduce and resist pests and diseases in the presence of heat stress and poor seasonal nutrition (Hoffmann, 2013). Selection for adaptation is pertinent for sustained production and since adaptation traits are majorly in indigenous breeds which have limitations in performance compared to pure-bred breeds, they are often selected against or indiscriminately cross-bred to improve performance (Hoffmann, 2013). A long-term intensive selection for performance traits disregarding adaptation traits compromises breed survivability in the face of climate change due to loss of genetic diversity (Barbato et al., 2017).

For a more sustained sheep production and maintenance of their genetic resources, it is vital to understand the implications of climatic alterations on sheep genetic diversity. Further, understanding the evolutionary consequences of GCC and its long-term effects on the species (Pauls et al., 2013) will too be useful for conservation measures. According to Hoffmann and Sgrò, 2011, climate change will impact intraspecies genetic diversity in various ways including: (i) "changes in the distribution of genetic variants in space and time as the ranges of populations and species change, (ii) changes in levels of phenotypic plasticity of individuals and populations as they respond to new environmental conditions, and finally (iii) evolutionary adaptation to changing environmental conditions", moreover, these changes will reduce genetic diversity in populations and species and extreme situations may lead to species extinction due to reduced viability (Pauls et al., 2013).

The fundamental objective of sheep crossbreeding is to improve performance traits for improved productivity and efficiency, but maintenance of genetic diversity is equally important (Boettcher et al., 2015). The authors have recommended a directional selection strategy targeting both productivity and adaptation. The question here is, how does a common farmer determine adaptation traits to be selected for? Some seasoned farmers practicing extensive sheep farming have learned from experience morphological and behavioral traits for adaptation, but this does not solve low productivity problem. Breed and species organizations should come in handy to help farmers actualize farmers' objectives by facilitating directional breeding for adaptation and productivity for sustainable production.

In the current science world, use of technology has been vital in characterizing animal genetic resources, classifying them to their respective risk status i.e., high or low extinction risk or unknown risk status. These are listed in the Domestic Animal Diversity Information system of FAO (fao.org/dad-is/en/). According to FAO DAD-IS, 2020, out of above 6,468 local domestic animal species identified, 2,031 are classified as at risk, 719 not at risk and 4,425 unknown risk status, from 39 % reporting. 8.4 % of the local sheep breeds are extinct, 8.5 % are critically endangered, 11.2 % are endangered and only 16 % are not at risk (Fig. 2).




Data source: FAO DAD-IS, 2020

Fig. 2. The risk status of native sheep breeds

Loss of genetic diversity is a precursor for species extinction. Genetic diversity can be lost through inbreeding and intensive selection (Beuzen et al., 2000). To increase information on the genetic status of available sheep populations, which could offer a basis for decision-making for breed conservation, several studies have been made using molecular tools.

Studies by Ciani et al., 2012, in different sheep breeds in Italy, where sheep population has been on decline found that all the breeds under study were heterogeneous deficit, similar results were recorded by Dalvit et al., 2009, in a population structure study in indigenous sheep breeds in Italy undergoing in situ conservation. Expectedly, Kusza et al., 2008, in their study on Tsigai and Zackel sheep breeds in Eastern, Central and Southern Europe found similar results as in Italian sheep, similar to studies on Turcana, Tsigai, Racka and Teleorman Blackhead in Romania by Dudu et al., 2016.

Heterozygosity deficit was attributed to inbreeding and possibly unidirectional cross breeding with performance superior exotic breeds. Thus, predisposing native sheep in these regions to judgement of nature. Conversely, indigenous sheep in Egypt recorded high levels of diversity (Sallam et al., 2012; Rushdi and Sabry, 2015). Similar results were recorded in Kenyan indigenous sheep although with some levels of admixture (Muigai et al., 2008; Mukhongo et al., 2014). Indigenous sheep in Egypt and Kenya seem to be retained their endemic genes and have maintained their true adaptive genetic value since most of the sheep keepers are either small holders or pastoralists who could not afford cross-breeding with exotic breeds. However, Kenyan farmers seem to have begun to embrace commercial ways of farming by introducing performance superior genes and thus risking the breed.

Market et al., 2010, used estuarine crustacean *(Americamysis bahia)* with manipulated genetic diversity levels and found out that populations with low levels of genetic diversity demonstrated reduced fitness relative to high genetic diversity levels. Generally, all high genetic diversity populations persisted and tolerated all stressful environments throughout the experiment period while those with low genetic diversity were extinct in the stressful environments.

