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Physiological Adaptation of Animals to the Change of Environment: A Review

Aleme Asres[1*] and Negassie Amha[2]
1, Department of Animal Sciences, Adigrat University, Ethiopia
2, School of Animal and Range Sciences, Haramaya University, Ethiopia
*Corresponding author E-mail: almasres06@gmail.com.

Abstract
Animals living in different ecologies of the world have for several decades and for every moment of the day developed means for coping their environment as a matter of survival. Consideration must be given to effects and adaptive mechanisms for different environmental change. The concept of fitness of farm animal extends from ability to survive now and withstand environmental demands in future, to ability to produce sufficiently to justify cost of domestication. Homeostasis, physiological, biological and genetic adaptations are concepts in understanding the means by which animal cope with their environment. The concept of energy balance forms the central pivot which tilts the environmental change in different directions for animal to respond. Effective responses of animals to environmental change often result in depressed productivity even in attempt to apply mechanisms to ward off the pervading change of environmental condition. The responsibility of the producer is to understand these concepts in the management of the stock for survival and higher productivity by controlling the overbearing influence of the environmental change. Mammals are not only able to survive in arid environments, but they are able to thrive due to a wide array of adaptations. These adaptations allow the mammals to maintain a balance between thermoregulation and water balance. Mammals use evaporative cooling techniques to maintain a constant body temperature, while at the same time they use behavioral adaptations to reduce heat load and water loss. Many mammals do not need to ingest water to survive. Instead, they get it from the food they eat. Nasal counterflow, concentrated urine, and dry faeces also reduce the amount of water an animal loses. All these adaptations and more, play an important role in the animal's ability to conquer the change of environment.
Keywords: Physiological adaptation, homeotherm, and hyperthermia

1. Introduction

Climate change, defined as the long-term imbalance of customary weather conditions such as temperature, radiation, wind and rainfall characteristics of a particular region, is likely to be one of the main challenges for mankind during the present century. The earth's climate has warmed in the last century (0.74 ± 0.18°C) with the 1990s and 2000s being the warmest on instrumental record (Tanaka *et al*., 2007) Furthermore, the earth's climate has been predicted to change continuously at rates unprecedented in recent human history (Tanaka *et al*., 2007). Current climate models indicated an increase in temperature by 0.2°C per decade and predicted that the increase in global average surface temperature would be between 1.8°C to 4.0°C by 2100 (Tanaka *et al*., 2007). The variation in climatic variables like temperature, humidity and radiations were recognized as the potential hazards in the growth and production of all domestic livestock species. High ambient temperature accompanied by high air humidity caused an additional discomfort and enhanced the stress level which in turn resulted in depression of the physiological and metabolic activities of this animal.

An adaptation is defined as "a trait that increases fitness relative to an alternative trait" or any behavioral or physical characteristics of an animal that help it to survive in its environment. These characteristics fall into three main categories: body parts (e.g. feet, mouthparts), body coverings, and behaviors. Any or all of these types of adaptations play a critical role in the survival of an animal (Schluter, 2000). When we talk about the adaptations of individuals we mean the way in which an animal fits into its environment and uses its resources. The adaptive characters that describe an individual its physical attributes (morphology), physiology, and behavior are determined first by the processes of natural selection and secondly by its history over evolutionary time, its phylogeny. Adaptive responses may occur fundamentally at a molecular level, but they "appear" at various different spatial levels in the whole animal. Some responses are essentially sub-cellular, and others affect the morphology or activity of whole cells. Yet others manifest as effects on entire tissues or organs, for example changes in muscle size, heart volume, or arrangements of vascularization. An animal's shape, size, and appearance can reveal a great deal about its environment and how it lives. An adaptation like thick fur, for example, suggests that an animal is exposed to cold temperatures. Body shape, coloration, forelimb structure, and jaw or beak shape are other examples of evolutionary adaptations that help an animal survive and reproduce (Klir and Heath, 1994).

Seventy percent of animals live in arid or semi-arid and the remaining in temperate climate (Climate averages, 2000). Arid regions are characterized by receiving 100-250 millimeters of rain a year and semi-arid regions are characterized by receiving 250-500 mm of rain per year (Costa, 1995). Not only are these regions faced with sparse rainfall, but they are also confronted with extreme temperatures. During the summer months of January and February, temperatures regularly exceed 40°C in the arid regions (Climate averages, 2002). The temperatures are even more scorching for small animals that live close to the ground because the soil becomes much hotter than the air (Walsberg, 2000). Therefore, mammals must have adaptations to cope with the heat and lack of available water. Additionally, they must have adaptations to balance thermoregulation with water regulation. This paper will address these different physiological adaptations and explain how they work.

