Veerasamy Sejian · Raghavendra Bhatta
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S.M.K. Naqvi · Rattan Lal *Editors*

Sheep Production Adapting to Climate Change

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Contents

Abbreviations

12WT	Twelve-month live weight
3,4-DHP	3-Hydroxy-4-[1H]-pyridone
6WT	Six-month live weight
9WT	Nine-month live weight
A/G	Albumin/globulin
ACACA	Acetyl-coenzyme A carboxylase alpha
ACTH	Adrenocorticotropin hormone
ADF	Acid detergent fibre
ADG	Average daily gain
AHCS	Automated head chamber system
AHCY	Adenosylhomocysteine hydrolase
AHL	Accumulated heat load
AHS	Acute heat stress
ALA	Alanine
ALT	Alanine aminotransferase
AOPP	Advanced oxidation protein products
AP2	Activating protein
ASIP	Agouti signalling protein
AT	Air temperature
ATP	Adenosine triphosphate
AVA	Arteriovenous anastomose
B Cells	B lymphocytes
BAP	Biological antioxidant potential
BCS	Body condition score
BGHI	Black globe-humidity index
BGT	Black globe temperature
BGTHI	Black globe temperature-humidity index
BLAST	Basic local alignment search tool
BMEC	Bovine mammary epithelial cells
BMP2	Bone morphogenetic protein 2
BTV	Bluetongue virus
BW	Body weight
BWT	Birth weight
CASA	Computer-assisted sperm analysis

CBM	Carbohydrate binding molecules
CC	Climate change
CD4	Cluster of differentiation
CH_4	Methane
Cl^-	Chloride
CL	Corpus luteum
CLA	Conjugated linoleic acid
CMAase	Carboxymethyl cellulase
CN	Casein
CO_2	Carbon dioxide
CoA-SH	Coenzyme A
CoB7SH	N-7-mercaptoheptanoylthreonine phosphate
CoB-SH	Coenzyme B
CoM-SH	Coenzyme M
CoM-S-S-CoB	Heterodisulphide of CoM and CoB
COX-2	Cyclooxygenase
CP	Crude protein
CPR	Common property resources
Cr	Chromium
CRH	Corticotrophin-releasing hormone
CRISPR	Clustered regularly interspaced short palindromic repeats
CrPic	Chromium picolinate
CSN3	Kappa casein
CSP	Community sequencing programme
CSWRI	Central Sheep and Wool Research Institute
CTs	Condensed tannins
DAMPS	Damage-associated molecular patterns
db	Dry bulb temperature
DM	Dry matter
DMI	Dry matter intake
DNA	Deoxyribonucleic acid
DPT	Dew point temperature
DTR	Diurnal temperature range
Ech	Energy-conserving hydrogenase
EHH	Extended haplotype homozygosity
ENSO	El Niño-Southern Oscillation
EOs	Essential oils
EPA	Eicosapentaenoic acid
ESI	Environmental stress index
ETI	Equivalent temperature index
EU	European Union
EVHL	Evaporative heat loss
EWS	Early warning system
F_{420}	Reducing hydrogenases
$F_{420}H_2$	Reduced form coenzyme F_{420}

FAANG	Functional Annotation of Animal Genomes
FAD+	Flavin adenine dinucleotide (oxidised form)
FADH	Flavin adenine dinucleotide (reduced form)
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FB	Feed blocks
Fdh	Formate dehydrogenase
Fd_{ox}	Oxidised form of ferredoxin
Fd_{red}	Reduced form of ferredoxin
FE	Facial eczema
FEC	Faecal egg count
FGF 2	Fibroblast growth factor 2
FGF	Fibroblast growth factor
Fmd	Formyl-MFR dehydrogenase
FSH	Follicle-stimulating hormone
Fst	Allele frequency
Ftr	Formyl-MFR:H_4MPT formyl-transferase
GCI	Global comprehension index
GDP	Gross domestic product
gEBV	Genomic estimated breeding values
GH	Growth hormone
GHG	Greenhouse gases
GHGs	Greenhouse gases
GIS	Geographic information system
GIT	Gastrointestinal tract
GLUT1	Glucose transporter 1
GLUT3	Glucose transporter 3
GNA13	Guanine nucleotide binding protein subunit alpha I3
GnRH	Gonadotropin-releasing hormone
GOI	Government of India
GOT	Glutamic oxaloacetic transaminase
gp96	Glucose regulated protein 96
GPT	Glutamic pyruvic transaminase
GPx	Glutathione peroxidase
GRASS	Grassland Regeneration and Sustainability Standard
GSH-Px	Glutathione peroxidase
GTPase	Guanosine triphosphate hydrolases
GWAS	Genome-wide association study
GWP	Global warming potential
H_2	Hydrogen
H_2O_2	Hydrogen peroxide
H_4MPT	Tetrahydromethanopterin
Hb	Haemoglobin
HCT	Haematocrit
Hdr	Heterodisulphide reductase

HGB	Haemoglobin
HIS	Heat stress index
HLI	Heat load index
HMG-CoA	3-Hydroxy-3-methyl-glutaryl-coenzyme A
HPA axis	Hypothalamic-pituitary-adrenal axis
HPG axis	Hypothalamic-pituitary-gonadal axis
HPR	Heart beat rate
HS	Heat stress
HSF	Heat shock factor
HSF-1	Heat shock factor1
HSP	Heat shock protein
HSPBAP1	Heat shock 27 Kda associated protein 1
HSPs	Heat shock proteins
ICAR	Indian Council of Agricultural Research
ICIMOD	International centre for integrated mountain development
ICSI	International commission for snow and ice
IFAD	International Fund for Agricultural Development
IFN-γ	Interferon gamma
IGF-1	Insulin-like growth factor 1
IgG	Immunoglobulin G
iHS	Haplotype mapping
IL	Interleukins
IL-10	Interleukin-10
IL-1β	Interleukin-1β
IL-6	Interleukin-6
INOS	Inducible nitric oxide synthase
IPCC	Intergovernmental panel on climate change
IT	Information technology
IVGTT	Intravenous glucose tolerance test
IWTO	International Wool Textile Organisation
JAK/STAT	Janus kinase/signal transducer and activator of transcription
JGI	Joint Genome Institute
K^+	Potassium
kJ	Kilojoules
KR	Kleiber ratio
LCA	Life-cycle assessment
LCT	Lower critical temperature
LD	Linkage disequilibrium
LDH	Lactate dehydrogenase
LDL	Low-density lipoproteins
LEP	Leptin
LFMM	Latent factor mixed model
LH	Luteinising hormone
LMD	Laser methane detector
Mch	Methenyl-H_4MPT cyclohydrolase

MCH	Mean corpuscular haemoglobin cell
MCR	Methyl-coenzyme M reductase
MCV	Mean corpuscular volume
ME	Metabolisable energy
ME1	Malic enzyme 1
MFR	Methanofuran
Mha	Million hectare
MHC	Major histocompatibility complex
MITF	Microphthalmia-associated transcription factor
MJ	Megajoules
MoEF	Ministry of environment and forests
MPV	Mean platelet volume
MRT	Mean retention time
MSTN	Myostatin
MT	Million tons
MUFA	Monounsaturated fatty acids
N	Nitrogen
N/L	Neutrophil/lymphocyte
N_2O	Nitrous dioxide
Na^+	Sodium
NAD+	Nicotinamide adenine dinucleotide (oxidised form)
NADH	Nicotinamide adenine dinucleotide (reduced form)
NADP	Nicotinamide adenine dinucleotide phosphate
NADPH	Nicotinamide adenine dinucleotide phosphate (reduced form)
NASA	National Aeronautics and Space Administration
NCAD	Cadherin-2
NDF	Neutral detergent fibre
NDSU	North Dakota State University
NEFA	Non-esterified fatty acids
NFC	Non-fibre carbohydrates
NF-κb	Nuclear factor kappa B
NH_3-N	Ammoniacal nitrogen
NK Cells	Natural killer cells
NO	Nitric oxide
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NPY	Neuropeptide Y
NRC	National Research Council
NRDC	Natural Resources Defense Council
NSC	Non-structural carbohydrates
NSW	New South Wales
NWS	Norwegian white sheep
OS	Oxidative stress
OTUs	Operational taxonomic units
p38	Mitogen activated protein 38 kinase

PA	Plasminogen activator
PAC	Portable accumulation chambers
PAMPs	Pathogen-associated molecular patterns
PBMC	Peripheral blood mononuclear cells
PCA	Principal component analysis
PCT	Plateletcrits
PCV	Packed cell volume
PDW	Platelet distribution width
PG	Plasminogen
PGE_2	Prostaglandin E_2
PGgRC	Pastoral Greenhouse Gas Research Consortium
PHA	Phytohemagglutinin
PIT1	Pituitary transcription factor 1
PL	Plasmin
PLCB1	Phospholipase C beta 1
PLT	Platelets
PPR	Peste des petits ruminants
PR	Pulse rate
PRCV	Coefficient of variation of monthly precipitation
PRLR	Prolactin receptor
PRR	Respiratory rate predictor
PRRs	Pattern recognition receptors
PSM	Plant secondary metabolites
PUFA	Polyunsaturated fatty acids
PVP	Partial vapour pressure
QTL	Quantitative trait loci
QUICKI	Quantitative insulin sensitivity check index
RA	Rumenic acid
RBC	Red blood cell count
RDO	Number of days with >0.1 mm rain per month
RDW	Red cell distribution width
REA	Rib eye area
RELA	REL-associated protein
RH	Relative humidity
ROH	Genotyping of homozygote regions
ROM	Reactive oxygen metabolites
ROS	Reactive oxygen species
RR	Respiratory rate
RT	Rectal temperature
SAM	Spatial analysis method
SARA	Sub-acute ruminal acidosis
SCC	Somatic cell count
SCFAs	Short-chain fatty acids
SCS	Somatic cell score
Se	Selenium

SF_6	Sulphur hexafluoride
SGOT	Serum glutamic oxaloacetic transaminase
SLC2A3	Glucose transporter 3
SLC5A1	Sodium/glucose co-transporter 1
SNP	Single nucleotide polymorphism
SOCS-3	Suppressor of cytokine signalling-3
SOD	Superoxide dismutase
SOD-2	Superoxide dismutase 2
SR	Solar radiation
SRH	Somatotropin-releasing hormone
SSCP	Single-strand conformational polymorphism
SUN	Maximum possible sunshine
T	Dry bulb temperature
T_3	Triiodothyronine
T_4	Thyroxine
Ta	Ambient temperature
TALEN	Transcription activator-like effector nucleases
T-Cells	T lymphocytes
TCF	T-cell-specific transcription factor
TCI	Thermal comfort index
TCRs	T-cell receptors
Td	Dry bulb temperature
td	Dry bulb temperature
Tdb	Dry bulb temperature
TDN	Total digestible nutrients
Tdp	Dew point temperature
Th Cells	T-helper cells
THI	Temperature-humidity index
TLR	Toll-like receptor
TLRs	Toll-like receptors
TNF	Tumour necrosis factor
TNF-α	Tumour necrosis factor-alpha
TNZ	Thermal neutral zone
To	Dew point temperature
TS	Total solids
TVFA	Total volatile fatty acid
Twb	Wet bulb temperature
TYRP	Tyrosinase-related protein
TYRP1	Tyrosinase-related protein 1
TZDs	Thiazolidinediones
U1	U1 spliceosomal RNA
UCSC	University of California, Santa Cruz
USGCRP	United States Global Change Research Program
USSR	Union of Soviet Socialist Republics
UTMPs	Uterine milk proteins

V	Vanadium
VA	Vaccenic acid
VFA	Volatile fatty acid
VFAs	Volatile fatty acids
VFI	Voluntary feed intake
Vit E	Vitamin E
Vit A	Vitamin A
VP	Vasopressin
WANA	West Asia and North Africa
WBC	White blood cell count
WS	Wind speed
WTI	Water intake
WWT	Weaning weight
ZFN	Zinc finger nucleases
Zn	Zinc

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Dr. Raghavendra Bhatta, PhD is the director at the ICAR-National Institute of Animal Nutrition and Physiology (NIANP), Bangalore, India. Dr. Bhatta and his team for the first time have developed the all India district-wise inventory on enteric methane emission. Dr. Bhatta has published 63 research papers in journals of high impact factor, 25 book chapters and 83 conference papers. He also edited a book on *Livestock Production and Climate Change* published by CABI. He was the recipient of prestigious JSPS Postdoctoral Fellowship at NILGS, Japan. He has been recognised as an expert of the Technical Advisory Group (TAG) of the Food and Agricultural Organization of the United Nations (FAO).

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Adapting Sheep Production to Climate Change

1

Veerasamy Sejian, Raghavendra Bhatta, John Gaughan,
Pradeep Kumar Malik, S.M.K. Naqvi, and Rattan Lal

Abstract

Apart from contributing to the climate change phenomenon, sheep production system is also sensitive to its adverse impacts. This poses a great challenge for developing sheep sector around the world. Currently the economic viability of the sheep production system worldwide is jeopardized due to the devastating effects of climate change. Among the multiple climatic stresses faced by sheep, heat stress seems to hugely destabilize production efficiency of the animals. Heat stress jeopardizes the growth, wool, meat and milk production in sheep. Further, climate change leads to several vector borne diseases to sheep by compromising the immune status of the animals. The animal employs several adaptive mechanisms to maintain homeostasis through behavioural, physiological, neuroendocrine, cellular and molecular

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responses to cope up to the existing climatic condition. Sheep also significantly contributes to climate change through enteric methane emission and manure management. Further, climate change can alter the rumen function and diet digestibility in sheep. Hence, enteric methane mitigation is of paramount importance to prevent both the climate change and dietary energy loss which may pave way for sustaining the economic return from these animals. Further, various other strategies are required to counter the detrimental effects of climate change on sheep production. The management strategies can be categorized as housing management, animal management and monitoring of climate, and these strategies are ultimately targeted to provide suitable microclimate for optimum sheep production. Nutritional interventions involving season-specific feeding and micronutrient supplementation may help the animal to sustain its production during adverse environmental conditions. Body condition scoring system developed specifically for sheep may help to optimize economic return in sheep farms by minimizing the input costs. Finally, sufficient emphasis must be given to develop appropriate adaptation strategies involving policymakers. These strategies include developing thermotolerant breeds using biomarkers, ensured water availability, women empowerment, early warning system and capacity building programmes for all the stakeholders. These efforts may help in augmenting sheep production in the climate change scenario.

Keywords
Adaptation • Climate change • Heat stress • Sheep • Housing • Sprinkling • Thermotolerance

Contents

1.1 Introduction

Climate change has emerged as the major threat ever experienced by humankind (IPCC 2013). It has turned up to be the global phenomenon and is mostly concerned about the intimidous atmosphere it is creating worldwide. Accelerated rate of greenhouse effect arising from the abruptly increasing anthropogenic emission of greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) is considered to be the primary root cause of climate change. Through its growing potency to destabilize the ecological balance of the earth and to debilitate the global economy, the phenomenon draws global attention. Population explosion is another global event exacerbating the adversities of climate change since the anthropogenic contribution to climate change is crucial. The world population is projected to increase from its present level of 7.5 billion in 2017 to 9.7 billion by 2050 which is quite alarming (FAO 2013). Food security is greatly at stake in the changing climate scenario because of the alarming consequences imposed on the agricultural production system (FAO 2009). Further, alterations in temperature, precipitation, atmospheric CO_2 levels and water availability arising from the anthropogenic-driven climate change greatly impact the agriculture and animal productivity (Hatfield et al. 2008; Melillo et al. 2014).

Global earth surface temperature is rising at an alarming level. Projection is that surface temperature will rise between 2.6 and 4.8 °C, and sea level is expected to increase 0.45–0.82 m by the end of 2100 which has deleterious effects on both natural and human systems (IPCC 2013). Weather is getting more variable with effects like changes in El Ñino or thermohaline circulation (Gregory 2010). Precipitation pattern and seasonal monsoon are fluctuated resulting from altered hydrological cycle due to temperature rise. Sea surface temperature rise accompanied with ocean acidification is significantly influencing marine ecosystem and curtailing the ocean productivity and hence the economic output from this sector. The probability of occurrence of extreme events like severe heat emission, droughts, floods, cyclones and wildfires is more in the changing climate. Crops may be susceptible to new insect and disease problems declining agricultural production (FAO 2013). Climate-related disasters are on the rise and since 2004, 262 million people were affected by the extreme climatic events (Blaikie et al. 2014). Developing countries are more prone to such disasters because of lack of proper early warning system and infrastructure. Anticipating the future in the changing climate scenario, concerted efforts for developing proper adaptation, mitigation and amelioration strategies have become the need of the hour for sustaining the survival of species in our planet.

The interference of anthropogenic activities oriented GHG emission to climate change has stimulated the global research efforts pertaining to livestock contribution to global warming. Efforts are further needed to comprehensively assess the multifaceted impacts of climate change on different components of ecosystems to have a thorough understanding on the subject (Naqvi and Sejian 2011; Shinde and Sejian 2013). Among the different sectors, agriculture generated considerable interest in the last couple of decades as evident from the detailed research efforts that established the disadvantageous position of this sector for the adverse impacts of climate change (Baumgard et al. 2012).

Sheep industry, which ensures the livelihood security and economic sustenance of the poor farmers, is practiced in almost all climates ranging from cold to hot and dry and hot and humid climates. Among the various climatic factors, heat stress seems to be the major intriguing factor which hampers the productive and reproductive performance traits of sheep (Sejian 2013). Prolific sheep breeds in hot and humid coastal region, excellent carpet wool breeds in hot and dry regions, fine wool breeds in cold and dry temperate climate and mutton breeds in hot and humid plains evolved through the process of adaptation. Open fleece in hot and humid region facilitates the dissipation of body heat while close fleece in temperate region helps in conservation of body heat, both the fleece character plays an important role in balancing heat dynamics. Similarly, prolificacy trait in coastal sheep breeds is associated with higher temperature coupled with humidity. Fine wool breeds of temperate countries performed poorly in the tropics because of unfavourable climate, which does not allow them to sustain and produce (Shinde and Sejian 2013). It has been realized from earlier attempts that fine wool production is feasible in temperate locations of the country.

The adaptation of sheep breeds to different locations/climates depends upon temperature, humidity, vegetation and wool cover and resistance/susceptibility to various diseases. Sheep breeds can tolerate a wide range of climate and convert poor-quality forage into quality animal protein. These characters favour their rearing under extensive system among poor rural people in harsh climate (Shinde and Sejian 2013). The future anticipated changes in climate may cause shifting of sheep from one region to another, change in breed composition, change in livelihood and nutritional security of farmers, shifting trend of sheep breeds from wool to mutton type, emergence, re-emergence of newer diseases, etc. Therefore, efforts are needed to develop world-class resource materials compiling the research efforts from different parts of the world pertaining to sheep production adapting to climate change. This could help researchers to battle against climate-induced vagaries on sheep production and optimize the economic return for the poor and marginal farmers around the globe.

Therefore this particular volume attempts to collate and synthesis information pertaining to multifaceted impacts of climate change on sheep production and contribution of sheep to climate change. Efforts were also made in this volume to describe the different adaptation strategies to find solution to sheep-induced climate change by curtailing their GHG emission. Further, attempts have been made to highlight various adaptation strategies to reverse the adverse impacts of climate change on sheep production. These details on adapting sheep production to climate change are addressed elaborately in four different sections of this volume.

1.1.1 Climate Change and Livestock Production

Livestock sector plays a major role in securing the global economy. Animal husbandry contributes to around 40% of global agricultural gross domestic product (GDP). Livestock is a main source of income for poor people around the globe and provides employment opportunities for over 1.3 billion people (FAO 2006). Livestock sector contributes milk, meat, wool, hides, egg, manure, etc. But nowadays production from livestock sector is found to be decreasing as a result of increased frequency of weather-related natural calamities. Climate change affects livestock sector through many ways by altering feed grain production price and availability, quality of pastures, quality of water availability and pest and disease outbreak and by affecting directly the animal production, reproduction and health (IPCC 2013).

Increased ambient temperature is one of the most exacerbating attribute imposing severe consequences on livestock production. Heat-stressed animals reduce feed and water intake. This can alter the endocrine profile thereby increasing the energy requirements for maintenance leading to negative impact on the production performance of livestock (Gaughan and Cawdell-Smith 2015; Sejian et al. 2016). Extensive and semi-intensive systems of sheep rearing are more vulnerable to the devastating effects of climate change than the intensive production systems (Nardone et al. 2010). Similarly, the magnitude of decrease in meat and milk production is higher in grazing-based livestock systems, and this could be attributed to less foraging of animals as they try to remain in the shade during hot weather conditions (IPCC 2013).

Milk production is reduced during heat stress, and in general high-producing animals are more vulnerable as compared to the low-producing animals (Pragna et al. 2017). Further, beef cattle with intense and darker hair coat are very sensitive to heat stress (Nardone et al. 2010). Heat stress affects the meat quality by increasing the pH of the meat and decreasing the Warner–Bratzler shear force causing darker meat (Nardone et al. 2010). Heat stress greatly affects poultry industry through consequences on body weight changes and carcass characteristics (Tankson et al. 2001; Feng et al. 2008).