## GENE SELECTION FOR ADAPTATION

Various genetic markers have been used to study and analyze the genome of small ruminants for genes under selection in varied ecoregions as a measure of adaptation to local conditions. Use of modern technology such as genome wide studies on livestock adaptation to extreme environments have provided a clear roadmap in genomic selection for adaptation traits (Yang et al., 2016). Previously, animal breeding focused on performance traits which led to cross-breeding, diluting the landrace traits, exposing livestock population to vagaries of changing climate. According to Gesualdi et al., 2014, the ability of animals to withstand environmental stress like heat stress varies with breed and species and thus long term cross breeding could lead to loss of fitness trait to the environment.

Sustained animal production strategies include selection for animal genetic resources adapted to local conditions like heat stress. Thus, species genetic diversity within and between populations provides opportunity for improvement of breed for performance trait. Gaughan et al., 2019, adds that, genetic diversity and presence of adaptation genes per se does not improve animals' response to environmental shock, considering non-genetic factors too should be considered.

In the current world, there is an increased demand of animal proteins and the trend is projected to increase, farmers are modifying their animal production systems as well as intensifying selection for improved profit (Osei-Amponsah et al., 2019). Consequently, breeding efficiency needs to be improved hence use of genomic selection for desired genes. It is also important to note that adaptation by an animal can be non-genetic or genetic. Non-genetic adaptation is short term although, efficient response to stressors is genetically driven. Genetic adaptations are long term, they take effect after several cycles of targeted selection (Gaughan et al., 2019).

In general, sheep employ several mechanisms in adapting to the environmental stressors. These mechanisms are influenced by gene-environment interaction and are believed hereditary although with low heritability (Olivier et al., 1998). In the section below, we shall discuss several adaptation mechanisms to heat stress and highlight some genes responsible, as inferred by several studies, in some cases, we will also include studies done in different livestock species.

## 1. Adaptive mechanisms for heat stress

Despite small ruminants being less susceptible to environmental heat stress, heat stress is still a concern since it affects their reproduction, growth, susceptibility to prevailing diseases and pests as well as increased mortality rate (Berihulay et al., 2019). Morphological, behavioral, physiological, and genetic base are among the mechanisms of adaptation that are influenced by the genetic base of an animal (Gaughan et al., 2019).

### *1.1. Morphological Adaptation*

Morphology of an animal can be defined as their physical characterization or appearance (Asamoah-Boaheng and Sam, 2016). When under a long-term selection, they enhance fitness of an animal in a production environment. They include body size and shape, hair type and length, coat and skin color (melaninization) and fat storage (Kim et al., 2016; Seid et al., 2016; Berihulay et al., 2019; Yurchenko et al., 2019). Gaughan et al., 2019, reported that animals with light color coat absorbed less heat than dark color coat. Similarly, shiny and sleeky coated sheep reflect greater air radiation than woolly ones whereas woolly sheep protects themselves from solar radiation by facilitating cutaneous heat dissipation.

On the other hand, body size and shape in mammals is linked to thermoregulation capacity and/or efficiency (Pafilis et al., 2013). Kim et al., 2016, further states that large- bodied breeds are found in temperate regions, characterized by low temperatures, abundant and good quality feeds contrary to adaptability of small- bodied breeds found in tropical regions which are characterized by high temperatures, low nutritive pasture.

A study by Esquivelzeta et al., 2011, on characterization of Ripollesa sheep breed based on morphological analysis (body size and live weight vs withers height and ear length) revealed sub-populations attributed to geographical locations, selective history and genetics strongly suggesting that morphological traits under selection influence adaptation of the breed to environmental conditions and loss of adaptive selection signatures could lead to loss of species in the event of climatic conditions shift. More genes influencing animal's morphology as a means of adaptation have been detected in several studies (Table 2) indicating that gene-environment interaction influence morphology for adaptation, loss of genes responsible for adaptive morphology may reduce adaptability of individual animals and the entire species in long term.

*Table 2*

Genes under selection influencing adaptation

| Genes under selection | Species | Trait/function | References |
|---|---|---|---|
| MC4R, IGF2, CHCHD3, BMP2, HOXA | Pig | Body structure | Fan et al., 2011 |
| MEF2B, RFXANK, GRM1, POL, MBD5, UBR2, RPL7 and SMC2 | Sheep | Performance-Body weight gain | Zhang et al., 2013 |
| ASIP, KITLG, HTT, GNA11, OSTM1 | Goat | Body size | Wang et al., 2016 |
| CDK2, SOCS2, NOXA1, and ENPEP | Goat | Hypoxia adaptation | Wang et al., 2016 |
| FNGR2, MAPK4, NOX4, SLC2A4, and PDK1 | Sheep | Hypoxia adaptation | Yang et al., 2016 |
| FSTL1, PVR, EXT2, ALT4, HAND2 | Sheep | Morphology (body size) | Yang et al., 2016 |
| NPR2, HINT2, SPAG8, INSR | Sheep | Limp, skeleton and tail development | Ahbara et al., 2018 |
| ALXX4, HOXB13, BMP4 | Sheep | Body weight and height | Ahbara et al., 2018 |
| DNAJCi8 | Sheep | Body weight and height | Ahbara et al., 2018 |
| RXFP2 | Sheep | Morphology of horns | Ahbara et al., 2018 |
| NPR2, MSTN, GDF-8 | Sheep | Morphology | Rochus et al., 2018 |
| ABCG2, RXFP2 | Sheep | Milk production and horn development | Rochus et al., 2018 |
| *GRIK3*, *DLGAP3*, *THRAP3* and *SFPQ*) | Cattle | Personality and behavioural traits | Eusebi et al 2018 |