2. Physiological Adaptation of Animals to Hot Environment

Animals achieve thermal balance through a combination of physiological, behavioural and physical processes. As their environmental temperature changes, they may elect to redistribute internal body heat or alter their exposure to different microhabitats in order to achieve their optimum temperature. Some animals, namely, endotherms (e.g. birds and mammals), produce their own heat, and as such, must have mechanisms for conserving this heat, whereas most other animals (e.g. fish, amphibians, reptiles and invertebrates) are ectothermic, and derive their body heat from their environment. In other words, they utilize behavioural mechanisms to capitalize on physical processes in the environment (radiative, convective, conductive or evaporative heat exchange).This can be effected by**:** Behavioural means e.g. moving away from heat source, drinking more water, looking for shed or cold surface, Reduction in body insulation e.g. (a) vasodilatation to the ears, legs and tongues as more blood flows there to dissipate heat by taking advantage of hairlessness of the body parts, Shedding of hair: If environmental temperature is equals to body temperature, vasodialation ceases to be very effective, Increase in temperature loss: This occurs either from the skin or respiratory tract. The evaporation from skin is by sweating through sensible and insensible heat loss. Loss of heat energy from respiratory tract is by panting as often noted in chicken or dog, by lower rate of heat production if exposed to heat stress. The appetite drops and animal consume less feed. It also reduces its motor and thyroid activities. The thyroid gland regulates basal metabolism for homeotherms and increase in the reflectance of hair coat to solar radiation. Animal with lighter hair coat reflect more heat than those with darker coat colour. The relative importance of cutaneous and respiratory evaporation varies from specie to another. A sweating animal controls the amount of water while a panting animal controls the amount for larger proportion of total evaporation than European type of cattle. Also within a breed, heat tolerant animal have higher cutaneous and lower respiratory evaporation than heat intolerant counterpart (Klir and Heath, 1994).

2.1. Homeothermy

Mammals can be broadly classified as homeotherm, which means their body temperature is relatively independent of the external environmental temperature (Ricklefs, 2001). Mammals and birds keep their body temperatures between 37°C and 38°C; however there are exceptions (Walsberg, 2000). Maintaining a constant internal temperature requires animals to have mechanisms to regulate their body temperature. This is challenging for desert animals due to the extreme heat and lack of water. Many of the cooling techniques mammals use involve evaporation. However, the animals also have unique physiologically adaptations to counter the evaporative water loss.

2.2. Evaporative cooling techniques

When the surroundings of a mammal are cooler than its body temperature, conduction and radiation are the main ways an animal will dissipate heat (Schmidt-Nielsen, 1964). However, the air temperature is often higher than mammalian body temperatures in the environment, so the only physiological thermoregulatory mechanism available is evaporation (Farid, 1989). Mammals use three evaporative cooling techniques that include sweating, panting, and saliva spreading. Most small mammals do not sweat because they would lose too much body mass if they did. For example, in a hot desert the amount of water a mouse would use to maintain a constant body temperature would be more than 20% of its body weight per hour (Schmidt-Nielsen, 1954). This is a lethal amount; therefore, smaller animals must find other ways to regulate their body temperature. Camels do not visibly sweat because the sweat is forming and evaporating from under the fur on the surface of the skin (Schmidt-Nielsen, 1964). Evaporation from the skin maximizes the amount of heat transported from the body and minimizes water lost through sweating, as compared to evaporation from the fur of an animal. When sweat evaporates from the fur, less cooling occurs, and the animal has to sweat more to maintain a constant body temperature.

Panting is rapid, shallow respiration that cools an animal by increased evaporation from the respiratory surfaces. It is a common technique that small animals make use. According to Bligh (1972), as body size increases the effectiveness of panting decreases. Mammals smaller than 100 kg employ panting as the primary cooling mechanism, while mammals larger than this use sweating (Schmidt-Nielsen, 1972). For example, kangaroos and rodents employ panting as the major source of heat loss (Dawson, 1972).