Livestock production and climate change are a two-way phenomenon comprising the impacts of climate change on its production as well as its role in climate change through release of GHGs (Naqvi and Sejian 2011). Therefore if efforts are made to improve sheep production during climate change, they must invariably target both these pathways. This warrants simultaneously efforts to reduce sheep-related GHGs as well as reduce the impacts of climate change. These are all the type of efforts that are needed to improve sheep production in the era of climate change. Figure 1.1 highlights the different concepts associated with sheep production adapting to climate change.

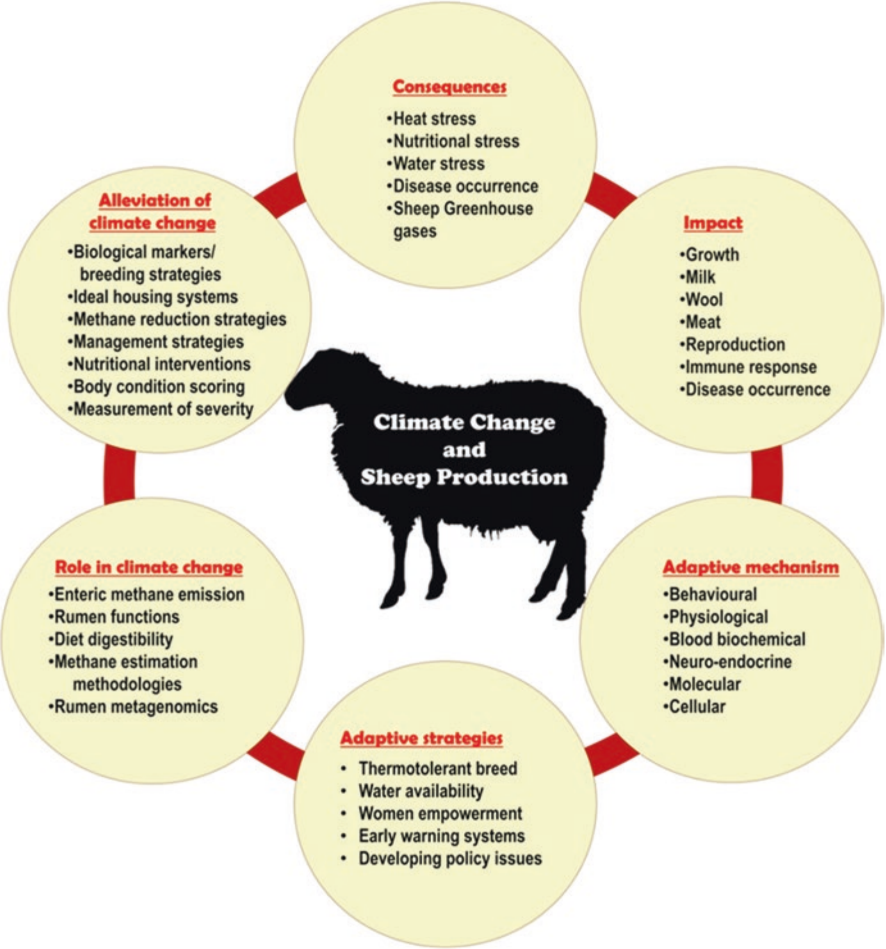

Fig. 1.1 Concepts associated with climate change and sheep production

1.1.2 Climate Change and Types of Environmental Stresses

Apart from the usual suspect heat stress, there are numerous other environmental stresses such as nutrition, water and walking stresses (Sejian et al. 2016; Shaji et al. 2016b). During summer season there is severe depreciation of pastures which hampers the livestock production drastically (Sejian et al. 2011a). It is not only the quantity but also the quality that gets compromised during extreme heat stress condition (Sejian et al. 2014a). Further, the animals have to walk a long distance in search of these limited pasture resources. This locomotory activity also imparts severe stress to the animals (Sejian et al. 2012a). Ideally during a summer season, all these stresses happen simultaneously, and hence research efforts are needed to quantify these cumulative stress responses rather than establishing heat stress impact alone

(Sejian et al. 2012b, 2013a). Such cumulative environmental stresses may have much more lethal impact on livestock production as compared to one stress at a time. This adverse stress response could be attributed to inability of the animals to cope to different stressors simultaneously as well as lack body resources to support life-sustaining activities (Sejian et al. 2010a; Shaji et al. 2016a).

1.2 Climate Change Impact on Sheep Production

Section I is covered in eight different chapters addressing the adverse impacts of climate change on sheep production. Special attempt was made to highlight the impact of climate change on growth, wool production, meat production, reproduction, immune response and adaptive capability of sheep. Efforts were also made to highlight the different emerging diseases in sheep as a result of climate change. Further, this section also elucidates the genetic diversity and breed differences associated with sheep adaptation to climate change. Additionally, this section also addresses in detail the water stress and the impact it had on the sheep production.

1.2.1 Sheep Production in the Changing Climate Scenario

Increased extreme weather events emerging due to climate change have received greater attention in the recent decades. Although climate change is a global phenomenon, its damaging effects are more severe in developing countries as a result of strong dependence on natural resources (Wheeler and Von Braun 2013) and weak institutional support. Variable climate, less accessibility to feed and water and extensive system of rearing have compromised productivity of the animals in tropical regions (Sejian et al. 2010a; Vermeulen et al. 2012). Small ruminants are well adapted to the extreme climatic conditions compared to other livestock species and add livelihood security for poor and marginal farmers in the tropical environment (Shinde and Sejian 2013). Sheep possess superior ability to convert more fibrous and low-quality feed to meat than cattle. Native sheep breeds of arid and semiarid regions have higher adaptability to harsh environmental conditions compared to exotic breeds. Hence, appropriate breed selection is an effective tool to sustain production in the changing climatic conditions (Iniguez 2005). Even though sheep show higher adaptation to harsh environment, the fast-changing climate could affect the sustainable production through low feed intake, variation in energy and mineral metabolism, alterations in water and protein balances, etc. (Finocchiaro et al. 2005; Marai et al. 2007). The key constraints such as thermal-, nutritional- and water-related stresses reduce productivity of the sheep in hot and dry regions (Kandemir et al. 2013; Sejian 2013). In addition, the indirect effects of increased incidence of disease and parasite infection and reduced pasture availability also contribute to additional stress and produce decreased wool, milk and meat production in sheep (Singh et al. 2012). Since most of the sheep population are owned by poor sections of the society, loss of production may lead to severe poverty in rural areas. Hence, development of appropriate amelioration strategies is very much essential for sustaining the sheep production during adverse environmental condition.

1.2.2 Impact of Climate Change on Sheep Production

Animals can maintain their thermal balance within a range of thermal environment through their behavioural and physiological responses (Sejian et al. 2013b). The dissipation of heat from the animal body is influenced strongly by the environmental variables such as high temperature, high humidity and solar radiation. Exposure to such extreme weather events elicits the compensatory and adaptive mechanisms in the animals to re-establish homeothermy, and such an effort is very essential for the survival of the animals. Thus while trying to adapt to the extreme environmental condition, their productive performance are compromised primarily due to the deviation energy consumed to adaptive processes (Indu et al. 2014).

Climate change affects sheep production both directly and indirectly. The production losses incurred for climate change in sheep could be attributed to the low pastures, low water availability and disease outbreaks (Sejian et al. 2014a). Changes in the availability of pastures during summer season can affect sheep production by altering the supply of feed (Sejian et al. 2014a; Indu et al. 2015). Quantity and quality of wool is declining in marginal agricultural areas. Likewise a reduction in wool fibre diameter has been reported in response to deteriorating pasture quality and availability (Howden et al. 2003). Heat stress can reduce the productivity of sheep flock by tumbling the growth rate of animal by appetite suppression (West et al. 1991; Harle et al. 2007).

Increased ambient temperature negatively affects sheep production by drastically affecting all the growth parameters (Indu et al. 2015). Collective effects of decreased feed intake and increased energy allocated for heat dissipation, gut physiological and metabolic process could be the reason for reduced body weight (Indu et al. 2015). The altered growth performance during heat stress could be attributed to the increased tissue catabolism and decreased anabolic activity (Marai et al. 2006; Kandemir et al. 2013). Further, the reduced body condition score (BCS) of the animals could be attributed to the less feed intake during heat stress condition (Sejian et al. 2010a). In addition, during summer season the reduced BCS along with heat stress can negatively influence the reproductive efficiency and lambing rate in sheep (Sejian et al. 2010b). Reduced feed intake and nutritional constraints resulting from the high ambient temperature negatively affects the conception rate, oocyte quality and reproductive hormone levels in sheep (Sejian et al. 2010a). Heat stress has significant influence on meat quality and carcass characteristics in sheep. Dressing percentage declines in heat-stressed sheep (Rana et al. 2014). Similarly an increase in meat pH and darkness of meat has been reported in male Ujumqin wool sheep during heat stress condition (Liu et al. 2012). Figure 1.2 highlights the impact of heat stress on various reproductive activities in sheep

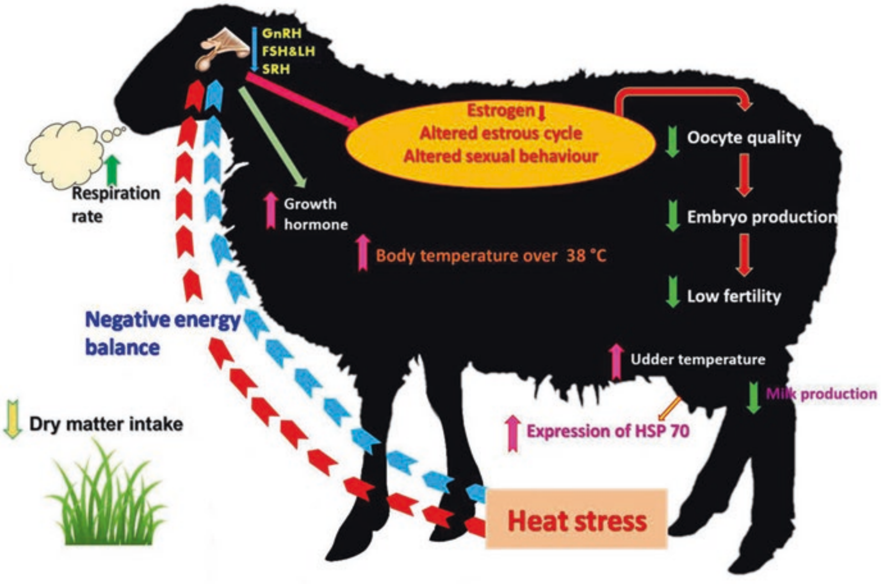

Fig. 1.2 Description of heat stress influencing various reproductive activities in sheep

1.2.3 Climate Change Impact on Immune Response

Climate change and its devastating impacts on livestock sector are now well-established facts gaining much global attention. With growing demand for livestock products for keeping pace with the population rise which is about to surpass 9.5 billion by 2050, attention is drawn more towards the production losses from this sector (Yatoo et al. 2012). Besides the direct effect of changing climate by excess temperature, indirect effects arise through feed and water shortages, microbial populations, vector-borne diseases and host resistance to infectious agents impacting animal health.

Different components of innate and adaptive immune responses are mostly jeopardized during heat stress (Daramola et al. 2012; Sophia et al. 2016a). Neutrophils serve the first line of defence against pathogens by recognition of distinct pathogen-associated molecular patterns (PAMPs) using specific Toll-like receptors (TLRs) (Salak-Johnson and McGlone 2007). Adaptive immunity plays the role of producing specific antibodies against antigens or foreign proteins which are derived from cells such as T- and B-lymphocytes, antigen-presenting cells and natural killer (NK) cells.

During environmental stresses the animal elicits a number of thermoregulatory activities including behavioural, physiological, neuroendocrine and cellular responses in order to maintain the homeostatic balance and survival (Gaughan 2012). But during the process, immune responses in the animal usually get suppressed (Aggarwal and Upadhyay 2013; Shini et al. 2010). Primary and secondary lymphoid organs, T cell in blood, antibodies and competence against Newcastle disease in heat-stressed sheep are diminished (Liew et al. 2003; Daramola et al. 2012). Contrary to the report stating the immunosuppression tailing heat stress, antibody titers getting overproduced in young chicken and these contrary results are attributed to breed and age (Daramola et al. 2012). Release of corticosterone which is the primary stress-relieving hormone involved in heat stress in animals is usually followed by upregulation of circulating cytokines which is dominated by rising levels of interleukin-6 (IL-6), interleukin-10 (IL-10) and soluble receptors for interleukin-1β (IL-1β), tumour necrosis factor (TNF-α) and IL-6. Welc et al. (2013) reported that TLR-8 and TLR-10 could be used as immunological markers for goats during heat stress (Sophia et al. 2016a, b). Further, it is also suggested that the lesser severity of heat stress on immune functions is observed compared to nutritional stress in animals (Sophia et al. 2016c).

Several studies have indicated alterations in innate immunity and induced immune response in heat-stressed animals by production of stress protein such as heat shock protein (HSP): HSP60, HSP70, HSP90, and gp96 (Tsan and Gao 2009). Overproduction of HSP in heat-stressed animals, which is a cellular stress response, will trigger the antigen presentation, activation of macrophages, lymphocytes and activation and maturation of dendritic cells. Studies in heat-shocked human cells suggested that TLR-2 and TLR-4 induction was independent of HSP70 production (Zhou et al. 2005). The study further reported the influence of p38 kinase on induction of TLR-2 and TLR-4 that might aid in improved response to pathogen-associated molecule patterns (PAMPs).

1.2.4 Sheep Adaptive Mechanisms to Climate Change

Adaptation of sheep to different location depends upon prevailing climatic condition, type of feed availability, wool cover and vulnerability to various diseases. Sheep reared in hot environment are exposed to heat stress and nutritional deprivation. In addition, reduced grazing land during extreme climatic condition predisposes for long distance walking in animals (Sejian et al. 2010a, 2013a). Sheep can tolerate very high range of temperatures and has the capacity to convert low-quality forage to quality animal protein (Shinde and Sejian 2013). Moreover, indigenous sheep breeds possess various morphological characteristics such as carpet-type wool, light-coloured fleece, thinner skin, shorter hairs and fat tail to facilitate better heat dissipation in hot climates (McManus et al. 2009).Whenever the animals are under stress, glucocorticosteroids in coordination with other hormones bring about specific behavioural, physiological and biochemical responses (Wingfield and Kitaysky 2002; Sejian et al. 2010a). Behavioural alterations reported in sheep during high ambient temperature include shade seeking, open-mouthed panting, increased salivation and water intake (Stockman 2006). Ewes exposed to multiple stresses (heat, nutritional and walking stress) show increased physiological parameters such as rectal temperature, pulse rate, respiration rate and sweating rate as thermoregulatory adjustments to maintain homeostasis (Sejian et al. 2013a). In addition, rectal temperature also acts as an indicator for multiple stresses in sheep. Further, combined effects of restricted water intake and higher evaporative loss caused hemoconcentration and lead to higher PCV and Hb levels in the ewes during heat stress condition. In addition, high temperature directly affects the satiety centre and cause decreased feed intake to suppress internal metabolic heat production. Likewise, heat stress also disturbs hypothalamus pituitary axis and reduces thyroid-stimulating hormone production leading to lower production of metabolic hormones such as T_3 and T_4 in sheep as a metabolic adaptation to control heat production during heat stress condition (Sejian et al. 2010a; Silva et al. 2016). Further, heat stress is found to alter cellular responses in sheep. Elevated productions of HSPs are reported in sheep exposed to higher environmental temperature as an adaptive mechanism to prevent protein and cell damage (Romero et al. 2013). All the above changes on the biological systems of the animals clearly establish the severity of multiple stresses in hot semiarid regions, and sheep are trying to cope with these stresses through behavioural, physiological, metabolic, endocrine and cellular adaptive mechanisms (Sejian et al. 2013a). Table 1.1 describes the various biological markers for heat stress in sheep.

Table 1.1 Different thermotolerant markers in sheep

Thermotolerant markers	Source	Characteristics	Species	References
Tyrosinase-related protein 1 (TYRP1) gene	Hair	Coat colour	Soay Sheep	Gratten et al. (2007)
Agouti signalling protein (ASIP)	Hair	Coat colour	Xalda sheep	Royo et al. (2008)
Melanocortin 1 receptor gene	Hair	Coat colour	Massese sheep	Fontanesi et al. (2011)
BMP2 and FGF genes	Skin	Skin pigmentation	Sheep and goat	Kim et al. (2016)
TBC1D12	Blood	Regulation of Rab GTPase and involved in protein trafficking and secretion during cellular stress along with HSP90	Sheep	Kim et al. (2016)
FGF2	Skin	Thermotolerance (melanogenesis)	Barki sheep	Kim et al. (2016)
GNAI3	Skin	Thermotolerance (melanogenesis)	Barki sheep	Kim et al. (2016)
PLCB1	Skin	Thermotolerance (melanogenesis)	Barki sheep	Kim et al. (2016)
HSP90	Skeletal muscle	Regulation of body temperature and increase cell survivability under heat stress condition	Merino × Poll Dorset crossbred ewes	Chauhan et al. (2014)
HSP70	Blood mononuclear cells	Protect cells against thermal injury	Pelibuey and Suffolk sheeps	Romero et al. (2013)

(continued)

Table 1.1 (continued)

Thermotolerant markers	Source	Characteristics	Species	References
	Skeletal muscle	Protect cells against thermal injury	Merino × Poll Dorset crossbred ewes	Chauhan et al. (2014)
HSP72	Skeletal muscle	Cytoprotective mechanisms delaying thermal injury	Merino × Poll Dorset crossbred ewes	Chauhan et al. (2014)
HSF1	Skeletal muscle	Activate transcription of genes coding for chaperone proteins such as HSP70	Merino × Poll Dorset crossbred ewes	Chauhan et al. (2014)
GPx-1	Skeletal muscle	Cellular protection against oxidative damage	Merino × Poll Dorset crossbred ewes	Chauhan et al. (2014)
SOD-2	Skeletal muscle	Dismutation of superoxide radicals generated in the electron transport chain in the mitochondria and prevents the oxidative damage to the mitochondrial membranes	Merino × Poll Dorset crossbred ewes	Chauhan et al. (2014)
Haemoglobin (Hb)	Blood	Shows severity of dehydration	Malpura ewes	Sejian et al. (2010a, 2013a)
Packed cell volume (PCV)	Blood	Shows severity of dehydration	Malpura ewes	Sejian et al. (2010a, 2013a)
Cortisol	Blood	Support hepatic gluconeogenesis	Malpura ewes	Sejian et al. (2010a, 2013a)
T_3 and T_4	Blood	Reduce metabolism	Malpura ewes	Sejian et al. (2010a) and Indu et al. (2014)
Respiration rate	Lungs	Support respiratory evaporative cooling	Malpura ewes	Sejian et al. (2010a, 2013a) and Indu et al. (2014)
Rectal temperature	Animal body	Indicates temperature of the whole animal body	Malpura ewes	Sejian et al. (2010a, 2013a) and Indu et al. (2014)
Sweating rate	Skin	Support cutaneous evaporative cooling	Malpura ewes	Sejian et al. (2013a)

1.2.5 Genetic Diversity and Breed Differences for Sheep Adaptation

The adaptive capability of sheep is determined by their genetic potential. The research findings from one type of sheep may not be necessarily applicable to the other kind of sheep. Another limitation is that most of the studies were for short term and conducted in laboratories located in the temperate zone on British/Merino breeds. Physiological responses in homeotherms are important indicators for reflection of homeostasis. In normal course, there are fluctuations in physiological responses and sweating rates, which give a normal range. These ranges vary with the changes in season in an effort to maintain normal body temperature irrespective of fluctuation in environmental temperature. Hence, these are considered as important indices for comparative adaptability of different genotypes. Genotype differences were observed in physiological response at high temperature. Exotic sheep breeds from temperate and subtemperate countries are less heat tolerant as compared to indigenous native breeds (Singh 1980). More and Sahni (1975) assessed exotic fine wool type Rambouillet sheep with indigenous carpet wool type Chokla sheep for their adaptability in hot environments. They indicated that Rambouillet sheep was less adapted as compared to Chokla breed to a hot environment. Diwivedi (1976) also established that exotic animals showed a higher physiological parameters. Native breeds exhibit superior adaptive capability than exotic breeds with respect to physiological responses. Mittal and Ghosh (1979) also reported similar findings in Marwari and Magra sheep for their adaptability in the arid zone of Rajasthan during hot months. Indian sheep in arid and semiarid areas under thermal stress utilizes cutaneous evaporative cooling mechanisms for dissipation of body heat more than respiratory evaporative cooling. Karim et al. (1985) established difference in stress responses between native and crossbred sheep watered on alternate days during summer. Dang et al. (1998) also established difference in physiological responses between native and crossbred sheep in the tropical environment. They observed better tolerance capacity in native breeds for heat stress in terms of physiological adaptability. Crossbreds produced with Rambouillet or Merino germplasm (Avikalin, Avivastra and Bharat Merino) are better adapted to hot environment than pure temperate breeds of sheep, but less adapted than their native counterpart (Malpura, Chokla, Sonadi and others). Heat also influences the productivity oriented Feb B gene in Garole x Malpura sheep (Sejian et al. 2015).