### *1.2. Behavioural adaptation*

Animals will respond differently when subjected to varied environmental stressors. Some, under heat stress, will hide under the shade, increase frequency of water intake, reduce feed intake, increase standing time and reduce lying time, reduce defecation and urination frequency (Gaughan et al., 2019). Higher temperatures above thermo-neutral zone for specific animals would drive them in the shade, consequently leading to reduced feed intake and further reduced production (Gaughan et al., 2019). Studies in cattle between Angus and Nellore breeds (Valente et al., 2015) and goats (Joy et al., 2020) deduced that breed differences affect water intake frequency, urination frequency, rumination time and water intake during heat stress periods.

Eating behavior is also an adaptive mechanism that aid in reducing effects of heat stress in mammals. According to Valente et al., 2015, and Gaughan, 2019, reduced feed intake reduces metabolic heat. While concluding that breed differences affect response to heat stress, Curtis et al., 2017, suggested that, relative humidity also contributes to the animal's response. Maternal-offspring behavior impacts the survivability of offsprings since it aids in earlier development. In sheep for example, Güngör and Ünal, 2020, established that, the mother-offspring bond post parturition varied genotypically in sheep breeds. Eusebi et al., 2018, also inferred that personality and behavior of an animal is a genetic condition as hence it is hereditary.

In conclusion, behavioral traits are genetically influenced and their selection could lead to varied genetic makeup within and between populations. Loss of alleles responsible for adaptation may lead to loss of genetic diversity, hence extinction of breed.

### *1.3. Physiological adaptation*

Physiological response is one of the novel mechanisms that aid an animal response to environmental stressors. Physiological response of an animal to environmental stress depends on the breed. Sheep and goats are homeothermic animals meaning they can exploit physiological mechanisms to maintain a constant body temperature (Al-Dawood, 2017). Some physical responses aiding in dissipation of excess heat include increased respiration rate, rectal temperatures, increased sweating rate, skin temperature and pulse rates (Gaughan et al., 2019). Experiment by Nejad and Sung, 2017, revealed that, Corriedale ewes when exposed to heat stress responds by increased respiration rate, panting and reduced heart rate contrary to Gesualdi et al., 2014, study where there were no observable differences in heart rate and respiratory rates between two sheep breeds (Santa Inês and F1 Dorper × St. Inês) in Brazil. However, Santa Inês and F1 Dorper a registered a drop in performance, carcass characteristics and physiological responses when subjected to heat stress.

For effective selection for heat tolerant traits, it would be vital to understand the physiological process underlying the response mechanisms. Al-Dawood, 2017; Berihulay et al., 2019; Joy et al., 2020, reviewed extensively on physiological adaptation mechanisms of small ruminants.

Conclusively, animals have developed physiological responses to environmental stress and since responses are breed dependent, it implies that it is genetically driven, consequently, sheep populations/breeds with low genetic diversity risk being extinct in case of change of climatic conditions.

In general, adaptation traits manifested though morphological, behavioral and physiological mechanisms, are genetically influenced, and their response pattern is determined by local environmental conditions, hence affecting their selection pattern (Table 2) which in the long term affects the genetic diversity of the breed.

## GENOMIC AND MOLECULAR TOOLS FOR BREEDING FOR ADAPTATION

Animal breeding involves selection and mating of males and females of the desired trait to produce phenotypically superior progeny than their parents (Dekkers, 2012). Several studies contacted infer that a trait of interest is influenced by multiple alleles at a locus, a location called quantitative trait locus (QTL) (Wei et al., 2020) alongside environmental effect (Dekkers, 2012).

Previously, estimation of breeding value was used as criterion for selection whereby quantitative phenotypic output like amount of milk per lactation, quality of milk, calving interval, litter size and many others, was the main consideration (Dekkers, 2012). Dekkers, 2012, define breeding value as the sum of the additive effects of all loci that contribute to the trait (quantitative trait loci or QTL), deviated from the population mean. The whole process of selection involved performance recording for individual performance and/progeny testing (Lush, 1935) for male and ecoregion selection (Specht and Mc Gilliard, 1960). The process took a long period of time before a significant genetic change could be recorded (Specht and Mc Gilliard, 1960).