Saliva spreading is a means of thermoregulation that marsupials use. During heat stress, saliva will drip from a kangaroo's mouth and is then wiped on its fore and hind legs (Dawson, 1972). This technique has two advantages. The animal is wetting its fur instead of the skin, and this induces the effectiveness of evaporative cooling (Dawson, 1972). Also, the animal cannot spread saliva when it is moving, so other techniques of evaporative cooling must be used in these situations (Schmidt-Nielsen, 1964).

2.3. Nasal counter flow

Evaporative cooling techniques use water, a resource that is scarce in arid environments. Therefore, adaptations that reduce the amount of water lost through evaporation are important. One such adaptation is the nasal counter flow system, which reduces respiratory evaporation (Walsberg, 2000). This system functions by lowering the temperature of exhaled air. Water loss can be reduced up to 85% by exhaling at a lower temperature (Schmidt-Nielsen, 1972).

The counter-current exchange system works because inhaled air flows over moist mucous membranes, and this causes water to evaporate from them. The evaporation cools the membrane and reduces its temperature. When the warm, moist air from the lungs passes over the cool mucous membrane on the way out, the air is chilled and water condenses on the membrane (Walsberg, 2000). Mammals that are adapted to desert conditions are better able to use this technique (Schmidt-Nielsen, 1964)

2.4. Hyperthermia

Although mammals are homeotherms, some are able to raise their body temperature as a way to decrease the amount of water used for thermoregulation. Camels and gazelles have been noted to increase their body temperature by 5-7°C during the day (Walsberg, 2000). This occurs more often when the animal is dehydrated. A 500-kilogram camel that is hydrated will face a temperature increase of 2°C, whereas a dehydrated camel's temperature will rise by 6°C (Farid, 1989). Hyperthermia serves two functions. First, the mammals are saving water by letting their body temperature increase instead of using evaporation to keep it at a constant temperature. Second, the mammals are also saving water through reduced evaporative cooling because the thermal gradient between the animal's body temperature and the air temperature has decreased (Walsberg, 2000). Therefore, hyperthermia is a physiological adaptation that mammals can use to conserve water.

2.5. Behavioral adaptations

Behavioral adaptations are used to reduce the amount of heat gained by animals, and, therefore, reduce the need for evaporative cooling. One basic behavioral adaptation is the timing of activity rhythms. Nocturnal animals are able to regulate their heat load by resting during the day, since night time temperatures can be 15-20°C lower than the day time maxima (Walsberg, 2000). Examples of nocturnal animals include the quoll, bilby, and the spinifex hopping mouse. Fossorial animals, such as mulgaras, spent much of their time below ground eating stored food (Costa, 1995). Crepuscular animals take advantage of the slightly cooler mornings and evenings and are only active at those times (Costa, 1995). All these behaviors are an attempt to escape the daytime heat, and to evaporate less water.

The use of microenvironments is another type of behavioral adaptation (Dawson, 1972). Since some animals are diurnal, they rest in the shade during the day to escape the sun.

Burrows are another type of microenvironment that is used by smaller mammals. According to Schmidt-Nielsen (1964), many burrows are at depths where evaporative cooling is not needed because it does not get hot enough in the burrows to require this technique. Additionally, absolute humidity in burrows can be three to four times higher than the outside air, which reduces the amount of water evaporated from the respiratory tract (Schmidt-Nielsen, 1964 & Costa, 1995).

Walsberg (2000) challenges the findings of Schmidt-Nielsen and others about burrow temperature and humidity. He claims that the measurements for the burrow temperatures were not taken from the hottest deserts, and many mammals place their burrows at similar depths in the hotter deserts. Walsberg (2000) also believes that in order for burrow temperatures to stay below 30°C, the burrows would have to be over 2.5 meters deep. This would have a large effect on the animal's heat budget and its thermoregulation because the animal would have to exert a great deal of energy to dig a hole this deep.

2.6. Torpor and metabolic rate

Many small mammals, such as rodents and squirrels, will enter a period of torpor in response to severe heat This is a period where metabolism decreases and the heart and respiratory system slows down based on a daily circadian rhythm (Costa, 1995). Torpor can be considered a water-conserving mechanism because the animal's body temperature is lowered, and it does not have to rely as heavily on evaporation. If the period of torpor becomes longer, it is called aestivation or summer dormancy (Costa, 1995). Aestivation allows an animal to survive when there are high temperatures and a scarcity of water or food. An aestivating animal can live longer off its energy reserves due to lowered metabolism, and there are reduced water loss though lowered breathing rates (Schmidt-Nielsen, 1964). Metabolic rates are lower during torpor and aestivation. However, mammals adapted to desert conditions have lower metabolic rates in general than similar mammals that live in less extreme conditions (Schmidt-Nielsen, 1972).This reduces the internal heat load, and therefore, the water used for evaporation.