1.2.6 Sheep Production and Water Stress

Optimum livestock production needs sufficient quantity of water. During extreme weather conditions, water is at stake and livestock suffers hugely due to non-availability of water. Climate change has detrimental impact on both the quantity and quality of water resources (Naqvi et al. 2015). Hence, livestock production has to undergo a lot of changes in order to cope up to the existing drought condition. Breed differences do exist in coping to water scarcity. The animals respond to drought condition by reducing their feed intake which may reflect in reducing their body weight as a result of loss of both body water content and body mass. Water deprivation may result in reduced milk production, reproductive inefficiency and reduced disease resistance (Jaber et al. 2013). Further, livestock and sheep in particular are reared mostly in the extensive system in tropical environment where water is very essential for their survival. Therefore, the animals in tropical environment must possess superior adaptive capability to cope with the drought condition (Kalyan De et al. 2015). Hence it is very important to disseminate well-adapted sheep breed which can thrive well in the increasingly challenging drought prone areas (Naqvi et al. 2015).

1.3 Role of Sheep to Climate Change and Its Mitigation

The contribution of sheep to climate change is dealt in detail in Section II of this volume. This section comprises of four chapters addressing sheep enteric CH_4 emission, different methodologies to estimate enteric CH_4 emission and strategies to mitigate enteric CH_4 emission in sheep.

1.3.1 Enteric Methane Emission in Sheep

Enteric methane (CH_4) arising through fermentation of feed is an important contributor to global climate change (Bell et al. 2016). Development of appropriate CH_4 reduction strategies for grazing sheep requires precise data on the emission rate of these animals. Although the relationship between feed intake and enteric CH_4 emission has been established in sheep, still a lot of variations have been established (Hart et al. 2009; Yan et al. 2010). This could be attributed to the extent of genetic variation in feed intake and CH_4 emissions, different environments, residence time in rumen and passage rate. Hence, these factors need to be reassessed to understand the basis of diet-related CH4 emission (Yan et al. 2010; Hammond et al. 2013). Currently, apart from the significance of measuring CH_4 from nutritional loss point of view, its impact from global climate change perspectives also gains equal importance. Measurements of both diet intake and CH_4 emission are needed to predict the exact CH4 yield relating to nutrient intake (Hammond et al. 2013). This chapter therefore provides importance in covering the various methodologies to quantify enteric methane emission. Apart from describing the CH4 estimation methodologies, the volume also provides insight into different equation-based prediction tools for enteric CH_4 emission in sheep (Zhao et al. 2016; Bell et al. 2011).

1.3.2 Heat Stress Influence on Rumen Functions and Diet Digestibility in Sheep

Studies pertaining to the influence of heat stress on rumen metabolites and diet digestibility are scanty, and hence these subsection compilations were made based on studies on other ruminant species. It has been observed that alteration in basal metabolism that is brought about by variations in somatotropin and thyroid hormone concentration during heat stress may alter the rumen functions (Beede and Collier 1986). There are reports suggesting influence of nutrition alone on the rumen ammonia concentration. For example, Chanjula et al. (2014) reported that energy-deficient diet significantly decreased rumen liquor NH_3-N concentration. The heat stress-induced reduced roughage intake, gut motility and rumination lead to decreased volatile fatty acid (VFA) production and altered acetate: propionate ratio (Kadzere et al. 2002). Further, there are also reports suggesting heat stress-reduced VFA production in dairy cattle (Tajima et al. 2007; Nonaka et al. 2008). Similarly, Salles et al. (2010) reported that the higher ruminal temperature significantly decreased the TVFA (total volatile fatty acid) concentration in cattle. Contradictory to these findings, there are also reports indicating that ruminal temperature did not affect the proportion of VFA in cattle (Salles et al. 2010; Yadav et al. 2013). This TVFA concentration difference between the groups could be attributed to the type of microbial population residing in rumen, and heat stress brings about these reductions by reducing the activity of particular microbes (Uyeno et al. 2010). In addition, there are also reports that heat stress brings about reduction in TVFA production by increasing the pH of rumen liquor (Hall 2009; Yadav et al. 2013).

Few authors have reported that changes in rumen fermentation pattern also may be brought about by changes in DMI (Smith et al. 2013; Yadav et al. 2013). Moreover, Nonaka et al. (2008) reported that the ratio of acetate to propionate decreased during heat stress. Rumen liquor pH has strong correlation with rumen microbial activity and rumen TVFAs production (Wang et al. 2008). Further, heat stress was also reported to lower rumen liquor pH in cattle (Kadzere et al. 2002; Yadav et al. 2013). Saro et al. (2014) also observed the significant influence of quality of nutrition on CMCase activity in sheep. They reported that the animal with low-quality feed had significantly lower CMCase activity in sheep as compared to high-quality feed in sheep. The reduced CMCase activities could be due to lower protozoa concentration as a result of nutritional stress. There are also additional reports suggesting lower CMCase activities in defaunated sheep (Santra and Karim 2002; Wina et al. 2006).

1.3.3 Methane Quantification Methods in Sheep

The methodologies that are used to quantify CH_4 emission in sheep are discussed in Chap. 13. There are several methods available to quantify CH_4 emission both indoor and outdoor (Lassey 2007; Pinares-Patiño et al. 2011; Storm et al. 2012). The most commonly used methods are respiratory chambers, SF_6 technique and in vitro gas production and CO_2 technique. Further, there are also a lot of advanced mechanistic models such as IPCC and other models to predict the CH_4 emission from sheep. Although there are several methodologies in use and few are being developed, still a lot of refinements are needed before they are actually applicable in the field condition (Storm et al. 2012). A thorough understanding of the potential applications of these methods is very important to plan, understand and interpret the experimental results (Sejian et al. 2011b; Broucek 2014).

1.3.4 Enteric Methane Reduction in Sheep

Efforts are needed to reduce enteric CH_4 emission in sheep as its concentration was predicted to increase and has a larger global warming potential (GWP) than CO_2. Further, it represents a loss of energy and if it is reduced it will improve livestock productivity. The inverse relationship established between level of feed intake and CH_4 production provides the opportunity to develop CH_4 mitigation strategies relating to feed consumed per unit of feed consumed (Hammond et al. 2013). There are enough reports targeting reduction of enteric CH_4 emission in sheep. There are several potential options to reduce enteric CH_4 including (1) improved animal management, (2) improved pasture management, (3) feed supplements, (4) animal breeding and (5) rumen manipulation. The three broader mechanisms by which enteric CH_4 reduction are targeted are as follows: (1) targeting the end product of digestion to propionate; (2) providing alternate hydrogen sinks and (3) supplementing anti-methanogenic agents to suppress methanogenesis.

1.4 Alleviation of Climate Change Impact on Sheep Production

Section III of this book highlights the different ameliorative strategies to prevent the economic losses incurred due to climate change in sheep farms. This information was covered in seven different chapters in this section. Efforts are made in this section to highlight several indices for measuring the severity of heat stress. Special emphasis was given to identify suitable biological markers for climate change impact on sheep production. Importance has also been given to identify strategies to improve sheep genetic resources in improving the thermotolerance capacity in different breeds of sheep. Finally, the various adaptive measures to be taken by the policymakers to sustain sheep production in changing climate are also covered in this particular section.

1.4.1 Measuring Severity of Heat Stress in Sheep

The animals perform efficiently in their thermoneutral zone. The zone above or below the critical temperature constrains the animal's productivity as they undergo stress. Exposure of sheep to severe heat stress demands the metabolic system of body to dissipate the excess heat by increasing respiratory rate, sweat rate, rectal temperature and pulse rate. This dissipation of body heat could be altered if heat stress is coupled with humidity and solar radiation. Wind is another important physical parameter of the environment which could play a role in curtailing the adverse impact of heat stress. Contrarily, when solar radiation couples with high temperature, it aggravates the condition particularly in the tropical environment. So, the environment temperature is a crucial factor for the well-being of an animal. Hence successful attempts have been made by researchers to measure the environmental temperature.

Various thermal indices like temperature-humidity index (THI), black globe-humidity index (BGHI), equivalent temperature index (ETI), environmental stress index (ESI), heat load index (HLI) and respiratory rate predictor (PRR) have been assessed for livestock considering the local weather condition including all cardinal weather parameters based on physiological adaptability (Hahn et al. 2003). The thermal indices are useful in evaluating the impact of weather parameters in a specific agro-ecological area. The THI is by far the best assessment tool to evaluate the adverse effect of heat stress on the productive performance of animals in tropical regions. The THI is generally very high and stressful if humidity couples with high temperature (West et al. 1998). The THI is also closely related with wind velocity, solar radiation and the production parameters (Zimbelman et al. 2007). The ETI is a simpler tool for assessing the impact of heat stress. It takes into account temperature, humidity and wind velocity to predict the detrimental effects of heat stress. Comparatively, HLI requires yet another factor, i.e. solar radiation to assess the heat stress severity. It was designed by Gaughan et al. (2008) and generally used to quantify the heat stress responses of Australian feedlot beef cattle.

1.4.2 Biological Markers for Climate Change Impact in Sheep

When an animal is subjected to heat stress, the body expresses a number of different haematological, physiological and behavioural traits and indicators to negate heat stress including respiratory rate, heart rate, ruminal movement frequency, rectal and skin temperatures and sweating rate (Marai et al. 2007). Various genotypic and phenotypic markers are expressed by the animal as a response to cope up to thermal stress condition. Few of the phenotypic indicators are haemoglobin (Hb) percentage, packed cell volume (PCV) percentage, respiration rate (RR), rectal temperature (RT), plasma cortisol level and levels of triiodothyronine (T_3) and thyroxin (T_4). Apart from alterations in these parameters, expression of few other biological markers like heat shock protein 70 (HSP70), tyrosinase-related protein 1 (TYRP1) gene, BMP2, fibroblast growth factor (FGF) genes, FGF2, GNAI3, HSP90, HSP72, heat shock factor 1 (HSF1), glutathione peroxidase (GPx-1) and superoxide dismutase (SOD-2) is recorded. The upregulation of these homeorhetic modifier genes helps the animal to adapt to heat stress by several mechanisms. Expression of HSP70 is associated with cellular and protein repair mechanisms (Collier et al. 2006); GPx-1 and SOD-2 are involved in protecting the cell against the oxidative damages by scavenging the free radicals (Chauhan et al. 2014); HSP72 delays thermal injury (Romero et al. 2013); FGF2, GNAI3 and TYRP1 induce thermotolerance by modifying coat colour and skin pigmentation (Gratten et al. 2007; Kim et al. 2016). Bioinformatics analyses suggest that following heat stress, animals increased the stress-regulating genes while decreasing expression of energy metabolism genes in order to maintain the body homeostasis (Banerjee et al. 2014).

1.4.3 Ideal Housing Pattern for Sheep

The principle of any animal housing is to alter the microclimate and provide an ideal environment for exhibiting the normal behaviour of an animal. The housing must reduce the quantum of stress during adverse environmental condition and provide a suitable environment for the animals to survive and produce optimally. Among the various climatic factors, high temperature and relative humidity seem to be the major intriguing factors affecting sheep production. Therefore, the housing design must take into account all the cardinal weather parameters in order to develop a most appropriate shelter for sheep. Further, the cost associated with the animal housing should be minimal involving indigenously available materials for the farmers to easily adopt such housing pattern. As animal shelter influences the productivity of the animals to a larger extent, appropriate shelter design is the prerequisite for ensuring optimum production in sheep farms. There are different shelter designs available, and the choices depend on the type of breed, local weather condition, availability of housing materials, etc. Efforts are also needed to ensure ideal shed requirements comprising of appropriate ventilation, shade, drainage and lighting in the sheds to ensure optimum production in sheep farms.

Sheep are morphologically versatile species found in most of the geographical locations, particularly concentrated in arid and semiarid regions (Sejian 2013). In these regions, rearing of sheep is not followed under intensive farming system. Small farmers and landless farmers hold the majority of the sheep population in the developing countries like India (Delgado 2003). The type of housing to ensure the well-being of sheep is more important in extensive and semi-intensive production systems as compared to intensive system as the former productive systems are more vulnerable to global warming (Nardone et al. 2010). Housing system affects the feed intake, growth rate and behaviour of lambs during postweaning (Villeneuve et al. 2009).

Different housing designs are needed for different production systems depending on the specific needs of such rearing systems. The construction design and materials used for the shelter should be chosen in such a way that these structures last long enough to accommodate several flocks to ensure optimum economic return from these farms in a long run. While considering floor material, the bedding should be dry and well-drained. Lighting and ventilation are the two factors that influence the production parameters to a great extent. Well-ventilated shelter systems are preferred as moisture, and bad odour will be naturally removed effortlessly. Open-sided walls are more preferred than all side closed walls to ensure appropriate ventilation for the animals. Provision also should be made for isolation pens while designing the animal house to house the sick and diseased animals in quarantine away from the main flocks.

The different types of shed are mainly categorized into open, semiopen and enclosed type. The sheep shelter should be constructed in accordance with the agro-ecological regions. In highlands, house should be constructed with raised floors to protect from heavy rain. In humid areas of mid-altitude, slit floors are desirable whereas in drier areas packed earth or concrete floor is preferred. In lowlands nomadic flocks are raised in open yards in night-time enclosure, and during day time, natural shades of tree provide protection against direct solar radiation. The real challenge for the sheep researchers in the coming years is to identify proper measures to characterize the existing region-specific climate in an effort to provide an appropriate microclimate for the sheep to survive and produce optimally (Naas and Moura 2006).

1.4.4 Management Strategies to Improve Sheep Production

Sheep are found ubiquitously around the world. Most of the flock being maintained by small scale farmers, their contribution to the subsistence, economy and social livelihoods is immense in developing countries. The demands for livestock products are huge in the coming decades, and hence mitigation of the adverse environmental impact on livestock production is the need of the hour. This can be achieved by applying appropriate management and feeding strategies. Substantially increasing the productivity of these animals by adapting various management strategies including housing and animal management and climate monitoring may enhance production capacity of the flock, and hence better output can be expected from the animals in terms of meat, wool, milk and number of offspring. Simultaneously efforts are also needed to identify the most appropriate strategies for a particular location and the other factors that influence the genetic merits of the animals that question their survival in a particular environment (Kosgey and Okeyo 2007).

The management strategies can be categorized as housing management, animal management and monitoring of climate. Under housing management, the type of shelter, availability of shade and water and ventilation and light availability inside the shed are considered as the major factors affecting the productivity of the animal. At times of heat stress during summer, water and shade availability around the shed are crucial factors. Better ventilation within the shed removes the moisture, bad odour and keeps the floor dry (Hassanin et al. 1996). Protecting the animals from climatic stresses and thus reducing the production loss is related to housing management.

Animal management itself is another important factor to be considered. Way of handling the animal (transport, shearing, sorting) imparts a major effect on the productivity of the animal (Beatty et al. 2008). Although the tropical and sub-tropical region indigenous sheep shows signs of estrus and breed year-round, the higher ambient temperature accompanied by high relative humidity impedes the sexual activity of animals. Impaired reproduction is an outcome of reduction in body weight, average daily gain (ADG), growth rate and body total solids in sheep post-exposure to elevated temperature (Bernabucci et al. 2010). Hence the feeding, health and also disease status has to be monitored regularly. Apart from these factors, selection of breed is given primary importance as sheep farming nowadays is production oriented. So selecting the genetically superior breeds for a given trait like meat, wool, milk and adaptation capability is advisable to get desirable income (Alhidary et al. 2012).

The heat exchange between the animal and the surrounding is determined by a physical factor called thermal environment surrounding the animal. This heat exchange is significant as the animal has to maintain its core body temperature (Hahn 1985). When there is fluctuation in the ambient temperature, the animal homeorhetic system responds to the changing climate condition by altering its metabolic systems. Hence it is advisable to develop few thermal indices and predict the climatic conditions which may help to take up mitigation strategies to abate the stress related problems (Gaughan et al. 2008).

1.4.5 Nutritional Interventions to Improve Sheep Production

The main objective of sheep rearing is to satisfy the raising demands for sheep meat, wool, milk and other byproducts. The main productive parameter in sheep is reproduction and is biologically a costly process involving huge demand for energy. So to ensure regular lambing, proper and balanced nutrition has to be supplemented to the sheep. Further, nutrition (energy balance) is closely linked to fertility (Beam and Butler 1999). The drastic increase in the animal population in the last two decades has led to a consequence of feed scarcity coupled with climate changes.

Sheep often depend on low-quality crop residues for their nutrition in tropical regions, and this may not be sufficient to meet the production expenses of the flock, eventually leading to low production output (Naqvi et al. 2013). There are few nutritional interventions that need due consideration to sustain sheep production in the changing climatic condition. The specific nutrient requirements generally differ during thermo-neutral and heat stress condition in sheep. Use of trees, shrubs and cactus as fodder supplements is advantageous in dry areas (Salem and Smith 2008).

Seasonal specific feeding is one of the factors to be considered in nutrition management. Enticing the sheep to take more feed can be done by increasing the feeding frequencies and placing the feed in shade during winter. To combat the summer influence on fodder production efficiently, ensiling and feed blocks (FB) methods can be used. Also, locally available nonconventional feeds can be used according to their availability (Nefzaoui and Ben Salem 2002).

During the summer, the limited water availability directly affects both the productive and reproductive activities of the animals. Feeding low fibre with high protein is advantageous when the diet is balanced (Bunting et al. 1987). Development of new nutritional technologies (e.g. protected-fat feeding) may offer particular advantages in warmer environments (Duske et al. 2009). Feed supplements like vitamins E and A, zinc, selenium and selenium-enriched yeast help in reducing the impact of heat stress (Mahmoud et al. 2013; Sejian et al. 2014b). Subsequently, providing the sheep with diets with higher per unit energy content, effective and more digestible fibre, lower protein degradability and more bypass nutrients is advisable to increase the productive performance. This concept is termed as ‘cold diet’.

1.4.6 Sheep Body Condition Scoring

Body condition scoring (BCS) is an easy to use tool to assess the condition of animal based on muscle and fat distribution (Sejian et al. 2010b). The animals are given scores based on the level of distribution pattern of fat and muscles over and around the vertebrae in the loin region. The protrusions of both spinous and transverse process in the vertebral column are felt and used to assess the individual animal BCS. The most widely used BCS system is based on a scale of 1 to 5 (USA) and it represents the score in the range of emaciation to obesity. The BCS is a valuable tool for the producers to take appropriate decision. The sheep producers must know the body condition of their flock during different phases of production such as breeding, late pregnancy and lactation in order to provide proper nutrition and maintain the animals' body to be not too thin or not too fat but just right (Maurya et al. 2010). The BCS varies between breed and within the breed at a particular stage of life cycle of an animal. Hence, weight can be considered as the best indicator for a given stage of production. The ideal score falls between 3.0 and 3.5 during different production stages in sheep (Russel 1991).

While some sheep are thin and emaciated due to undernutrition, others are obese due to overfeeding. So, a proper nutrition has to be supplemented to maintain the ideal body condition (Maurya et al. 2010). The BCS gives a relative idea on plane of nutrition to be maintained at each phase of production. Since availability of fodder is also not constant throughout the year, BCS helps in planning the distribution of nutrients to the flock based on their requirement in each productive period (Sejian et al. 2010b; Maurya et al. 2010).

In general, obese and emaciated ewes have low prolificacy rate compared to the ideal body-conditioned ewes. The BCS at mating influenced the ovulation rate and hence the lambing percentage. The weaning weight of lambs is also influenced by the BCS of the ewe (Armstrong et al. 2002). In rams the reaction time, time taken for first and second ejaculation, semen volume and motility of spermatozoa are few sexual behaviours that are decided by BCS. Rams with lower BCS have low plasma testosterone concentration due to low energy feeding and also reduced scrotal and testicular morphological characteristics that can be used to predict the reproductive efficiency of a ram (Maurya et al. 2012).

Sheep are mainly reared for its meat, wool and milk. To avail maximum production and profit, one should ensure proper nutrition to the flock, because the lower availability of energy curbs, the lower growth rate in lambs (Butterfield and Thompson 1983). In marketing of live sheep for mutton purpose, the primary concern of the consumer is the BCS that gives a fair idea on muscling and fat percentage. In mutton industry, carcasses of sheep with 3.0–3.5 BCS are most preferred as they are valuable from economic point of view (Van Heelsum et al. 2003).

1.4.7 Adaptation Strategies to Sustain Sheep Production

Despite many challenges faced by the sheep producers, heat stress is the crucial factor which negatively influences the production. To abate the deleterious effects of thermal stress and to ameliorate the normal physiology of animals' body, many adaptation strategies like genetic selection, nutritional interventions, improving water availability, maintenance of animal health and women empowerment can be followed (West et al. 2003). Genetic development of thermotolerant breeds to heat stress is a trendy and much needed step for sustained sheep production. Animal breeding systems that use marker-assisted selection of genetically superior and heterogeneous breeds which possess genes related to both productive and adaptive traits are one of the most widely practiced adaptation strategies (Hough et al. 2013). For sustained sheep production in the event of climate change, several nutritional modifications have to be considered. The use of unconventional feed resources including trees, shrubs and cactus as fodder supplements is advantageous especially during drought season in dry areas (Salem and Smith 2008).