This process of breeding was successful in developed countries where individual large scale farmers keep their own performance records, but in developing countries where most of the livestock production is done by small holder farmers, performance recoding was done by breed associations (Mrode et al., 2019). This method has however not been able to select for non-additive traits (Eggen, 2012) like adaptation traits and the accuracy levels were significantly low. Similarly, the method could not measure some performance (quality) traits of an individual animal without it being killed or would take a long period recording performance of relatives before the estimated breeding value of an individual is determined. All processes that led to determining true breeding value were tedious, time-consuming and full of human errors (Dekkers, 2012).

With the advent of genomic selection tool, improvement of population genetic value has been hastened (Mrode et al., 2019). The success of this technology was attained after discovery of millions of single nucleotide polymorphisms (SNPs) (Eggen, 2012), following successful sequencing of economically important livestock species allowing genome wide studies to map out genes influencing traits of interest (Eggen, 2012). Effectiveness of genomic selection depends on how well gene-environment and animal's physiological mechanism interaction is understood (Thomas, 2010) and their correlation to performance.

There is a need to characterize genetic structures of various sheep populations and defining sheep genetic resources based on whether they are endangered or not. This can be achieved though studying genetic diversity status using tools of DNA markers by using a strategy called marker assisted selection (MAS) (Beuzen et al., 2000). Use of genetic markers compliments quantitative genetics to improve efficiency in selection. This is done by evaluating phenotypes to identify genetic influence, then performing whole genome sequencing to evaluate alleles or genes behind the phenotype expression (Beuzen et al., 2000).

Several polymorphic markers have been used to evaluate the genetic structure of livestock populations. These include microsatellites, restricted fragment length polymorphism (RFLP) and single nucleotide polymorphism (SNP) (Beuzen et al., 2000). Molecular markers and their use in animal breeding have been discussed extensively by various review articles (Beuzen et al., 2000; Khlestkina, 2014; Al-Samarai and Al-Kazaz, 2015).

Single nucleotide polymorphism (SNP) is a third generation marker after RFLP and microsatellite (Al-Samarai and Al-Kazaz, 2015). SNPs involve the substitution of one nucleotide for another or the addition or deletion of one or more nucleotides (Beuzen et al., 2000). According to Beuzen et al., 2000, SNPs are current preferred than other markers like microsatellite because they are: (i) "prevalent and provide more potential markers near or in any locus of interest, (ii) located in coding regions and directly affect protein function, (iii) more stably inherited than microsatellites and (iv) more suitable than microsatellites for high throughput genetic analysis using DNA microarray technology".

However, more SNP markers are required to give information obtained from a single microsatellite, but this problem can be solved by whole genome sequencing (Al-Samarai and Al-Kazaz, 2015). SNPs have been successfully used to investigate genetic variations among species and breeds, and the technology has been made more efficient with the use of high through-put genotyping (Beuzen et al., 2000; Khlestkina, 2014).

## CONCLUSIONS

Sheep selection should not only consider meat, milk, hides and wool production traits but also gene-environment interaction should be considered. Changing climate is exposing these small ruminants to environmental stress like heat stress, floods, poor quality pasture, outbreak of pests and diseases that threaten survivability, reproduction, and performance of sheep. Performance of sheep in the above-mentioned stressful environment will depend on how resilient the breed is, and this depends on the genetic makeup influenced by production environment. Animals activate several mechanisms including morphological, behavioral, physiological, in tolerating extreme environmental stressors. These mechanisms are genetically influenced and hence inherited. Thus, animals with favourable allele combination influencing fitness traits in that environment survives but those without, risk being wiped out. Species with higher genetic diversity stands higher chances of surviving in case of shift of climatic conditions. Therefore, breeding for productivity should be complimented by selection for adaptability and in case the breed is highly rated as risky for extinction, conservation measures should be activated to save the rare native genes.

Tools of molecular and genomic genetics should be used to map genes associated with adaptation and relevant economic traits to improve efficiency is selection and expedite genetic gain in populations. SNP markers are currently more preferred especially for high throughput analysis and their use is going to help in mapping out not only genes for productivity but also adaptability and further correlate phenotype and the prevailing climatic condition. This will help in improving precision in selection for a specific climatic condition. Efficiency in selection will call for a multidisciplinary approach system in mapping out genes and correlating them with phenotypic expression. For instance, participatory approach where all scientists, nutritionists, local farmers, meteorologists will put their resources together for a common course of sustainable food security, animal welfare as well as environmental management will be sufficed.

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