2.7. Water and food consumption

Humans obtain about 60% of the water they need from ingested liquid, 30% from ingested food, and 10% from metabolism (Campbell *et al.,* 1999). A rodent adapted to arid conditions obtains approximately 90% from metabolism and 10% from ingested food (Campbell *et al.,* 1999). It is estimated that the Euro can go 2-7 days without water and possibly much longer (Schmidt-Nielsen, 1964). The predaceous marsupial mulgara can go its whole life without ingesting water (Costa, 1995).These mammals still need water, but they have adapted to obtaining water from the food they eat and from metabolism. The fawn hopping mouse eats seed, small insects, and green leaves for moisture, and Kowaris eat insects and small mammals to obtain water (Vandenbeld, 1988). Both of these animals, and most other desert animals, are generalist (Costa, 1995). Generalist feed on varied food sources, which is important when food resources are scarce, as they often are in arid regions (Costa, 1995).

2.8. Excretory adaptations

The ability to excrete concentrate urine and dry faeces is an important adaptation to arid conditions. Mammals that are adapted to the desert have very long loops of Henle compared to animals that live in aquatic environments and less arid regions (Campbell *et al.,* 1999). A longer loop of Henle allows urine to become very concentrated due to the osmotic gradient in the kidneys (Farid, 1989). Desert rodents can have urine five times as concentrated as that of humans (Schmidt-Nielsen, 1964). Antidiuretic hormone (ADH) is important in regulating the volume of urine excreted and its concentration. ADH is produced in the hypothalamus and is released into the bloodstream in response to increased blood osmolarity (Campbell *et al.,* 1999). A larger release of ADH leads to a fast renal response that causes increased reabsorption of water (Schmidt-Nielsen, 1964). This leads to a smaller volume of more concentrated urine being excreted.

Camels produce dryer faeces than other ruminants (Farid, 1989). For example, sheep produce faeces with 45% water after 5 days of water deprivation, while camels produce faeces with 38% water after 10 days of water deprivation (Farid, 1989). Even when fresh, the droppings of camels and desert rodents are almost dry to the touch (Schmidt-Nielsen, 1964). This water reabsorption takes place in the alimentary canal and the colon, and functions to help maintain an animal's water balance (Farid, 1989).

2.9. Body features and circulatory adaptations

Some mammals have long legs to hold their bodies as far away from the solar heated ground as possible. Many have light colored coats to help reflect solar radiation. Others, such as bilbies and rabbits, have large ears that help cool the animal. The ears are covered with tiny blood vessels that help radiate heat from the body (Costa, 1995). When the animal is hot, vasodilation occurs. This increases the diameter of superficial blood vessels resulting in escalated blood flow (Campbell *et al.,* 1999). More heat will then be transferred to the environment through convection, radiation, and conduction. Camels, the fat-tailed marsupial mouse, and other herbivorous mammals store fat as a morphophysiological adaptation to arid conditions (Costa, 1995). This fat can be turned into metabolic water during times of water or food scarcity.

2.10. Energy efficient locomotion

Energy is required to overcome friction and gravity for all types of locomotion. However, different types of locomotion require varying amount of energy. Many mammals hop, which is an energy efficient type of locomotion. When animals go from walking to running, there is an increasing energy cost; however, once kangaroos start moving there is no additional energy cost (Campbell *et al.,* 1999). This is because when a kangaroo lands, energy is stored in the tendons of its hind legs. This stored energy is used to power the next hop (Campbell *et al.,* 1999). For example, when a kangaroo is hopping at 30 kph, its energy costs are about half that of a similar sized animal running at the same speed (Campbell *et al.,* 1999).