In the changing environment, conserving and improving the water availability through integrated water resource management may help to suffice the flocks with large population (Mader and Davis 2004). During stress periods, the incidences of disease occurrence are frequent which ultimately culminates in reducing the production in an animal. Adapting rational approaches to disease diagnosis and management part advances the sheep health and productivity (West et al. 2003). Since in rural areas the sheep farming is mainly taken care of by women who consider the livestock as an asset, their empowerment is a fundamental step to improve the livestock sector in the current scenario. Hence developing various policies that favour and encourage women to take up sheep farming as a livelihood means is an essential approach to improve the sheep production (Kristjanson et al. 2014). Climate change communication and early warning system are the two measures that can predict the occurrence of natural calamities and hence aid in the possibility of minimizing the loss of lives and the adverse effects through proper mitigation strategies (Luber and McGeehin 2008; Basher 2006).

1.5 Research and Developmental Priorities

The last section (Section IV) of this volume would focus on summarizing the views of authors of different chapters. Further, this section also would project to the readers the planning that has to be in place for meeting challenges ahead in coping the sheep production systems to adverse environmental condition. The focal point of discussion in this section would be highlighting the importance of reducing the adverse effects of climatic change impact on sheep husbandry. Emphasis would be given to put forth the various future strategies that may pave way to reduce the adverse impacts of climate change on sheep production. This section also would signify the importance of minimizing the adverse impact as well as to curtain sheep related GHG production in an effort to sustain sheep production in the changing climate scenario. Finally, the section would emphasize on developing suitable agro-ecological zone-specific breeds with higher thermotolerance to be the most crucial future strategies to cope up to the changing climatic condition.

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Climate Change Impact on Sheep Production: Growth, Milk, Wool, and Meat

2

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Abstract

Sheep production is looked upon as the primary meat industry in the future due to production efficiency of mutton and adaptability of the sheep to changing climate. More than 50% small ruminants of the world are located in arid region, indicating their adaptability and future suitability to increasing temperatures. Sheep graze in the ranches, wastelands particularly in Asian and African countries, and also in pasturelands of Australia; this not only reduces emission of the greenhouse gases (GHG) but also increases fertility of land. Increased temperatures will be the first impact of climate change. Cyclones, droughts, heavy rainfall, unpredictable climate, and diseases are other factors which will affect the sheep husbandry; however threats posed by these factors can also be ameliorated with scientific planning and execution. Disease resilience in genomics of sheep can be exploited apart from nutritional interventions for mitigating these challenges. 2050 will see a high demand of food from exisiting resources to feed ~10 billion people, and sheep will play a major role with advanced genomic selection. In sheep, growth traits and meat quality are important criteria. Selection of sheep breeds and candidates that are high producing and also tolerant to the adverse effects can be a mitigating option. Reaction norms in genotype by environment interaction are important, and selection of genotypes for suitability in the future needs considerable research inputs. Revised selection criteria may be a need of the future, where production in the compromised environment seems to be the need of time. The decline in profitability of wool and environmental impacts have forced wool to take backstage; however, wool fiber production consumes significantly less energy than popular man-made fibers. Importance of the sheep husbandry as sustainable livelihood option for landless, marginal, and small farmers needs to be realized along with its global emergence as the desired food animal in the climate change era.

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Contents

2.1 Introduction

Across the world, distribution of resources has been unequal among animals as well as human beings. The problem of widening drift between the have's and have not's is well recognized and least prioritized. It has been observed that the nations with problems of food security that include majority of Asian and African countries have dependency on livestock, and among livestock, small ruminants form the indispensable backbone of rural livelihood security. Agriculture, interwoven with livestock sector, has been the primary force responsible for biological, social, and cultural upliftment of human beings throughout the course of evolution, development, and renaissance of man as a technologically advanced creature. Livestock sector with all its rich biodiversity has been the mainstay for quality protein resource to human beings since time immemorial. Sheep is one of the oldest and first ruminants, which were domesticated by man more than 10,000 years ago in the Neolithic period in Central Asia. Domestication of sheep has seen changes from wild hairy sheep to woolen and hairy domestic sheep of Mesopotamia, Mohenjo-daro, and Harappa civilizations. Asian sheep, which is said to have been originated from mouflon (*Ovis orientalis*), lead to divergence of sheep genetic resources due to its recruitment from the wild several times for domestication (Hiendleder et al. 2002; Bruford and Townsend 2006; Rezaei et al. 2010). Breed development took place in the Western

Europe and Southwest Asia after import of sheep from Asia to Europe. Selection of woolen sheep took place nearly 6000 BC, whereas use of wool for garments has started during 4000 BC. The exact history of sheep domestication remains unknown; however, its utility as major food and fiber animal leads its way to diversification worldwide resulting into more than 1400 breeds (Scherf 2000) currently recognized in today's agricultural systems. Sheep have spread and established themselves to wide geographical regions due to their adaptability to relatively nutrient-poor diets, tolerance to extreme climate from very cold to very hot and humid, and also due to their small size for better management (Kijas et al. 2009). Local geographical conditions, climate, and selection by the farmers and graziers for desired traits finally evolved the sheep in its present-day form.

The utility of sheep is multidimensional. Sheep produces meat, fiber, milk, and hides. Manure also fetches economic importance due to its use in organic farming. The type of production system in any area is multifactorial; the main factor is the availability and cost of pasture, the climate, and the interaction with other livestock and cropping systems. Extensive round-the-year grazing with large flocks (>2000) and no or less handling of animals are the sheep management system in major wool-producing countries like Australia, New Zealand, South Africa, and Uruguay. In Europe, due to intensive system, confinement during winter and access to pasture for the rest of the year are the preferred system of sheep management. Shepherding small flocks of sheep and goats along roadsides and in available common grazing areas or common property resources (CPRs) is a typical management system in the Middle East and Asia (Kahn 2010). In Asia, the system of land use is often complex. Here usually sheep and goats browse or graze together and feed on relatively resource-poor land where productive cropping or plantation enterprise does not exist. In such circumstances the opportunities for major changes in the management system are limited. However, the business of sheep rearing since ages that runs in the family (e.g., *Raika* and *Gurjars* of Rajasthan India, *Bharwad* and *Rebari* of Gujarat, *Dhangar* of Maharashtra) has been there in India and other Asian countries, especially in the arid and semiarid regions. This system has been successful with given resources and migratory habits. The degree of mobility used to be dependent on several variables which include the flock size, the location of the village, as well as the amount of rainfall in that particular year. However, recent changes in human dwellings, little interest of younger generation to carry forward this business, and shrinking CPRs have brought limitations to this business.

Human population has been on steep rise with 3.08 billion during 1961 and 7.32 billion during 2015 (FAOSTAT 2014); this steep increase has reduced the land availability and pressure on available food resources. Sheep population was nearly 0.99 billion during 1961 and it could reach 1.21 billion during 2014 (FAOSTAT 2014). This increase has neither kept its pace with human population growth, nor was the trend linear. As per the 2013 estimates of FAO, 537 million sheep are slaughtered every year to meet the demand of mutton, with an average yield per animal of 16.0 kg as carcass weight. Carcass weight in Africa is 13.8 kg; in Asia it is 16.2 kg; in Australia and New Zealand, it is 20.5 kg; in European Union (EU), it is 15.1 kg; and in least developed countries, it is 12.3 kg. As far as sheep slaughtered is concerned, Asia contributes 48.8%, followed by Africa 22.7%, whereas EU combined with Australia and New Zealand contributes for 20.7%. As far as milk production from sheep is concerned, a total of 220 million animals are said to have been recorded for milk yield during 2013, resulting into 46.1 kg milk per lactation, with the highest average in EU 105.8 kg and lowest in Africa 29.9 kg. World wool production is about 1.3 million tons per year, of which 60% goes into apparel. Australia is the leading producer of wool, followed by New Zealand and China.

2.1.1 Climate Change and Sheep Husbandry

A long-term change in the earth's climate, principally due to the change in GHG composition, is referred to as climate change. The climate has been changing from warmer to cooler states over a period of 1000 years. A rise of 1.8–4 °C is expected in the coming 100 years depending on the GHG emission rate (IPCC 2007). Carbon dioxide, methane, nitrous oxide, and fluorinated gases are the main GHGs originated due to electricity generation, heat production, industry, agriculture, livestock, transportation, etc. Livestock contributes for nearly 18% of total anthropogenic GHG emissions (Thornton 2010). Sheep is considered as the animal of the future due to its realized importance in vulnerable climate such as droughts, disease outbreaks, increased natural calamities, glacier melting, ozone layer depletion, etc. Small ruminants are the substitute in instances like failure of cash crops and natural calamities. They not only act as small teller machines by instant sale of animal for small liquid cash requirement but also serve as quality food resource for humans. Sheep is also vulnerable to the changing climate and its impact on productivity, reproduction, and health; however they are relatively more resilient to impact of climate change as compared to large ruminants.

The Intergovernmental Panel on Climate Change's (2013) fifth assessment report states that the human influence on the climate system is now evident, and the effects can be seen from the increase in GHG concentrations in the atmosphere, increased global temperatures, and deep understanding of the climatic science. Climate change represents one of the greatest threats faced by our planet, its population, and economies (Skuce et al. 2013). It is observed that the rate of climatic change in the current era is highest than during the last 1000 years (Marino et al. 2016). According to the forecast of the IPCC, the next 90 years will see an increase in global temperatures by 1.8 and 4.0 °C (Yatoo et al. 2012). It will have a great effect on present-day livestock production and health.

2.1.2 Significance of Sheep from Climate Change Perspective

The world has wide distribution of sheep. Nearly 56% of the small ruminants are in arid regions of the globe, whereas 27% and 21% are in temperate and humid regions, respectively (Marino et al. 2016). Small ruminants have an important socioeconomic role to play in the management of landscapes and also to the conservation of biodiversity. They also provide bioavailability of high-quality protein food. In agriculture and livestock production, controlling and decreasing emission of harmful gases such as methane, carbon dioxide, nitrous oxide, and ammonia has become important for environmental protection (Klinedinst et al. 1993). Comparing the world average, we can observe that the production of such gases per capita is very less in developing and least developed countries as compared to the developed nations due to the nature and kind of rearing system and feed resources availability of the animals. Sheep, in particular, follows a grazing system of feeding, by searching for the feed resources in the ranches and wastelands, particularly in Asian and African countries. This pattern not only reduces the emission of such gases but also increases the fertility of the soil. Grazing and mixed rain-fed systems raise nearly 70% of all ruminants of the world and face a challenge of loss by climate change that can be significant (Shinde and Sejian 2013). It would be worthwhile to assess the damage and to counteract the factors which may pose such threats.

Climate change affects sheep production through (a) the pasture availability and its sustainability, (b) the forage production with regard to its quantity and quality, (c) unpredictability in the distribution of diseases and pests, and (d) the adverse effects of extreme weather events on health and production (Sejian et al. 2013). Sheep husbandry is usually practiced across the climatic shores worldwide. Sheep breeds can tolerate wide range of climate and convert poor quality forage into quality animal protein. These characters favor their rearing under extensive system among poor rural people in harsh climate (Karim and Shinde 2007). Sheep rearing contributes to livelihood security of poor farmers in drought-affected regions and acts as adaptation and coping instrument to ameliorate the stressors. The sheep reared by farmers is not just for production but also for its multiple (livelihood, social, environmental) contributions (Shinde and Sejian 2013). In regions where more than 60% of the geographical area is under arid and semiarid regions and prone to drought and famine, the sheep husbandry contributes toward risk reduction and adaptation to climate variability (Shinde and Sejian 2013). Development of the sheep throughout the course of evolution was a result of adaptability and selection for desired traits as per the need of the environment and people rearing the sheep. Due to this reason, we find fine apparel-type wool breeds in the temperate region to mutton-type coarse wool/hairy breeds with open fleece in hot humid region, excellent carpet wool breeds in hot and arid region, and prolific sheep in the regions where the coastline affects survivability to maximum extent (Garole breed of Sundarban in India). Changing climate may pose a threat to sheep husbandry; however given its history of adaptability and migratory lifestyle, this animal has a long anticipated future union with man.

2.2 Stress of Changing Climate in the Near Future

All the living cells and living systems must intake energy and spend it judiciously to stay alive and to contribute to the next generation. The synthetic reactions that occur within cells, like the synthetic processes in any factory, require the input of energy.

Organisms transform energy and matter from their surroundings, as the living organism is an open system. Every living system must maintain a dynamic steady state, which requires constant investment of energy, devoid of which it decays toward an equilibrium with its surroundings (Nelson and Cox 2008). Changing climate will require every organism to invest most of the hard-earned ATPs for maintaining this steady state alone. Production will take a back seat as survivability will be at stake. We anticipate several factors coupled with their effects which are harmful mostly to affect the sheep husbandry worldwide. Important stressors which may affect the sheep production and utilization in the climate change era are discussed here.

2.2.1 Increase in the Environmental Temperature

The first impact of climate change is seen in terms of increase in the environmental temperature. Biome, as a unit of life on earth, faces this drastic challenge in the near future. Livestock are a function of evolved biological units over space and time. They have evolved and selectively adapted to the present-day situation with all its variation kept intact in a particular place. In a given population, genetic variations in individuals by chance, along with natural selection, have resulted in the evolution of today's enormous variety of organisms, each adapted to its particular ecological niche (Nelson and Cox 2008). Among all the environmental stressors, the key stressor is ambient temperature (Horowitz 2002). Acclimation, acclimatization, or phenotypic adaptation is often referred to as the adaptation to climatic change or stressors in livestock production (Naskar et al. 2012). The average surface temperature of the globe has increased by about 1 degree Centigrade since the late nineteenth century, mainly due to higher carbon dioxide (CO_2) and other hazardous industrial emissions in the atmosphere. According to independent analyses by NASA and the National Oceanic and Atmospheric Administration (NOAA), the earth's 2015 surface temperatures were highest since 1880. Globally averaged temperatures of 2015 were even higher by 0.13 degree Celsius than the previous set point of year 2014 (NASA 2016).

The first impact of increased temperature is seen on production traits of the sheep followed by reproduction and health. This is a cumulative effect of reduced grazing as an effect of harsh conditions and falls in the live body weight of the animals due to stress and reduced feed intake. This function then leads to a drop in the body weight and reproductive efficiency of the sheep, where sheep may skip a reproductive seasonality or may not conceive or drop a chance to carry fetus; busy in maintaining the homeostasis, parasites may find entry in the system easier. Research on native sheep breeds revealed that they undergo various physiological and blood biochemical adaptive action to combat nutritional stress. But the magnitude of stress was severe when only 60% of their nutritional requirement is available (Sejian et al. 2014). Increased temperatures also have behavioral problems, such as erratic temperament, where it will be difficult to handle the animals during routine management practices leading to chaos. This may happen due to heat stress and incompatibility of the animals to cope with the environmental temperature and failure to maintain the homeostasis due to exceeded biological limits. It was seen that the body temperatures beyond 45–47 °C are fatal in most species. Among all the stressors, heat stress is an important factor in determining specific production environments (Zwald et al. 2003). It is a well-established fact that the temperate breeds perform better when increased production potential is demanded, whereas tropical breeds are better for criteria like heat tolerance. This kind of situation may lead to erosion of the germplasm and genetic resources. Earth as a planet has seen such type of climatic changes over the centuries where erosion of established germplasm was witnessed. However, the changes then occurred were of long time frame as opposed to today's sudden change in the climatic temperatures.

Adaptation to such stressors can be selection of sheep breeds tolerant to the high temperatures such as hairy breeds or open fleece breeds. Apart from the permanent solution like this, which is time-consuming and needs concentrated efforts of the government and public synergistically, local efforts for managing other factors may also have fruitful effect. Looking into the rising temperatures, plantation of the trees for shed and fodder such as *Prosopis cineraria*, *Ailanthus* spp., *Azadirachta indica*, etc., in paddocks can therefore be useful.

2.2.2 Drought and Variation in Rainfall Prediction and Volume

Unpredictability in weather prediction, heavy rainfall, or absolutely no rainfall is a routine picture in today's world. India has seen such situation since the last 2 years, where no or very less rainfall during monsoon and heavy rainfall when not required have posed a lot of pressure on farming communities. As far as agriculture is concerned, drought and unpredictable rainfall act as plague for productivity. For sheep rearing, availability of feeding resources is a primary criterion, without which we cannot expect sheep to meet our needs. The change in future precipitation is expected to follow existing trends of uncertainty, along with the trend of reduced precipitation over subtropical lands and increased precipitation at subpolar latitudes and some equatorial regions (NOAA 2007). Data analysis of extreme events from 1960 till 2010 revealed that there is increase in the frequency of droughts and heat waves with simultaneous occurence. There has been increase in the extremely wet or dry events within the monsoon period since 1980. Such stress results in poor pasture and fodder quality and quantity. Drought can also lead to fires and pose a risk of threatening to the pasturelands. All the stressors are cumulative and lead to the same effect. This situation in turn leads to heat stress, water shortage, and ultimately loss of genetic resources. As far as water scarcity in the coming era is concerned, as per the study conducted in the United States, most countries will face higher risks of water shortages by mid-century due to global warming. Nearly more than 400 countries will have high risks of water scarcity (NRDC 2010).

Control measures to ameliorate the effects of such determinants are required to be searched out and implemented. Pragmatic solutions need to be explored in detail. Plantation of drought-tolerant pastures and fodder resources is one such option where effects of drought can be well tolerated. However, this needs to be supplemented with the water resource sustainability and storage of feed resources in scarcity period.

2.2.3 Cyclones and Flood Threat

Destruction of pasture availability is the main threat posed by such disaster. This may also lead to loss of livelihood of man as well as animals; a recent instance of cyclones and flood threat is in Tamil Nadu (India) and northwest Pakistan, where a number of livestock along with pasture available were lost. Sudden change and resulting cyclones or floods also bring with them pests and diseases due to favorable breeding ground for the vectors. This stress is coupled with the feed scarcity and drowning of the animals. It has been observed that the sheep breeds, which are located in the coastal region like Sundarbans of India, are evolved and adapted to such climatic stress. This is so, because they have experienced this stress for centuries together and coevolved with this stress. Now they have a mechanism to adapt to the challenges faced by cyclones and floods. Garole sheep of India which is reared in the Sundarban delta is a prolific sheep from which the Booroola gene was utilized worldwide for enhancing prolificacy (Ghalsasi and Nimbkar 1993). This breed being raised in the flood-prone area has always faced a threat of extermination or erosion. To combat this stress, nature has incorporated a mutation in its Booroola gene for prolificacy. Mortality caused by floods and cyclones is thus negated by the prolificacy of this breed so as to continue the germplasm evolution. Similarly, Garole has also adapted to the heavy worm load of *Haemonchus contortus*. Studies at ICAR-Central Sheep & Wool Research Institute Avikanagar (India) revealed that Garole as compared to other sheep breeds in arid and semiarid region has more natural resistance toward the *H. contortus* (Swarnkar et al. 2008). Rearing of such breeds can be one option for mitigating the challenges posed due to cyclone and flood threat.

Salt contamination in the drinking water and salt-caused damage to the pasture and fodder available are another dimension, where threat of increased sea level, cyclones, or floods is observed. Areas near the sea that include the coastline will also face the problem of reduced land area for grazing and shelter in the recent future. Mitigating these challenges includes locating the sheep farms at higher altitude; however, this is not the permanent solution. Planting of salt-tolerant pastures is one option that can lessen the impact to some extent. Strategy like colonization of more tolerant species in the worst affected areas and colonization of the less tolerant species on the fringe areas can emerge as a balancing design along with due care for some species (perennial ryegrass).

2.2.4 Susceptibility to New Pathogens

Change in the climatic conditions poses a threat of contracting new diseases by means of spread of diseases to new hosts in new environments. The pathogens, vectors, and hosts and their interaction are affected by climate that affects the spatiotemporal distribution of diseases that also include influences on their intensity. The short-term weather events and also seasonal rainfall trigger the outbreaks of diseases like African horse sickness, anthrax, bluetongue, peste des petits ruminants, and Rift Valley fever (Van den Bossche and Coetzer 2008). Virgin geographical locations such as higher altitudes are usually prone to loss of genetic diversity as increased temperatures due to reach of vectors like mosquitoes along with the dreaded pathogens like bluetongue virus, etc., may present unprecedented threats. In Himalayan ranges (Kumaon hills) in India, in the past, it was difficult to spot mosquitoes; however with change in the climatic conditions and rising temperatures, mosquitoes are a common sighting in many parts of this region now. This will have effect on the incidence of diseases such as malaria, bluetongue, and other mosquito-borne diseases. Change in the temperature profile of any region can harbor the population of new vectors for new diseases, and it is probable to see low-altitude marked diseases in high-altitude areas (Naskar et al. 2012). The projected challenges associated with climate change such as heat stress, poor nutrition, and increased disease risk will not be fundamentally different than what the livestock faces today specially for the tropical world. It only becomes a major concern that these changes may outpace the adaptability, and hence the future portfolio of genetic diversity no longer offers the option to adapt, because we already lost some of the important genetic traits and germplasms (Naskar et al. 2015). The importance of reaction norm to changing environment is therefore important.

Breeding of animals resistant to diseases and parasites is one option that has been in practice; however, it must be noted that the breeding for disease resistance and improved immune response usually comes with its cost on production (Singh and Swarnkar 2010). However, there are examples where superior production profile of breeds having resilience or resistance is observed. Germplasms that are resistant to diseases are also better in production profile as compared to other breeds in the same environment (Baker 1998); it is well known that the trypanotolerant germplasms have better productive potential than susceptible animals under *tsetse* fly challenge (Agyemang et al. 1997). Breeding of sheep for *H. contortus* resistance has seen successes for creating resistant and susceptible lines of Malpura and Avikalin sheep at CSWRI Avikanagar. The animals of S line (susceptible) required strategic as well as tactical anthelmintic intervention, whereas the animals of R line (resistant) were maintained without any anthelmintic intervention (Swarnkar et al. 2008). Along with these options, management of diseases more effectively at local levels and at national and international levels is essential. Screening of the sheep for dreaded diseases through sero-surveillance, vaccination of the sheep for known notified diseases, use of technologies like GIS for mapping, and survey of the disease pattern and control are essentially required in the era of climate change.

2.3 Climate Change Impact on Sheep Production: Present Status and Forecast

2.3.1 Growth

Animal in the production stage demands more energy than in the maintenance stage. Growth of the animal and sheep in concern is highly demand specific. Input of food is a mechanical source of energy that is broken down by the enzymatic activity and converted to the simpler products such as glucose and amino acids. Upon fulfilling the requirement for maintenance of the body, the resources are then utilized for deposition of fat and protein. The sheep utilizes the protein apart from enzymatic requirement, not only for muscle growth but also for wool production and good quality end products. Not shearing a sheep for a long time or sheep in its lactating stage is found to shed its wool to channel the protein requirement for this crucial process.

Sheep is reared worldwide for its varied products; however, out of all the products kept together, meat obtained from the sheep fetches primary value. Sheep meat is a function of live weight of the animal that is translated to the mutton as carcass yield post slaughter. Here we focus on the growth characteristics of the sheep, its importance, and impact of changing climate on sheep growth. In response to the environmental stress, metabolism of the body gets stimulated and products of energy and protein metabolism may get altered, and it may also suppress appetite, reduce growth rate, alter rumen function, and compromise immune function (Loerch and Fluharty 1999). Present-day sheep rearing in most of the Asian, African, and other developing or least developed countries is input-free and, hence, requires longtime grazing in the field. Stresses of any nature can have harmful effects on sheep husbandry; however only if its of inherent nature, it gets coded in genetic material to impart resistance to those particular stresses.

2.3.1.1 Growth Traits and Their Estimates

In sheep, growth traits are usually defined as live weight of the animal measured at several time points and derived units thereafter. Birth weight of the animal is measured within the shortest possible time post lambing. Weaning weight is measured at the stage where weaning of lamb from the dam takes place. Usually, weaning is carried out at the age of 3 months; however at many places, weaning at 2 months is no rarity. Live weight of sheep at 6-month age is considered as the most important criteria for selecting the sheep for higher body weight. Worldwide this trait is used intensively for selecting the heavy animals. Weight at 9 months and then at 12 months are other important time points where sheep is evaluated. Apart from this, average daily gain (ADG) is another criterion for measuring the growth rate of the animals. This trait has been used even in selection indices for harvesting higher gains. ADG can be estimated as pre-weaning ADG, where per day gain in live weight since birth to weaning (90 days) is estimated (ADG1 = (weaning weight – birth weight)/90). Post-weaning ADG can be estimated as per day gain in live weight from weaning to 6-month age (ADG2 = (weight at 6 months – weaning weight)/90). Daily gain can also be estimated throughout the growth trajectory of the animal for any two important time points. Another unit of measurement of growth is the Kleiber ratio (KR). KR takes into consideration the metabolic body weight of the animal, thus minimizing the error variance. KR for period from birth to weaning (KR1 = ADG1/WWT$^{.75}$), Kleiber ratio from weaning to 6 months (KR2 = ADG2/6WT$^{.75}$), and KR from birth to 6 months (KR3 = ADG3/6WT$^{.75}$) can be estimated using daily gains and metabolic weights of the animals.

Growth of the sheep in terms of live weight has been recorded to be influenced by many factors which include mainly environmental determinants apart from genetic effects. A study on Malpura sheep over a period of 25 years (1985–2010) reported that the estimates of growth traits in kg (LSM ± SD) for birth weight (BWT), weaning weight (WWT), 6-month (M) live weight (6WT), 9-month live weight (9WT), and 12-month live weight (12WT) and in g for ADG1, ADG2, and ADG3 ((12WT – 6WT)/180)) were 3.05 ± 0.54, 14.53 ± 3.20, 21.24 ± 4.45, 24.36 ± 5.06, 27.77 ± 5.46, 127.20 ± 33.23, 87.91 ± 50.33, and 36.64 ± 23.40, respectively (Gowane et al. 2015). Significant effect of sex of the animal, season, and period of birth on most of these traits was observed. In another study at the same station for Bharat Merino sheep, a crossbred sheep with 75% exotic inheritance of Rambouillet and Russian Merino, least squares means for growth traits were BWT, 3.06 kg; WWT 14.25 kg; 6WT, 21.26 kg; 9WT, 24.50 kg; and 12WT, 27.99 kg. In this study, sex, year, and season of birth were found to affect the growth significantly (Gowane et al. 2010a). In Avikalin sheep which is a synthetic sheep (50% Malpura x 50% Rambouillet), the estimates for growth traits were BWT, 3.02 ± 0.008 kg; WWT, 13.89 ± 0.05 kg; 6WT, 20.15 ± 0.07 kg; 12WT, 25.51 ± 0.09 kg; ADG1, 120.65 ± 0.54 g; ADG2, 73.58 ± 0.62 g; and ADG3, 38.46 ± 0.60 g. All the traits were mostly affected significantly by sex, year, and season of birth (Prince et al. 2010). Estimates all across the world differ with respect to breed size. Small-sized breeds such as Garole and Kendrapara attain adult body weight in the range of 16–18 kg only; however, most of the breeds in cold climate attain higher weight. Many breeds such as Hungarian Merino, Suffolk, Texel, Charollais, etc., attained weaning weight in the range of 19–23 kg (Komlosi 2008), with significant effect of sex, type of birth, and damage on weaning weight and ADG. Similar reports from Afshari lambs were obtained where environmental factors affected the growth significantly (Ghafouri-Kesbi and Notter 2016). All the sheep breeds worldwide report influence of environmental determinants on growth trajectory of the sheep (Safari et al. 2005; Mekuriaw and Haile 2014).

2.3.1.2 Estimates of Genetic Variance for Growth

For growth characteristics, genetics of the individual is most important. Good proven ram mated with elite female guarantees the best bet for market price in terms of fast-growing lambs which reach market weight at early age. Knowledge of genetic parameters is essential to formulate the breeding strategies. Early recorded traits in life are affected by maternal effects (Robison 1981). When the maternal genetic effects are important and are excluded in the statistical model, the estimates of heritability are usually biased upward, and the realized response to selection is reduced as compared to expected (Nasholm and Danell 1994). Therefore, for gaining response to selection, especially in growth traits, it is essential to consider the direct and maternal components of the variance in statistical model (Gowane et al. 2014). The estimates of the weighted means of heritability for growth traits were reviewed by Safari and coworkers (2005). Estimates were moderate to large in magnitude (0.15–0.41) with low noise (standard error 0.01–0.04). The average additive variance for BWT and WWT was nearly similar and heritabilities increased with age to adult weights. A tendency of the mean heritabilities to be higher for the wool breeds than for dual-purpose and meat breeds was observed.

Pre-weaning growth is a very important criterion in sheep breeding, as it has a lifetime impact on growth trajectory of sheep. Apart from nongenetic factors, the maternal environment was found to affect this trait significantly. It is a biological fact that mothers can adjust their phenotype in response to their environment and shape their offspring's phenotype accordingly, for example, poor nutrition during the last phase of pregnancy results in low birth weight. During this process, mothers transfer information about the environment to their offspring (Maestripieri and Mateo 2009). Nongenetic maternal effects account for cross-generational phenotypic plasticity and make a significant contribution to individual's fitness with the environment (Mousseau and Fox 1998a, b). In sheep breeding it was observed that maternal permanent environment (c^2) affects the growth significantly. The birth weight (BWT) of the sheep is technically significantly influenced by the uterine capacity of the dam. Usually it has been observed that the ewes that are in their mid-career are better mothers, as they can provide enough space for the growth of the fetus and also provide better maternal care post lambing. In the experiments conducted at CSWRI, it was found that mostly the maternal permanent environmental effect (c^2) that is the effect of maternal uterine condition has significant association with the BWT. The estimates of c^2 for BWT were 0.20 ± 0.02 (Gowane et al. 2010b) and 0.24 ± 0.02 (Prakash et al. 2012) for Malpura sheep, 0.12 (Kushwaha et al. 2009) for Chokla sheep, 0.22 ± 0.02 (Prince et al. 2010) for crossbred Avikalin sheep, and 0.19 ± 0.02 (Gowane et al. 2010a) for Bharat Merino sheep. Safari et al. (2005) reviewed the estimates for several sheep breeds together, and average estimates for wool breeds were 0.10 ± 0.02, 0.09 ± 0.02 for dual-purpose breeds, and 0.19 ± 0.05 for meat breeds. The moderate estimates of c^2 for BWT are also commonly reported for several exotic sheep breeds (Bromley et al. 2000; Neser et al. 2001). Maternal effects were important at birth; this reflects differences in the uterine environment and the interaction of quality and capacity of the uterine environment for fetus growth. Not only this but also maternal nutritional effects, competition among ewes for the available feed resources, extra supplementation of concentrate mixture during the last phase of pregnancy, etc., also affect the phenotype of lambs at birth (Gowane et al. 2014).

2.3.1.3 Impact of Climate Change on Growth Traits and Mitigation Strategies

As far as growth is concerned, it is well established that the breeds in the cold climate perform better as compared to the breeds in the arid and semiarid region or humid-moist region. However, climate change is expected to affect the very base of production niche. Interactive consequences of the climate change in terms of stressors such as nutritional, physiological, and thermal stress finally affect the growth performance of the sheep. Under the nutritional stressors, feed and water scarcity, mineral imbalances, poor intake, and exhaustion during grazing and migration coupled with high energy losses lead to low body weights, poor immunity, low body depots, and starvation. This results in metabolic disorders such as ketosis, secondary complications, stillbirth in ewes, abortion, pregnancy toxemia, and starvation-exposure syndrome. Thermal stressors have an impact in terms of poor quality water availability, dehydration, hyperthermia, mineral imbalance, poor immunity, and increase in newborn deaths. Physiological impacts include the reduced body reserves, disturbed production cycle, mis-mothering, low birth weight, poor survival, stunted growth, debility, stillbirth, abortion, and water toxicity (nitrate, nitrite, and fluorine) (Dubey and Shinde 2010).

Feed intake is severely affected by the heat stress due to efforts to dissipate body heat, increase respiration and sweating, and demand for more water (Marai et al. 2007). Apart from feed intake, feed conversion efficiency of the sheep is also compromised due to exposure to the heat stress under climatic chamber as compared to shelter during spring (Padua et al. 1997). Some of the factors like depriving animals of water, nutritional imbalance and deficiency may worsen the blow of heat stress. However, it was seen that sheep, as compared to cattle, are not much sensitive to heat stress, at a maintenance feed level (Marai et al. 2007). Among many other measures, the provision of shade shelter is considered as a practical option under extensive conditions (Silanikove-Nissim 2000); this is the most common practice by shepherds in the hot and arid regions during afternoon hours in the grazing areas. In one of the studies on Malpura sheep that was carried out at CSWRI Avikanagar, India, it was observed that the average adult weight of the ewes exposed to thermal, nutritional, combined, and multiple stresses decreased significantly as compared to the control group (Sejian et al. 2011). ADG in control group was 85.7 g; however it was 57.1 g in thermal stress, 85.71 in nutritional stress, 71.4 g in combined stress, and 41.7 g in multiple stress group. Increased temperatures will affect the growth profile of the lambs. According to CSIRO, in 2030, Victoria may have reductions in pasture growth and continued strain on water resources. Apart from several other factors, it will have impact on decreased growth rates of sheep. There was a crossbreeding program for fine wool production in the semiarid region of Rajasthan, India, where Rambouillet and Russian Merino sheep were crossed with the local breeds. In spite of the good genetics of the crossbred sheep, it was observed that the environment in the semiarid region posed constraints for this genotype to fully express its potential. Shifting these animals to a subtemperate region (Gowane et al. 2010a) revealed better growth of the animals. This indicated the importance of climate on the productivity of animals and the extent to which it can impact the success or failure of any breeding program.

We therefore need to have a better risk management approach for ameliorating the effect of climate change in the near future as follows:

- Establishing the priorities: Profitable sheep husbandry means reproductively and productively successful unit of sheep. We need to increase the profit by means of traditional approaches and new information.
- Identify the climate risk: It is evident that rise in temperature, fluctuating weather, reduced forage, contaminated water, salinity of soil, etc. may reduce the growth potential of the animals.
- Analyze the climate risk: Quantifying the foreseen impact of climate change requires several approaches.
  - Modeling the forecast: Predictions with regard to risk associated with climate change with associated variables are required.
  - Targeting the critical points: Energy metabolism is the primary target point. Disturbance in this metabolism will lead to fall in production and healthcare problems. Factors discussed above such as cyclone, temperature and heat extremes, soil salinity, and new vectors need to be at target for analyzing the climate risk.
- Evaluating the climate risk: How to mitigate the risk or exploit opportunities (costs and benefits)? Costs posed by climate change on growth traits are more as compared to benefits. Costs are genetic erosion for fast-growing germplasm, depression in growth rate, and overall fall in production. However benefits are few. Opportunities posed by climate change can be viewed from the perspectives of sheep breeds and their rearers in already harsh climate. Many regions in tropical countries have experiences of handling the issues of erratic climate change. Using such germplasm for forecasted climate change needs may be one of the options for mitigating the effect. One such example is sheep in Sudan. El-Hag et al. (2001) reported that the most critical or important time period for grazing sheep in the semidesert zone of Sudan starts from February to June. Otherwise nomadic sheep spend the dry spell near the regions where water is available. During winter months, when temperatures are mild and the pastureland has greens to offer, the flocks can extend the interval of watering from 10 to 15 days, only to reduce the interval after winter to 3–5 days when conditions are harsh (Mukhtar 1985).
- Treating the climate risk: Several tactical and strategic responses have been delivered by Crimp et al. (2008). Working on these points, we can think of the following options:
  - Increasing fallow or pasture: In the human populated area, this option remains futile, due to ever increasing need for shelter and agriculture by the man. However, it must be noted that altering the cropping pattern and performing mixed animal–crop farming can be practiced for better results.
  - Reducing dependency on the environmental factors: Growth is mainly affected in the pre-weaning phase. Availability of good quality and quantity of milk from dam and pasture availability thereafter are essential for better growth. However, if the unpredictability of weather takes advantage, then this system may fail permanently. Therefore a packed system of rearing animals unlike poultry may help produce better by manipulating the microclimate. In some experimental studies, it has been reported that micromanipulation at the management level can have positive effect on animals for climatic stress. A

study conducted on sheep production in the rangeland of Kordofan region of Sudan indicated the importance of nutrient supplementation on productive and reproductive performance in the climate change. It was shown that the supplementation and application of Kunan during breeding season was a successful strategy to adapt to the climate change in the rangeland of Kordofan (Idris et al. 2014).

– Management of the sheep grazing: Sheep grazing in arid and semiarid regions is mostly nomadic where searching for new locations for food and water is essential. This involves competition with native livestock and challenge of shrinking CPRs. During the era of climate change, conflicts are expected to increase. During hot climate, the alternative strategies for grazing are allowing animals to graze during late hours or early morning hours to avoid the hot sun during the afternoon. It is very essential for animals to reach resources and rehydrate themselves. This also leads to indirect selection of germplasms with tall legs and ability to cover more distance in a given time. One such example is evolution of Kheri genotype in Rajasthan, India. Migration was common during drought (Rathore 2004) for native Malpura sheep in semiarid region. However, during migration the Malpura sheep was crossed with the Marwari sheep from arid region that resulted in the production of crossbred animals (Kheri) which are sturdier, have long legs, and are best for migration purpose. There is a preference for this by farmers whenever there is a need for migration (Gowane et al. 2010a). This was an instinct by sheep breeders and repetition of such examples will be a common stance in the climate change era.

2.3.2 Carcass Characteristics

2.3.2.1 Sheep Meat Production and Climate Change

Climate change has been affecting and will continue to affect the food production globally if steps are not taken and effectively implemented to counteract the effect on food production system. The climate change is adversely affecting the quality and quantity of the food produced. It has been responsible for the frequent occurrence of drought at one part while flood-like situation in another part with huge impact on fodder production. The animal husbandry is dependent on the supply of forage and fodder. Any disaster is severely affecting the quality and quantity of nutritional resources. Depleting grazing resources and encroachment of common property resources (CPR) are major concerns affecting the animal husbandry. In the twenty-first century, the world will have to deal with the global food security threat due to climate change (Myers et al. 2014). The rapidly changing lifestyle, pressure on traditional food resources of man, and urbanization are drivers of demand for livestock products. Therefore, the livestock production and climate change need considerable attention in order to ensure the animal products to the global population.

2.3.2.2 Meat Production Status and Carbon Footprint

The average world sheep carcass yield per animal is 16.0 kg (FAOSTAT 2014). Out of the total sheep slaughtered, Asia and Africa contributes nearly 71.5% in numbers. This region harbors mostly extensive sheep production system, where animals are mainly reared on grazing with minimal extra supplementations, unless essentially required. Being primarily fed on grazing, these animals are prone to the effects of climate change. The extensive animal production system is more prone to the climate change than the intensive production system. The climate change has impact on the availability of the feed and fodder resources for the sheep. The low levels of energy and protein resources will have adverse effect on growth resulting in reduced slaughter weight, carcass weight, dressing yield, and higher carcass shrinkages during the storage. Compared to the world average, carcass yield in least developed countries is 12.3 kg, and in India it is 12.0 kg. Many reasons can be attributed to this finding. Genetic differences among the breeds are one; however energy and protein deficiency and early slaughter age are the main factors for limiting the carcass yield.

Estimates on GHG emissions from sheep for producing the products like meat (kg/kg of product) are set to be very high. Carbon emission from small ruminants is a point of concern when we talk about the meat production from sheep in changing climate era. Small ruminants contribute nearly 475 million tons CO_2 eq. (6.5%) of which 299 MT are allocated to meat production and 130 MT to milk. The estimates of world emissions for milk production are the same for sheep as well as for goats. However, emissions for mutton production are very high than chevon. For the emission intensity (CO_2 eq. emitted per kg of small ruminant product), sheep milk has high values (8.4 vs. 5.4, Table 2.1) than goat milk (Opio et al. 2013). Small ruminant meat has a lower carbon footprint as compared to large ruminant's meat (23.8 vs. 46.2 and 53.4 kg of CO_2 eq./kg of carcass weight). Difference arises due to (a) higher production potential of dairy cattle and (b) high prolificacy, reproduction efficiency, and growth in small ruminant's meat production (Marino et al. 2016).

2.3.2.3 Stressors in Relation to Mutton Quality

High ambient temperatures, along with relative humidity (RH), air flow, and solar radiation, raise the body temperature above the critical level. This results in physiological side effects on animal production (Kadim et al. 2008). In Barbados Black Belly lambs, different temperatures (20 °C and 30 °C) affected the meat color from the rib-eye area (REA), fat, leg, and *longissimus dorsi* muscle. Higher values for lambs in low temperature as compared to lambs in the high temperature were observed (Jallow and Hsia 2014). Depletion of muscle glycogen pre-slaughter increases the pH of meat due

Table 2.1 Milk and meat production (x year) from sheep and its CO_2 equivalent emissions

Production		Emissions of CO_2 eq.			
Milk	Meat	Milk	Meat	Milk	Meat
Million tons		Million tons		kg/kg of product	
8	7.8	67.4	186.9	8.4	24.4

Source: Opio et al. (2013)

to stress (Bray et al. 1989). Kadim et al. (2007) concluded that pH above 6.0 is associated with dark meat color. Lowering of the pH contributes toward myoglobin oxygenation, affecting its visual appearance (Pogorzelska et al. 2013). In the indigenous sheep study, the heat stress had significant impact on carcass characteristics and meat quality. A decrease in dressing percentage with increase in exposure to heat was revealed (Rana et al. 2014). The study also highlighted the consequences of high temperature and its implication on mutton production.