2.11. Glycogen repletion

A recent study was done on how the Western chestnut mouse repletes its store of glycogen after physical activity. Rats and humans must eat following activity to totally restore their muscle glycogen (Bräu *et al.,* 1999). However, this is a problem for other animals because it mainly feeds on carbohydrate-poor grasses (Bräu *et al.,* 1999). In lower vertebrates, such as fish, frogs, and lizards, muscle glycogen can be resynthesized from endogenous carbon sources (Bräu *et al.,* 1999). It would be advantageous if the Western chestnut mouse and other mammals that have diets poor in carbohydrates could restore their glycogen completely without food (Bräu *et al.,* 1999). Bräu et al. (1999) designed and performed an experiment to test if the mouse could completely restore its glycogen without food. The mice were fasted for forty hours and then chased for three minutes on a track. A control group was fasted but not chased (Bräu *et al.,* 1999). Following this, the mice were anaesthetized after being allowed to recover zero or fifty minutes with no food. Rodents could completely recover, to pre-exercise levels, their levels of muscle glycogen without food. This is an important adaptation considering the lack of carbohydrate rich food in the rodent's diet, and the need to respond quickly in 'fight or flight' responses (Bräu *et al.,* 1999).

3. Physiological adaptation of animals in cold environment

The animal body can defend itself against cold by three means namely: storing or conserving heat, through insulation and by increasing heat production or a combination of all. Increasing the body insulation against cold is more economical considering energy expenditure involved. Differences in species nurtured by adaptation have favoured economic ways of supporting higher body insulation to animals living in cold climates (Willmer *et al.,* 2005). The body insulation is in three classes: Peripheral Tissue: This act by vasoconstriction of the coetaneous and sub-coetaneous to reduce the temperature gradient from the skin surface to the environment and also by the aid of subcutaneous fat, hair Coat Insulation: This depends entirely on trapped air which occupies over 95 per cent of volume of the air coat. The insulating capacity increases with thickness and air density of the air coat. For example, temperature and arctic species of animals tend to develop thick air coat while most tropical animal have thin air coat, insulation of the Air: This insulation is caused by the layer of air or boundary layer adhering to the surface of the hair coat in the hairy species and to surface of the body in non-hairy species (Yahav *et al*., 2005). It varies from one species to another and is almost independent of the body size. The insulating mechanisms of the boundary layer decreases with increasing air speed.

Table 1. Physiological adaptation of animals' response to environmental change

Effectors	**Response to low temperature**	**Response to high temperature**
Smooth muscles in arterioles in the skin	Muscles contract causing **vasoconstriction**. Less heat is carried from the core to the surface of the body, maintaining core temperature. Extremities can turn blue and feel cold and can even be damaged (**frost bite**).	Muscles relax causing **vasodilatation**. More heat is carried from the core to the surface, where it is lost by convection and radiation (conduction is generally low, except when in water). Skin turns red.
Sweat glands	No sweat produced	Glands secrete sweat onto surface of skin, where it evaporates. Since water has a high latent heat of evaporation, it takes heat from the body. High humidity, and tight clothing made of man-made fibres reduce the ability of the sweat to evaporate and so make us uncomfortable in hot weather. Transpiration from trees has a dramatic cooling effect on the surrounding air temperature
Erector pili muscles in skin (attached to skin hairs)	Muscles contract, raising skin hairs and trapping an insulating layer of still, warm air next to the skin	Muscle relax and lowering the skin hairs allowing air to circulate over the skin, encouraging convection and evaporation
Skeletal muscles	**Shivering**: Muscles contract and relax repeatedly, generating heat by friction and from metabolic reactions (respiration is only 40% efficient: 60% of increased respiration thus generates heat	No shivering
Adrenal and thyroid glands	Glands secrete adrenaline and thyroxin respectively, which increases the metabolic rate in different tissues, especially the liver, so generating heat	Glands stop secrete adrenaline and thyroxin
Behaviour	Curling up, huddling and finding shelter	Stretching out and finding shade

Sources: (Schluter, 2000)

4. Summery and Conclusions

Animals living in different ecologies of the world have for several decades and for every moment of the day developed means for coping their environment as a matter of survival. Consideration must be given to effects and adaptive mechanisms for different environmental change. The concept of fitness of farm animal extends from ability to survive now and withstand environmental demands in future, to ability to produce sufficiently to

justify cost of domestication. Homeostasis, physiological, biological and genetic adaptations are concepts in understanding the means by which animal cope with their environment. The concept of energy balance forms the central pivot which tilts the environmental change in different directions for animal to respond. Effective responses of animals to environmental change often result in depressed productivity even in attempt to apply mechanisms to ward off the pervading change of environmental condition.
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