Heat stress, which may form a major thing in climate change, can impact on meat safety as well as organoleptic quality. Global warming would affect microbial burdens on carcass, if the animals have high enteric pathogens. The meat quality of sheep may be affected by extreme heat that provokes adrenergic stress response. Adrenaline stimulates peripheral vasodilatation and muscle glycogenolysis. Pre-slaughter, it results in high pH and darker meat, affecting meat quality (Lowe et al. 2002). If the animal is heavily exercised, developing hyperthermia pre-slaughter, the combination of high temperature and anaerobic metabolism leads to an early and stronger rigor and tougher meat. The protracted high temperatures will lead to dehydration in water-deprived animals. Meat becomes darker through shrinkage of the myofibers and has less weight. Ambient temperature affects the feed digestibility due to alteration in the volume of the GI tract and the rate of passage of the digesta (Conrad 1985).

The carcass traits of Chokla rams, a breed of arid region of Rajasthan, India, maintained under feed restriction followed by re-alimentation were evaluated. The lean yield, subcutaneous fat and intermuscular fat, and dissected bone yield were not affected. The findings of the present study suggested that restricted feeding followed by re-alimentation didn't adversely affect the carcass yield and traits. If optimum nutrition is provided after feed scarcity, the animals are able to compensate the weight loss (Gadekar and Shinde 2014). However, it must be kept in mind that breed differences may exist for such parameters.

2.3.2.4 Mitigating Impact on Carcass Characteristics

Mitigation of stresses arising out of climate change impacts on meat quality and quantity of sheep across the globe is the challenge put forth to us. Sheep is the animal of the future given its widespread availability, diversity, and adaptability to the harshest of the climates on earth. Breeding, feeding, heath, and technological interventions are call of the time for mitigating effects of climate change on meat production from sheep. In order to have optimum production from sheep, the animals should be protected from extreme stressors. One step from humanity toward ameliorating this stress will result in 1000 steps from the sheep sector to satisfy the hunger and provide quality protein food resource for humans.

2.3.3 Wool Production and Climate Change

Wool is an important by-product of sheep husbandry that is critical to the well-being of millions of people across the globe. Wool has been a livelihood resource for farmers and a luxury fiber for people in textile trade. The economic value of wool is governed primarily by the fiber grade. The fiber grade is a numerical designation of wool fineness based on the average fiber diameter and its variation. Wool produced all over the world is mainly grouped into three grades, viz., fine, medium, and coarse grade wool. The wool below 25 μ diameter is graded as fine wool. The fine wool has high economic value and suitable for apparels and garments. According to the International Wool Textile Organization (IWTO), approximately 40% of world wool production is attributed to fine wool. The medium wool is fit for making carpets, felts, and blankets and had fiber diameter range of 25–35 μ. The coarse grade wool has fiber diameter more than 35 micron and has relatively less commercial value. The commercial value of wool also depends on wool yield (clean fleece and greasy fleece weight). Majority of sheep breeds produce wool. The wool quantity produced from sheep depends on climatic region, breed, age, sex, nutrition, and shearing interval. Lambs produce less, yet fine, wool than aged sheep.

Globally, the number of sheep remained almost unvaried at around one billion in the last 30 years (FAOSTAT 2014), despite different trends in the last two decades (Fig. 2.1). Consequently, the wool production also remained stagnant or more precisely declined due to loss in profitability and environmental constraints. The factors such as decline in economic value; demise of wool reserve price scheme in Australia, New Zealand, and Africa (Abbott 2013); increased competition with synthetic fibers; limited market expansion; and rising production cost caused reduction in profits from wool production. Thus focus is being shifted toward dual-purpose breed, which can produce meat along with wool, for high profitability.

Wool production, along with sheep husbandry, is also being affected due to climate change. The profitability and environmental impacts of different sheep systems in Australia suggested that Merino crossbred flock is more profitable than pristine Merino (Kopke et al. 2008). It indicates a shift from traditional Merino

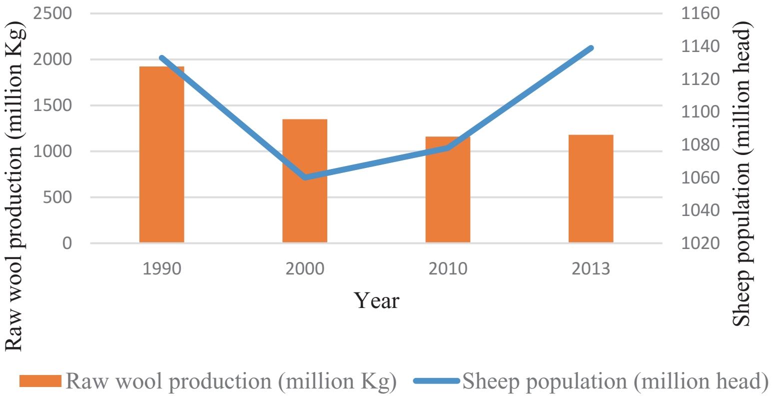

Fig. 2.1 Sheep population and wool production in the last three decades: a decline in sheep number and wool production during 1990–2000 followed by stagnancy in the next decades. The number of sheep is increasing since 2010, but wool production is still stagnant (Source: Roche, International wool trade Roche 1995; International Wool Textile Organisation, Market information report 2014; FAO STAT report 2010)

sheep system to crossbred sheep system. It seems the shift is more sustainable as the crossbred sheep system emits less greenhouse gases (GHG) and reduces groundwater recharge; however, not to mislead, emissions associated with the sheep systems on other farms that produce the purchased replacement ewes should also be considered. In developing regions and least developed parts of the world, the condition is grave, as the resources are limited, groundwater is already deepening, and climate change is ticking an alarm. Non-profitability of wool as a primary product from sheep is certain, and hence changing the sheep husbandry systems, with renewed goals and priorities, is the need of the hour.

2.3.3.1 Climate Change and Life Cycle Assessment (LCA)

Sheep is considered as a source of GHG emission, so is wool. The LCA approach can systematically quantify emission rate of wool. Typical LCA studies are confined to wool production on farm gate. The activities such as sheep husbandry (pasture feed, nutrient supplements, etc.) and energy inputs (fuel, electricity, etc.) are considered for emission assessment. Various studies (Brock et al. 2013; Cottle and Cowie 2016; Barber and Pellow 2006) conducted LCA of wool to measure its contribution in GHG emission and impact on climate change.

The LCA study of Australian Merino wool (19 μ) emitted approximately 24.9 kg CO_2-e/kg greasy wool (Brock et al. 2013). The sheep manure and urine are the major emission sources directly and indirectly. Direct enteric CH_4 emission from manure and urine contributed 86% of the total emissions. Whereas, 5.2% and 1.1% of the emissions are attributed to the direct and indirect emission of N_2O, respectively. The total emissions per kilogram of greasy wool decreased with increase in fiber diameter, reduction in fleece weight, and selection of dual-purpose sheep (meat and wool production). Wool in the United States reported comparatively lower emission (19.2 kg CO_2-e/kg greasy wool). This may be due to difference in genetic traits, fiber quality, and market conditions.

In another study (Cottle and Cowie 2016), livestock GHG emission was modeled using LCA approach for sheep production system and compared with system expansion and economic allocation methods. LCA of sheep production system, comprised of wool and meat, is highly sensitive and significantly differs with other methods. The GHG emission differs with climate and wool productivity. The emission of 8.6 kg CO_2–e/kg of wool was reported for wool in New South Wales and Western Australia states. The GHG emission has attributed 78% to livestock emission, 14% to transport, and 8% to pasture emission.

LCA can also be used to study the impact of wool production on climate change through energy requirement. Interestingly, wool fiber production consumes significantly less energy than popular man-made fibers. The LCA study of Merino wool in New Zealand (Barber and Pellow 2006) showed that the total energy consumption of wool fiber from New Zealand farm to spinning mill in China was 48 MJ/kg of fiber. The energy and resources required for wool are 50% less than polyester and 75% less than nylon. However, synthetic fibers are cheaper maybe due to industrial bulk production (Berry 2015). On-farm wool production accounted 52% energy which is attributed to fossil fuel and fertilizer consumption, whereas wool top processing contributed 45% of the total energy in which wool scouring and topmaking are the highest energy-consuming processes. Improved fertilizer efficiency and less energy-intensive wool processing should be encouraged to improve environment profile of wool.

2.3.3.2 Climate Change Impact on Wool

Climate change may have substantial effects on the sheep livestock, thus on wool, directly and indirectly. Extreme weather, drought, floods, rise in temperature, and water availability can directly impact the sheep livestock. The agroecological changes, fodder quantity and quality, and disease epidemic may affect indirectly (Thornton 2010). Climate change may cause increase in cost of livestock production and variable production system (Barwick et al. 2011). Increased cost of production will affect wool quality, economic values, etc. There is very little literature that elaborates on implications of global climate change on wool yield or quality. Harle et al. (2007) studied the effect of climate change on Australian wool industry. The study predicted that the wool production and market may shift its geographical location based on the climate change and forecasted that Australian wool industry will sustain the effects of climate change in the long run.

Climate change has an impact on wool through a number of factors. It mainly includes availability of fodder, sheep nutrition, sheep health and availability of grazing land, water resources, and their competition with cropping. Increase in cropping area will replace land use for sheep production area (Rowe 2010). The fodder quantity and quality may be adversely affected with change in rainfall. This may cause sheep malnutrition. Furthermore, the variations in temperature due to climate change may adversely affect sheep health with increased range of pests and diseases. The sheep sustainability may be highly challenged with shrinking land and water resources which may be prioritized for agriculture cropping. All these combined factors will have implication on wool quality, on wool yield, and ultimately to wool industry and stakeholders.

2.3.3.2.1 Impact on Wool Quality

Fiber diameter, fiber diameter variation, staple length, staple strength, and amount of impurities are some of the important traits which determine its performance during subsequent processing stages. All these important traits are likely to be influenced by the effect of climate change. The fiber diameter may shift from finer to coarser quality with the rise in temperature and reduction in rainfall. In the climatic variability, it would be a challenge to produce and sustain fine quality wool for apparels, whereas, the coarse quality wool can be more resistant to climate change (Harle et al. 2007). However, this would reduce income from wool since fine quality wool always yields good price.

The change in pasture availability with good nutrition value will generate tender wool on sheep. The tender wool may have fine fiber diameter which can yield good income. However, it is associated with short length and low staple strength which makes wool difficult to process during fabric manufacturing. The staple strength may be increased or decreased depending on location and nature of climate change.

Vegetable matter, dirt, and dust in raw wool are yet another trait which will get affected by climate change. The raw wool in high rainfall region is likely to have high vegetable matter content. Low rainfall region may also lead to accumulation of high amount of dirt and dust in the raw wool. In both cases, energy-intensive cleaning operations will add cost and also deteriorate fiber traits, like length and staple strength, affecting the quality of the final product (Harle et al. 2007).

2.3.3.2.2 Impact on Wool Yield

The declining number of sheep and reduction in average fleece weight due to pasture conditions may cause further drop in wool production (Berry 2015). The wool yield will depend on climate and pasture variables for particular regions. Wool production is a function of pasture growth and animal genetics. Wool-producing ability of lamb depends on secondary follicle generation which is related to feed intake during gestation of ewe. The low feed intake can cause follicle impairment in lambs (Harle et al. 2007). High cost of fertilizers and reduced pasture production will invariably reduce feed quality and quantity to sheep. In addition, high heat stress on sheep in tropical and subtropical region due to rise in temperature may lower the wool yield. Wool-producing breeds are being replaced by dual-purpose sheep breeds. This may hamper the wool production. Wool-producing breeds are at risk due to low profit margins and therefore face the risk of becoming extinct. It is a threat to biodiversity and may further lead to intangible adverse impact on climate change.

2.3.3.2.3 Impact on Wool Products

More temperate climate will reduce demand for woolen apparels made from fine wool. The demand for coarse wool fiber for making carpets and other interior textiles may not be susceptible to climate change. Wool products are vulnerable to competition with synthetic fibers which are largely to remain unaffected by climate change. However, wool is a natural and eco-friendly fiber in relation to synthetic fibers which ensures sustainability. In addition, wool fiber is less energy intensive than petroleum-based synthetic fibers. Wool is mainly used in higher-valued textiles and clothing and may enjoy the luxury status for a long time. The properties of wool fabrics such as inherent breathability and adaptability to climate cannot be matched with synthetic fibers. Through manufacturing interventions (Grogan 2013), the demand of wool fiber for high performance in sports and high-altitude clothing is likely to increase. The next-to-skin lightweight knitwear from Merino wool is an opportunity especially for Australian wool due to warmth, moisture adsorption, and odor reduction (Rowe 2010).

2.3.3.3 Mitigation Strategies

Mitigation of global greenhouse gas emission and climate change impact has a strong economic potential that can balance the emission rate in the future. Hence mitigating emission and increasing productivity and profitability of both, industry and farm, should be aligned. This cumulative and holistic approach is necessary since the polarized efforts and interventions of industry and farm management are making them vulnerable to economic risk and climatic variability. The mitigation strategy should cater to three interlinked objectives. First is to reduce GHG emission from wool at the farm and industry level. Second is to improve sustainability of wool and wool products. Finally the most important is the increase in productivity and profitability of farm as well as industry.

2.3.3.3.1 GHG Emission Reduction

The GHG emission from wool can be reduced with effective interventions at farm and industry (Fig. 2.2). Various farm interventions may need to combine to reduce GHG production depending upon the location, climatic conditions, and resource availabilities. Dual-purpose sheep (crossbred) may help to reduce the emission and enhance the economic returns (Brock et al. 2013; Kopke et al. 2008). The study (Alcock et al. 2015) on Merino ewes in Southern Australia with farm interventions found the combination of influence of joining maiden ewes at a young age, increasing lamb weaning rates, and effect of a 10% genetic improvement in fleece weight, in feed efficiency on profit, and also on annual methane emission. Joining maiden ewes at a younger age of 7 months instead of 19 months allowed higher number of ewes to be mated. The total enteric emissions in both cases remained the same. Moreover, increase in wool and meat yield brought sustainability to the entire trade. Higher lamb weaning rates increased wool production and also reduced wool emissions' intensity by 7–8%. Superior genotypes with improved traits improved profitability and importantly reduced emissions and emission intensity by a greater extent. It is worth noting that the results obtained are due to the cumulative interventions only.

Optimizing lambing time based on geographical wool growing location and climate variability can be a sustainable and profitable strategy. The late winter/early spring lambing in high rainfall zones generally ensures sufficient pasture availability to the energy needs of ewes and lambs with minimum supplementary feeding.

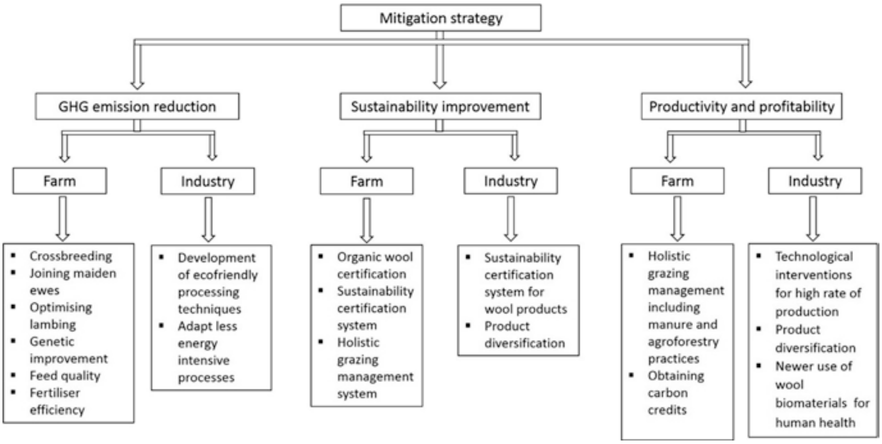

Fig. 2.2 Mitigation strategy for wool production system

Lambing in April/May instead of August could reduce the wool emission intensity (Kg-CO_2-eq/kg of clean wool) from 40% to 8% in the Victoria region of Australia (Alcock et al. 2015). The industrial interventions include adaption of eco-friendly and less energy-intensive processing practices. For instance, use of ultrasound and microwave-assisted scouring can reduce the time, energy, and chemicals to obtain the clean wool. Interventions in nonwoven manufacturing can significantly reduce the energy requirement for wool fabric manufacturing.

2.3.3.3.2 Sustainability Improvement

The certification system such as organic certification and sustainability certification can be a drive to gain economic advantage and to improve sustainability of wool. For instance, the Grassland Regeneration and Sustainability Standard (GRASS) certification of wool is a certification system in Argentina (Argyropoulos 2014) that encourages sustainable grazing throughout the Patagonian Grasslands and creates a value chain that aims at maintaining and regenerating these fragile ecosystems through the consistent demand of wool in a sustainable manner.

Holistic grazing management is a planned decision-making framework that ensures the decisions are environmentally, economically, and socially sound. The holistic management practice is discovered by Allan Savory and Jody Butterfield. They successfully implemented the practices in southern Africa and America. This includes increasing the stocking rates given the frequency data for each ecological zone and performing intensive livestock rotational grazing within smaller plots of land for shorter periods of time. By having the sheep in smaller areas for shorter periods of time, they are able to till and aerate the soil, urinate and defecate in order to provide nutrient cycling, and then be moved to another land plot in order to repeat the process. The holistic management allows improving profits and livelihood, increasing carbon sequestration, reversing desertification, and improving biodiversity. Flora and fauna can thrive together with this approach without disregarding economic profits to livestock sector (Butterfield et al. 2006). Adaptation of low-emission grazing systems, more sustainable management of the rangelands, and improved management of climatic variation could significantly reduce the snares of climate change impacts (Harle et al. 2007). Effective land use planning is necessary to meet future demands from livestock sector.

2.3.3.3.3 Productivity and Profitability

The grazing management, manure management, and growing agroforestry species can provide high-quality dietary supplements for sheep. These interventions can also seize carbon emission. Such carbon sequestration has huge potential of income generation for sheep farmers, especially in tropical regions. Emission mitigating practices, both technological and management practices, at farm and industry will be readily adopted provided they would be productive and profitable. Microlevel adaptation, income-related response, institutional changes, and technological developments are the keys to adapt the climate change (Thornton et al. 2009). Increasing the production efficiency using the best available technology will ensure profitability and assist in reducing GHG emissions (Thornton 2010).

Wool is a highly technical fiber. It has potential to develop diversified fabrics for technical and smart applications. For example, wool due to its peculiar properties is useful in agriculture, sound insulation, and industrial thermal insulation. Wool can purify surrounding air by adsorbing toxic formaldehyde in the air (Huang et al. 2007), so it can be a source of air pollutant remover. Wool being a biopolymer and rich in keratin protein, novel applications for biomedical sciences are recently being studied (Rouse and Van Dyke 2010). Additionally, technological advancements in biotechnology and nanotechnology could prove instrumental for wool biopolymer. Thus, wool biopolymer has high potential in biomedical sciences. Certainly, these new application areas will fetch higher income to wool farm and industry while maintaining sustainability and mitigating climate change.

Sheep livestock sector for wool production is under stress owing to carbon emission, competition for land and water resources, high cost, low profits, and environmental effects. The life cycle assessment studies indicated that wool contributes to greenhouse gas emission. Hence, cumulative and holistic efforts are required to mitigate the emissions. The efforts should be linked with productivity and profits to farm and industry. The economic drive may offset the emissions in the future. In addition, wool as a fiber has an edge over other synthetic fibers in terms of biodiversity and sustainability. The properties and applications offered by wool fiber are still unmatched by an entire range of man-made fibers. The technological advancements in biotechnology and nanotechnology can further accelerate the wool biopolymer to develop products for human well-being.

2.3.4 Sheep Milk and Climate Change

According to Gerosa and Skoet (2012), the share of total dietary energy intake from dairy products is nearly 14% in developed and 4% in developing world. Globally, cow milk represents 85% of world production. The contribution toward milk production from goats (3.4%), sheep (1.4%), and camels (0.2%) is low. Although the contribution of sheep toward total milk production is negligible, it is really important in some countries (Syria, Jordon, Afghanistan, Greece, Iraq, Somalia and Algeria), where sheep milk contributes between 11 and 36% (Shinde and Naqvi 2015).

Sheep rearing for milk production is not common and mostly confined to Middle East and Mediterranean countries. Mediterranean countries that also include France, Greece, Italy, Spain, and Turkey together account for sheep milk production of nearly 2,900,000 MT (FAOSTAT 2012). In Mediterranean countries, 60% of sheep are reared totally or partially for milk, and 95% of milk is transformed into special milk products like cheese. Some of the sheep breeds in these countries are improved for their dairy characters by selection of pure breeds or crossbreeding or upgrading of the local populations with importation of Awassi from Israel. Among them Assaf (Israel), East Friesian (Germany), Lacaune (France), Sarda (Sardinia), Chios (Greece), Manchega (Spain), etc., are well-known dairy sheep breeds that are improved and reared under intensive system for milk (>200 kg milk/lactation) and cheese production, while Awassi dairy sheep in Jordan, Lebanon, Iraq, Palestine, and other countries of the Middle East are still reared under extensive system and produce 80–90 kg of milk/lactation, and most of the milk is utilized in traditional products and for household use. Milk from sheep in Middle East countries is an important source of dietary protein to people, mainly smallholders, landless people, nomads, and peasants, while in Mediterranean countries, milk from sheep is further processed into high-quality dairy products like cheese and yogurt. Due to its richness, sheep milk gives a high cheese-making yield (~ 15% for sheep milk compared with 10% for cow milk).

As per report of FAOSTAT (2012), China produced 1.58 million tons of fresh sheep milk followed by Turkey (1.01 million tons) and Syria (0.70 million tons). In most of the countries (China, Syria, Iran, Algeria, Afghanistan, Mali, Niger, Indonesia, Mauritiana, Egypt, Albania, Burkina Faso) where traditional system of sheep rearing is practiced, average milk yield of sheep ranges from 300 to 600 g/day, while in other countries like Turkey, Greece, Romania, Italy, and Bulgaria where semi-intensive system and improved breeds are introduced for dairy sheep farming, milk yield ranges from 600 to 1000 g/day. In Spain and France where sheep are stall-fed, improved high-yielding breeds are found, parlor machine milking exists, milk yield ranges from 1900 to 2100 g/day, and 90% of milk is used in cheese making. On an average, sheep milk production increased by 15.0% from 1992 to 2002 and by 27.5% during 2002–2012 in these well-known dairy sheep countries. Sheep milk is rich in nutrients, except lactose, compared to the milk of humans, cattle, and goats.

2.3.4.1 Climate Change and Dairy Sheep

According to Opio et al. (2013), the world emission for milk production is similar for sheep and goats with little higher values of CO_2 eq. emitted per kg for sheep than goats (8.4 vs. 5.4, Table 2.1). The global average of the carbon footprint for milk production for small ruminants is more than double than large ruminants. The Mediterranean region which contributes for the majority of the sheep milk is characterized by hot, dry summers and cooler and wet winters. The temperatures in the Mediterranean often exceed sheep thermoneutral zone (5–25 °C; McDowell 1972) that may result in the occurrence of heat stress (Hayes and Sackville Hamilton 2001). The adverse impact on livestock will be due to the lower rainfall and more droughts and solar radiation affecting plants and animals (Nardone et al. 2010). Pasture and forages in temperate zones are affected by climate change; however less impact is expected in comparison to other climatic zones (Sautier et al. 2013).

2.3.4.2 Effect of Climate Change on Milk Production

The direct effects are on the animals, and indirect effects are through effects on production of crops and exposure to pathogens and pests. Less attention has been given to the effects of heat stress and other climatic variables in sheep (Chauhan and Ghosh 2014). In sheep rearing regions, sheep are mostly kept outdoors; this affects, in addition to milk quantity, milk quality too. It is important because sheep milk is important for cheese making. Milk production traits in ewes have high negative association with temperature, RH than THI. The sensitivity to THI varies from sheep breed to breed. Solar radiation had less effect on milk yield; however it has more impact on casein, fat, and clot firmness in the milk of Comisana ewes (Sevi et al. 2001). Finocchiaro et al. (2004, 2005) reported a decline in production in Valle del Belice sheep when THI was ≥23. Milk and fat protein productions always showed negative phenotypic correlations with THI. There was a positive association of production traits with relative humidity. It shows how change in climate can affect production. Studies show that production is negatively associated with heat tolerance. Amaral-Phillips et al. (1993) have shown that deteriorated coagulating behavior of milk from sheep exposed to increased temperature is due to the use of fat and nitrogen reserves to supply energy through gluconeogenesis at the expense of the mammary gland and to increase milk pH due to high CO_2 dissipated by panting. Sheep milk from animals exposed to high temperatures resulted in higher neutrophil counts and also an increase of lipolytic and proteolytic enzymes (Sevi and Caroprese 2012). High ambient temperatures may also result in plasma mineral imbalance, due to reduction in Na, K, Ca, and P and increase in Cl concentrations (Caroprese et al. 2012). In Sarda ewes, milk yield is reduced by 15% if maximum ambient temperatures are higher than 21–24 °C and by 20% if minimum temperatures change from 9–12 °C to 18–21 °C; furthermore, Sarda sheep production performance can be reduced by 20% with THI passing from 60–65 to 72–75 (Peana et al. 2007).

Housing system was found to affect yield and quality of sheep milk during summer months in the Mediterranean basin (Casamassima et al. 2001). When reared indoor, dairy sheep require a proper ventilation. With a pending high heat load situation, a ventilation regimen providing 70 m^3/h/ewe can sustain ewe milk production (Sevi et al. 2002a, b) with lower ventilation rates having detrimental impact that was attributed to a greater energy waste for thermoregulation at the expense of milk synthesis (Sevi et al. 2003). Exposure to direct solar radiation reduces the levels of unsaturated fatty acids and increased saturated fatty acids. The ambient temperature may interact with a few predisposing conditions to exert an influence on udder health (Klastrup et al. 1987). Due to changes in fatty acid composition, unshaded ewes displayed an increase in the lauric + myristic + palmitic acid content in milk, which are considered to have a hypercholesterolemic effect on human health (Grummer 1991).

It is seen that the events during summer have deleterious effects on coagulating properties of sheep milk. Deteriorated coagulating behavior of milk in summer is mainly due to the use of fat and nitrogen reserves to supply energy through gluconeogenesis at the expense of the mammary gland (Amaral-Phillips et al. 1993) and to increased milk pH, due to high amounts of CO_2 dissipated via the panting (Habeeb et al. 1997). Plasmin activity was found higher and Ca and P contents were lower in summer milk. The incidence of udder health problems is higher in summer due to heat stress. Increased SCC in milk from indoor reared ewes than outdoor reared is attributed to the bad, stale air, litter and to fecal contamination (Casamassima et al. 2001). In late lactation milk, collected during summer months, Albenzio et al. (2004) found increased levels of SCC and macrophage cells. The increase in SCC commonly measured in late lactation milk yields during the hot season is responsible for the impairment of coagulating properties of milk. Finocchiaro et al. (2007) found increased milk SCS when ewe were exposed to higher solar radiation; sun hours and precipitation reduced SCS when ewes were exposed to higher air pressure and wind speed, which suggested importance of including weather information in genetic evaluation models for mastitis resistance.

2.3.4.3 Mitigation

Sheep are extensively managed mostly, and potential adaptations to climate change may be limited as management needs to take upper hand in any workable strategy. A series of research findings (Sevi et al. 2001, 2003; Sevi and Caroprese 2012; Caroprese et al. 2012; Todaro et al. 2015) highlighted the importance of the adequate management (e.g., proper ventilation regime, provision of shade, shift the time of feeding to afternoon) and nutritional strategies (e.g., whole flaxseed supplementation) for reducing the negative effects of thermal stress on sheep milk production. It was shown that the administration of whole flaxseed as fat supplement to Sarda ewes during summer leads to an increase in the milk yield by about 18% (Caroprese et al. 2012) due to increased concentration of C18 fatty acids in milk. Flaxseed diet resulted in an increase of the milk VA by about 50% in sheep exposed to solar radiation and by 18% in the sheep protected by the solar radiation. Flaxseed also improved total CLA content in milk (Caroprese et al. 2012). Housing management, weather forecasting, and better feeding can influence the milk quality. To minimize the impact of high summer temperatures on lactating ewes, the provision of shade and the change of feeding time to late afternoon can be useful. In order to cope with these climatic changes, animals more robust to extreme conditions will be needed. Menéndez Buxadera et al. (2013) found an important genetic variation for the response to heat stress in two breeds of goats in the south of Spain. Finocchiaro et al. (Finocchiaro et al. 2005) observed similar variation in dairy sheep in Valle de Belice in Palermo, Italy. This genetic variability for the response to climatic conditions can be used to select the most adequate animals (tolerant or robust) to cope with future climate changes.

2.4 Importance of Reducing the Impact of Climate Change on Small Ruminants

Animal production system is a biochemical process that is in continuous dynamic state of energy and matter exchange with its environment. An animal being an open system is always affected by the micro- and macroenvironment in which it resides. Small ruminants and, in particular, sheep act as a sustainable livelihood resource for majority of the landless, small, and marginal farmers across the globe. Not only this but also this species acts as a major profit making industry in Australia, New Zealand, and many other countries. Climatic stress acts through either nutritional or thermal stress resulting in the physiologically comprised state of the animal. This in turn not only affects the production profile of the animal but also harbors a challenge of loss of biodiversity; threat to the sheep industry for wool, meat, hides, milk, and other products; and threat to the sustainability of poor farmers. It is predicted that climate change will only have a mild impact on livestock production in the United States since most livestock are kept in protected environments (sheds, barns, etc.) and have supplemental feed (Adams et al. 1999). The scenario in the developing world is different. The animals are more exposed to the causal variants, and dependability on natural feed resources is higher. Therefore reducing the impact of climate change is of utmost importance.

2.5 Future Plans for Mitigating the Effect of Climate Change on Sheep Production

Sheep husbandry is a multifarious livestock enterprise that has diverse stakeholders across the globe. Shepherds are the real breeders who have been developing and improving numerous sheep breeds over the millennia for utilization of sheep products in diverse forms. The biggest question with climate change is the uncertainty surrounding its time frames and impact assessment. It is uncertain which regions will be affected by these changes and to what will be the magnitude of impact. This may lead to a reluctant approach for the initiation of mitigating measures (Rust and Rust 2013). Tropical regions like India, Sri Lanka, Pakistan, African continent, Southeast Asian countries, and Middle East countries are expected to suffer more due to several factors. These regions have a huge dependency on livestock and related activities. Loss of biodiversity, decline in production, compromised quality, and disease threats have potential to break the backbone of rural industry, and hence mitigating the impact of climate change is essential.

2.5.1 Breeding for Climate Change Adaptation and Mitigation

Throughout the human history and its association with livestock husbandry, man has been breeding the animals for production alone. Hardy traits have been utilized for horses due to their utilization in wars in the past and trade and races in the present. Fitness (not reproduction as it is usually considered but hardiness) has very little to do with production, as long as animal is in company of humans. Productivity and adaptability to heat tolerance are negatively correlated (Finocchiaro et al. 2005); there should be a trade-off between these two traits in breeding plan. Changing climate will demand many things from the animals to be included in the breeding program such as:

- Fitness in the given environment
- Disease resistance or resilience
- Shock absorbance for water scarcity, heat stress, nutritional stress, and combined stress
- High production per animal
- Excellent feed conversion ratio
- Low methane emission

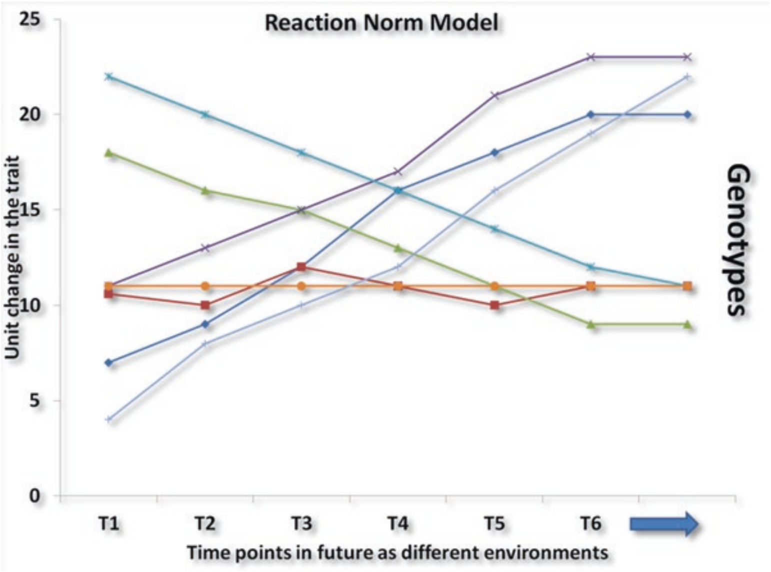

Fig. 2.3 A typical reaction norm model for different genotypes

Reaction Norms Different genotypes react differently to the selection pressure applied to them in different environments. Time in the future can be seen as the change in the environment from the present-day environment in the changing climate era. Temperature, humidity, rainfall, etc., are bound to change in the near future, and it will result in the creation of new environment. This will lead to genotype by environment interaction (GxE) resulting in the reaction norm (Fig. 2.3).

A selection program for different genotypes at the same time (one environment) with similar selection pressure will result in different magnitude of change in the genotypes due to GxE interaction. In the era of climate change, each time point in the future say, for example, a point after 10 years, 20 years, etc., will be different environments, and the genetic correlation between the same genotypes' measurement between different time points will not be one, but significantly less than one. This indicates that actually the trait of interest is never one in two environments, but rather they are two different traits, when measured in two different environments. Therefore, each genotype may behave differently in future environments, some may improve, some remain static, and some may decline in performance. This concept is very essential to understand and apply which genotypes are desired and which environments we expect to occur in the future. Selection for better production potential in the bad or not-so-good environment of the future seems to be the most successful breeding program in the near future.

2.5.1.1 Selective Breeding Program

Preference needs to be given to the indigenous breeds that evolved through the process of natural selection followed by man-made efforts for survival and production under harsh climate. High temperature and humidity provide a stressful climate for most of the closed fleece sheep of the cold region; however, such stress can easily be managed without compromising much of the production by sheep in tropical climate where open fleece is naturally grown. Selective breeding of such breeds can be a suitable option for managing the temperature-combined humidity stress. According to Habeeb et al. (1997), the morphological characteristics preferred for the hot climate breeds should include a large skin area to live weight ratio, shielded eyes, pigmented skin and eye lids, and a light-colored or white body cover and ability to walk long distances; to adjust to low water intake, to high intake of salts either in drinking water or in forages, to poor quality food, and to harsh treatment; and to resist ticks and other pests. Import of breeds from one area to other areas can be tried for utilizing the hardy germplasm in the changing climate regime. However, it is very essential to look for several parameters before doing it. The extent of climate change risk and associated factors such as health hazards, nutritional availability, water resources, accessibility to new vectors, and parasites may strongly influence the adaptive processes, and establishing the genetic role in this process is the future researchable issue.

2.5.1.2 Developing Crossbreeding Programs

This approach was exhaustively utilized for improvement in growth and wool yield and quality by several agencies worldwide. Some efforts have yielded good results; however at several fronts, failure was tested by the workers. The main reason for failure to use the crossbred germplasm was adaptability of the newly developed synthetic strain to the existing climatic conditions which were usually hot, arid or hot, and humid. In developing countries experiments showed that crossbreds required very high plane of nutrition to maintain themselves, and if they are managed on the same feeding regimen akin to natives, the differences which were conspicuous up to 6-month age became marginal at the age of 1 year for body weight traits. Due to insufficiency of required high plane of nutrition, mutton-type strains developed by crossing Suffolk, and Dorset with the indigenous breeds of India could not outdo the natives under village management conditions. Sheep breed of temperate origin has little significance with respect to improving production under climate change especially in hot climate. The data generated in temperate breeds showed that there is a linear decline in birth weight of Rambouillet lambs born to dams maintained under organized feeding and management regime over generations from VI to XI, while in Suffolk lambs, the effect is noticed from the second generation onward (Singh and Karim 1995). This experience counts a lot for planning such strategies in the future.

The main aim of futuristic crossbreeding programs will be adaptability to harsh climate with a margin of profit for production profile. This will certainly have a better future as breeds already adapted to hot, arid, humid, and related stressful areas with better production profile will be used for the breeding programs as donor breeds. As discussed earlier, the worm load resilience in Garole sheep and many coastal sheep breeds, heat tolerance, water deprivation management quality in most of the breeds of western Rajasthan in India and Sudan in African continent, traits for migratory quality, and yet unknown germplasm need to be thoroughly reviewed and researched for their unique characteristics. However, this approach needs a scientific breeding plan and huge inflow of funds from government and other funding agencies. Crossbreeding, given its scientific merit and correct hypothesis, can bring better gains in less time as compared to pure breeding, which is difficult and time-consuming and puts a lot of compromise on production front. Awareness of agricultural ministry and media across the globe is required to start a holistic approach in this regard.

2.5.1.3 Molecular Breeding and Introgression

This approach has futuristic applications, given the advancement of technologies for targeted breeding programs. In the past, crossbreeding with a targeted breeding approach has seen fruitful results for traits governed by major gene (fecundity in sheep); however given all its merits, crossbreeding is a time-consuming method of introgression for stabilization of transgressed gene in the synthetic population. With advancement of molecular techniques, breeders will have another tool for promoting alleles by genome editing in sheep breeding programs. There have been efforts by researchers that resulted in targeting of specific genes of interest, such as myostatin (MSTN), the double muscling gene in cattle, sheep, and pigs; POLLED allele in cattle; and RELA, a gene that may confer resistance to African swine fever in pigs (Hickey et al. 2016). The main techniques which edit the genome precisely include ZFN (zinc finger nucleases), TALEN (transcription activator-like effector nucleases), and CRISPR (clustered regularly interspaced short palindromic repeats). Using the best bet technique CRISPR, fixing of favorable alleles for monogenic traits can be positively applied by animal breeders; however, the question remains: how many traits which are important from climate change point of view are actually controlled by major gene? Usually traits are polygenic in nature and hence are complex for modification. Efforts with regard to HSP (heat shock proteins) and disease-resistant genes can augur a better future. Efforts in this direction are required from scientific community in general and funding agencies in particular.

2.5.2 Nutrition, Housing, and Management Interventions

Energy intake is the primary requirement of animal for survival and thereafter production. Climate change as discussed above is expected to bring with it an array of diversified problems, and dealing with all of them will require a multitasking approach. Nutrition, being a basic need, must be looked from the perspective of continuous energy supply to the animal. This requires tremendous efforts from people and government alike. Apart from several conventional approaches in nutritional mitigating methods, non-conventional resources for energy and protein requirements must be searched and utilized. It is a routine practice in arid and semiarid region, to store the feed and fodder for supplementation in the scarcity period within a year. Usually, rain-dependent regions have a problem of shortage of grazing resources for nearly 6 months or so during a year. This shortage may spread worldwide, and hence the mechanism to combat such stress shall be to store the feeding resources in availability season for its utilization in the scarce period by making hay, stacking or piling of the fodder, silage preparation, etc. Similarly effective utilization of the available feed resources by chaffing the available fodder and utilizing the newer feed resources is also one option. Rehabilitation of grazing lands by perennial grasses resistant to water scarcity in dry areas, development of silvopasture, and planting suitable fodder trees, bushes, and grasses for round-the-year forage supply to animals will ease the fodder scarcity in dry zones (Jakhmola et al. 2005). Plantation of trees for fodder and shadow is essentially required. This will not only provide shadow and feed in terms of tree lopping but also serve as the best bet for reversing the negative impact of climate change. Developing nutritional strategies, which not only support yield but also address metabolic and physiologic disturbances induced by heat stress, will help the sheep to maintain a normal metabolism for enhancing performance (NRC 2001).

Building of sheds which are open on both the ends is useful for dissipation of heat and cooling of the animal shed. Shade against direct solar radiation can be provided by either trees like banyan or house made of straw, thatch roof, and other locally available cooling materials. It is always evident that the animals kept outside during summer are comfortable under tree shade during peak hours of the day (Buffington et al. 1983). For tropical climate condition, loose housing system is considered most appropriate (Hahn 1981). The longer side of the animal shelter should have an east-west orientation reducing the amount of direct sunshine. Several novel approaches in housing management in heat stress climate can be applied. Ruminants may play a key role to the well-managed, mixed crop-livestock systems and may help in reducing the number of environmental impacts (Lemaire et al. 2014). Well-managed grazing can also improve the soil organic carbon and nitrogen reserves (Franzluebbers and Stuedemann 2010) and partially offset net GHG emissions (Soussana et al. 2010). Routine practices such as grazing management and watering management during harsh weather need to be logically adapted to the present conditions. Avoiding scorching heat is logical; similarly avoiding enhanced reproductive demand per sheep in the resource-deficient period of the year is also logical. We must ensure that the man-animal relationship is important and beneficial if it works two-way. Sheep has played a significant role in man's happiness index. Reducing the stresses on sheep shall stand as priority before we demand more production.

Nevertheless, climate change has brought a lot of challenges for us to tackle in the future, but it has hidden opportunities for opening new facets of the sheep breeding and management. We have a chance to mitigate the effects of the climate change and to sustain the animal genetic resources. The need to search for alternate feed resources for sheep, strategies to exploit heat tolerance, disease resistance, disease control, strategic crossbreeding, and preserving and expanding the CPRs are challenges that will lead to knowledge-based revolution in this century which is essentially required to counteract the unforeseen impact of climate change on sheep husbandry.

2.5.3 Technological Interventions

The last few decades has seen a tremendous change with respect to the use of information technology in all aspects of life. Prediction of weather has been one of the beneficiaries in developed part of the world, where minute-to-minute forecast of weather is available to end user. The use of such technology for prediction of weather, especially erratic rainfall, change in THI, cyclones, etc., is essentially required for farmers in the developing and least developed part of the world. Tropical region has a lot of variation form place to place and time to time with respect to climate. Age-old systems of local calendars for prediction of rainfall and other important events are not working accurately these days. Use of IT and advancement of meteorological science for accurate predictions is the need of the hour.

2.6 Conclusion

Sheep husbandry has seen many upheavals since ages. The demand of man has been more and the selection pressure on sheep has seen its impact. Today we have a diverse array of sheep germplasms which has specialization in either meat, wool, milk, or all products for utilization. Sheep sector for growth, meat, and wool production is under stress owing to carbon emission, competition for land and water resources, shrinking CPRs, low profits due to unorganized nature of this sector, and many other factors. Stressors of varied nature have potential to shrink the production followed by other harmful impacts on sheep husbandry. There is a need to assess the existing sheep biodiversity especially in developing and least developed part of the world, where controlled sheep industry can’t be practiced in the near future. Looking for the unique traits, breeding toward holistic sheep improvement goals linked to human demand and sheep welfare in the umbrella of changing climate needs attention. Concentrated efforts of sheep scientists, climate scientists, media, and government alike are required to create awareness and start the mitigating strategies for breeding sheep in climate change era. The importance of sheep produce and sheep as a sustainable livelihood option for most of the landless, marginal, and small farmers across the globe needs to be realized at every scientific and political platform for the better future of sheep husbandry in the near future.

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3

Impact of Climate Change on Sheep Reproduction

Davendra Kumar, Kalyan De, Veerasamy Sejian,
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Abstract

The climate is changing faster than the predictions, with expectations of more frequent warm spells, heat waves and heavy rainfall in the future. The magnitude of these will depend on the geographical features of that region. The extreme environmental conditions due to change in climate will impose various stresses on sheep and consequently will adversely affect their reproductive performance. Animals will experience heat stress due to high temperature and more solar radiation, and nutritional stress due to reduced quantity and quality of feed because of low rainfall, more droughts, poor crop yields and less pasture growth. Reproduction is a complex process that involves a timed sequence of physiological and psychological events governed by hormones, metabolites and environmental signals. In both the sexes, these events are very sensitive to high temperature and under-nutrition. Nearly all the reproductive processes such as gametogenesis, puberty, gamete transport, fertilization, early embryonic development, maternal recognition of pregnancy, gestation, parturition and post-partum recovery are influenced by environmental stresses either directly by affecting the functions of reproductive organs or by blocking the hormone-mediated cellular functions of the hypothalamic-pituitary-gonadal (HPG) axis. Sheep husbandry is the main activity of livelihood security of large populations in hot arid and semi-arid climates and is based on grazing. Sheep often have to

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walk long distances under hot solar radiation and they experience deprivation of feed for short or long periods. The potential effects of climate change on sheep reproduction would be increased incidence of reproductive disorders such as delayed puberty, fertilization failure, embryo mortality, retardation of foetal development and growth, abortion, and premature or still birth, culminating in low reproductive efficiency of animals. Further, climate change may affect seasonal breeding in sheep due to mismatch of nutrient availability with commencement of reproductive activities.

Keywords
Climate change • Embryo • Oestrus • Estradiol • Heat stress • Reproduction

Contents

3.1 Introduction

The change in climate is faster than the predictions of the Intergovernmental Panel on Climate Change (IPCC) models (Rahmstorf et al. 2007). Various predictive models have been given by climatologists for different climatic measures like temperature, precipitation, wind, ocean current, sea ice, permafrost, etc. The IPCC has estimated an increase in the frequency of warm spells, heavy rainfall, drought, tropical cyclones and high tides. The magnitude of these will depend on the geographical features of that region. Higher latitudes will experience maximum rise in temperature (Solomon et al. 2007). The rise in temperature, at least up to 3 °C, will reduce crop yield in tropical dry regions, while it will increase pasture growth in temperate regions (Easterling et al. 2007).

The extreme climatic conditions will impose various stresses on animals which will adversely affect their production and reproduction. The important environmental stresses include (1) heat stress due to high temperature and more solar radiation (Nielsen et al. 2013) and (2) nutritional stress due to reduced quantity and quality of feed because of low rainfall, more droughts, poor crop yields and less pasture growth (Niggol Seo 2010). These stresses will seriously affect animals reared under extensive and semi-intensive production systems compared to intensive production system. The effects of heat stress will be aggravated by high relative humidity.

Reproduction is a complex process that involves a timed sequence of physiological and psychological events governed by hormones, metabolites and environmental signals. Nearly all the events of reproduction including gametogenesis, puberty, gamete transport, fertilization, early embryonic development, maternal recognition of pregnancy, gestation, parturition and post-partum recovery are influenced by environmental factors such as temperature, humidity, photoperiod, water availability and quality, and nutrition. These factors may act alone or in combination. Any change in these environmental factors due to climate change will adversely affect reproduction directly by affecting the functions of reproductive organs or by blocking the hormone-mediated cellular functions of the HPG axis. Thus, the anticipated effects of climate change would be delayed puberty, defective gametes, aberrant expression of sexual behaviour, fertilization failure, early embryonic mortality, retardation of foetal development and growth, abortion and premature/still birth. The incidence of these reproductive problems will increase due to change in climate, culminating in low reproductive efficiency of animals.

Sheep husbandry is a major source of income of landless, marginal and small farmers, especially in arid and semi-arid climatic conditions. In these areas the animals often have to walk long distances under hot solar radiation, and they experience deprivation of feed for short or long periods. When the body is exposed to high external thermal temperatures, the core body temperatur increases beyond the physiologic homeostatic range, and thus the animal is considered to be exposed to heat stress. The thermal neutral zone varies between 20 and 30 °C for hair sheep, and the upper critical temperature is equal to 34 °C (Paim et al. 2013). For European sheep, lower critical temperature is −2 °C for adults and 29 °C for lambs, and upper critical temperature is equal to 32 °C and 30 °C, respectively (Paim et al. 2013). Each degree increase in upper critical temperature can be detrimental to the survival of these animals (Sejian et al. 2013). The impact of nutritional stress isstronger than that of heat stress (Mysterud et al. 2001). In this chapter the detailed effects of heat and nutritional stress, alone and in combination, on male and female sheep reproduction are described.

3.2 Impact of Climate Change on Seasonality of Sheep Reproduction

It is likely that climate change affects seasonality, which will ultimately influence seasonal reproduction in sheep. It is well known that the domestic sheep (*Ovis aries*) is seasonally poly-oestrous and spring is the most favourable time for lambing. Photoperiod (day length), breed and nutrition will determine the length of the breeding season. In temperate zones most sheep breeds show anoestrus during spring and summer and start cycling as the length of daylight decreases during fall. In the tropical zones where there is minimal variation in day length, indigenous sheep have a propensity to breed throughout the year (Mittal and Ghosh 1980).

However, high environmental temperature and feed scarcity may restrict sexual activity during some parts of the year in the tropics.

Seasonal reproduction ensures that lambs will be born in the spring or early summer when grass is available maximally in both quality and quantity. In the ewe, this involves an annual cycle of sensitivity of the gonadotropin-releasing hormone (GnRH) pulse generator to negative feedback by oestradiol. The sensitivity of the GnRH neurons to oestradiol increases on exposure to the long days of summer, thereby depressing GnRH pulse and inducing seasonal anoestrous. However, exposure to the shortening days of autumn will decrease the sensitivity of the GnRH neurons to oestradiol, thereby inducing oestrous cycles (Woodfill et al. 1994; Malpaux et al. 2002). Photo responsiveness is enforced by photoperiod down to about 30° latitude, below which it gradually becomes less responsive until it is lost in the mid- to deep tropics. This depends on breed; for example the Suffolk, a temperate breed of domestic sheep, can react reproductively to seasonal variation in photoperiod typical of 19°N (Arroyo et al. 2007) but, as expected, the same breed shows no response on continuous exposure to an equatorial climate having 12 h of light per day (Jansen and Jackson 1993).

Photoperiodic sensitivity is not necessarily the same in males and females. Testicular stimulation in the ram begins 1.5–2 months earlier than the ewe under annual variations (Ortavant et al. 1988). Testicular growth of Merino rams responded to photoperiod, but nutrition dominated these responses. However, in Suffolk rams, changes in testicular size can be completely out of phase with changes in body mass because they are driven primarily by photoperiod, with only subtle responses to changes in diet or nutrition. The testicular growth cycle in the Suffolk rams was driven by changes in the secretion of gonadotropins. In contrast, the seasonality of testicular growth cycle in Merino rams is driven nutritionally, associated primarily with changes in body mass, and thus this relationship cannot always be explained by changes in gonadotropin secretion. Nutrition and food supply do not influence melatonin secretion. This is well explained by ‘Mediterranean’ and ‘temperate’ genotypes, which have similar endogenous rhythms in melatonin secretion that are similarly modified by photoperiod but, in terms of seasonal changes in nutrition, they differ in both the physiological mechanisms that mediate those responses and the nature of their reproductive response (Martin et al. 2002).

Seasonality of reproduction might be influenced by global climate change. Ambient temperature and feed and fodder availability determine energy balance, and variation in energy balance is the vital cause of seasonal breeding in animals. The metabolic fuel hypothesis suggests that the circulating levels of oxidizable metabolic fuels such as glucose and fatty acids are monitored by the cells in the area postrema of the hindbrain (Schneider 2004; Wade and Jones 2004). This metabolic fuel is essential to support functions such as basic cellular, tissue and organ activities necessary for homeostasis, thermo-regulation, growth, and reproduction. Insufficient metabolic fuel in circulation is transmitted to the forebrain via catecholamine and neuropeptide Y projections where they slow down the GnRH pulse generator either directly or indirectly via corticotrophin-releasing hormone. This hypothesis is supported by considerable data including a solid demonstration that low circulating levels of metabolic fuel like glucose do indeed suppress the activity of the GnRH neurons (Zhang et al. 2007). However, the mismatch hypothesis predicts that reproductive success is maximized when animals synchronize their reproduction with the food supply. Invariably, both the hypotheses signify the importance of nutrition in GnRH pulse generation. Climate change is altering environmental conditions and thereby fodder availability, and there is concern that animals will not be able to synchronize their reproduction with changing food supply. This is well supported by the report that sheep populations that feed on vegetation of less predictable growth patterns ('desert type') have lengthy lambing seasons, while sheep populations that feed on vegetation exhibiting more predictable growth patterns ('alpine type') have shorter lambing seasons, typically two oestrous cycles in length (Bunnell 1982).

3.3 Impact of Heat Stress on Sheep Reproduction

Hyperthermia adversely disrupts the reproductive processes in the male and female, with the most pronounced consequences being decreased fertility in females and reduced quantity and quality of sperm production in males.

3.3.1 Impact of Heat Stress on Ewe Reproduction

Fertility of ewes were found to be improved if the breedable rams are maintained at cooler temperatures during the summer months; however, abnormally high embryonic loss (Dutt and Simpson 1957) indicates that some factors causing decreased fertility may be associated with the female reproductive system. The mechanism of action of heat stress on ewe reproduction is shown in Fig. 3.1.

3.3.1.1 Oestrus Intensity and Duration

In general, heat stress decreases the duration and intensity of oestrus in ewes. Exposure of Rambouillet cross ewes to severe heat stress from day 12 of the oestrous cycle can significantly extend the length of the cycle (Dutt 1963), and this could be due to a slower rate of follicular maturation after regression of corpus luteum. In addition, heat stress can influence the onset of oestrus (Sejian et al. 2011). Oestrus occurrence has been reported to derease on exposure of ewes to high ambient temperatures 1.5–6 days prior to oestrus (Sawyer 1979). The potential reason for the delay of onset of oestrus in ewes after exposure to heat stress is alteration in the pulsatile release of luteinizing hormone (LH) and decrease in estrogen secretion. An alteration in the frequency and amplitude of LH pulses from the pituitary may be due to reduced GnRH release patterns (Dobson and Smith 2000). This would result in abnormal ovarian functions. Furthermore, heat stress alters follicular development and dominance, thereby decreasing estrogen secretion (Indu et al. 2014). High plasma progesterone concentration due to heat stress could impact reduced oestrus percentage and duration during summer months (Sejian et al. 2011). In contrast,

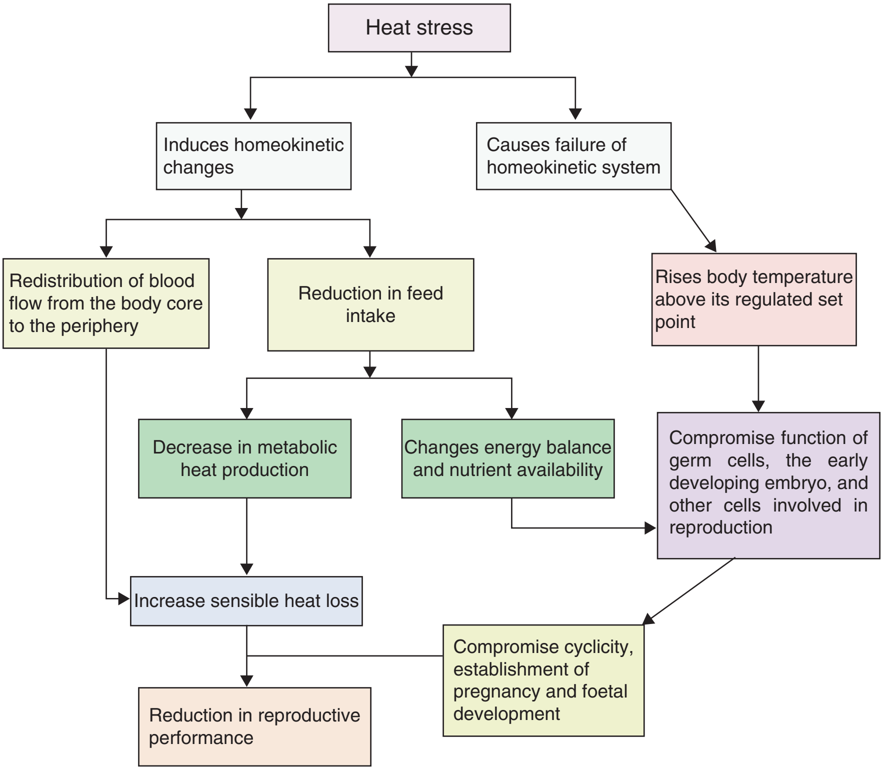

Fig. 3.1 Mechanism of action of heat stress on reproductive performance

Bell et al. (1989) reported that chronic exposure to heat stress reduced plasma progesterone concentration in ewes.

3.3.1.2 Sexual Behaviour

Heat stress reduces the normal manifestation of different sexual behaviours (Maurya et al. 2005), thereby decreasing the productive potential of animals. The variation in the pattern of sexual behaviour occurs in ewes during oestrus, i.e. perceptivity (active search of ram) and receptivity (stands to be mounted by ram) (Banks 1964). However, in Merino sheep, sexual behaviour includes circling, tail fanning, head turning, standing and approaching ram (Lynch et al. 1992).

3.3.1.3 Oocyte Maturation

The process of maturation of oocyte is a complex event and involves nuclear, cytoplasmic and molecular maturation. *In vivo* maturation of oocyte begins with the resumption of the meiotic process, which is facilitated by cumulus cells. The non-hormone-mediated meiotic induction is brought about by calcium ions present in cumulus of oocyte (Webb et al. 2002). Many research findings have concluded that the exposure of oocytes to high temperatures induced DNA fragmentation in oocytes prior to fertilization. One study found that exposure of oocytes to elevated temperature (41.8 °C) for 12 h reduces their potential to complete nuclear maturation and post-fertilization development. Heat stress may alter the biochemical composition of follicles, which indirectly affects the quality of granulosa cells and developmental competence of oocytes. Molecular changes that occur during oocyte meiotic maturation would affect the developmental competence of later-stage embryos.

3.3.1.4 Fertilization and Embryo Development

Exposure of ewes to 32 °C temperature on the 12th day of the cycle before breeding reduces the percentage of ova that are fertilized (Dutt 1964). Similarly, Thwaites (1971) and McWilliam et al. (2004) reported reduced conception rate and fecundity in ewes following heat stress. On the other hand, Dutt (1963) reported that exposure to high ambient temperature 24 h prior to fertilization has no influence on the fertilization rate but increases the incidence of embryonic abnormalities in ewes. Similarly, exposure of crossbred ewes (Bharat Merino) to heat stress (40 °C and 58.4% RH) of 6 h/d (10.00–16.00 h) for 4 weeks did not affect fertilization rate; however, the quality of recovered embryos was relatively poor (Naqvi et al. 2004). Harmful effects of high ambient temperature are more pronounced on the sheep zygote, especially during the initial stages of cleavage before it enters the uterus (Dutt 1964). Dutt observed that in ewes exposed to 32 °C one day after breeding, all ova were cleaved; however, 30.8% were morphologically abnormal. In the control group, 87.5% ewes lambed, but none of the ewes exposed to 32 °C before or at time of breeding lambed. In ewes exposed to 32 °C at 1, 3, 5 or 8 days after breeding, the percentage of lambing was 20%, 35%, 40% and 70%, respectively. Embryo mortality was significantly higher for all ewes exposed to heat stress except those in the 8-day group.

3.3.1.5 Effect on Superovulation

Superovulatry response of sheep in the multiple ovulation and embryo transfer programme was influenced by heat stress (Gordon 1997). Ewes exposed to heat stress produced embryos with relatively poorer quality than ewes that were not exposed to heat stress (Naqvi et al. 2004).

3.3.2 Impact of Heat Stress on Ram Reproduction

The intensity of heat stress varies not only between breed types but also between rams of the same breed, which appears to be due to differences in the ability of the individual animal to maintain testis temperature as well as an inherent susceptibility of the different germ cells (Arman et al. 2006). Merino rams with heavy skin wrinkle have a relatively poor ability to control testicular temperature during heat stress (Marai et al. 2006). Awassi rams showed a potential for heat stress adaptability, and this was evident from the reversal of adverse effects of heat stress on semen characteristics after subsequent heat exposure (Abi Saab et al. 2011); this could be due to the development of more efficient mechanisms for cooling their testes. When semen

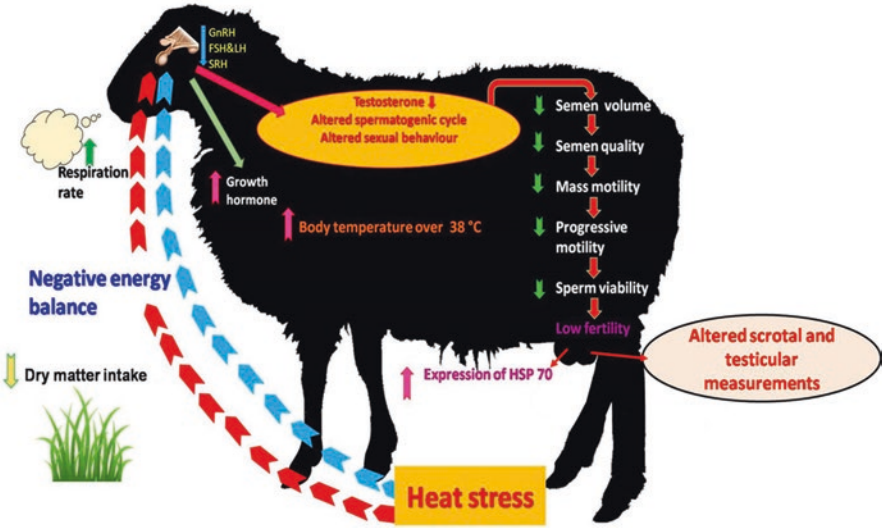

Fig. 3.2 Impact of heat stress on the reproduction performance of rams

quality is reduced by high ambient temperature, several weeks in the thermo-neutral environment are needed before semen quality returns to normal. Fig. 3.2 describes the impact of heat stress on the various ram reproductive variables.

3.3.2.1 Scrotal and Testicular Morphology

Scrotal circumference and testicular consistency, tone, size and weight are excellent predictors of sperm production capacity and spermatogenic functions. These testicular measurements get reduced under heat stress due to the degeneration of the germinal epithelium and partial atrophy in seminiferous tubules (Maurya et al. 2016) of testicles. A decrease of about 50% in the weight of rams' testes occurred 21 days after testicular exposure to 42 °C for 45 min (Setchell et al. 1991; Hochereau-de Reviers et al. 1993). The effect was more pronounced in rams exposed to a hot environment for 14 days, which is reflected in reduction in the weight of testes to about 70% of control values (Gomes et al. 1971). Abi Saab et al. (2011) reported that testicular volume decreased, whereas testicular circumference was not affected by heat stress in rams.

3.3.2.2 Spermatogenesis

The testes of most mammalian species are placed extra-abdominally in the scrotum and function at a temperature that is a few degrees lower than normal core body temperature. This is achieved by a complex thermo-regulatory system in the testis brought about by an arterio-venous plexus called the pampiniform plexus. The pampiniform plexus will regulate the testicular temperature by counter-current exchange of heat from warm blood entering the testis and cool blood draining from the testis. The degree of cooling is further controlled by two scrotal muscles: the tunica dartos that regulates scrotal surface area and the cremaster muscle that controls the relative position of the scrotum to the body. The low intra-testicular temperature is necessary for spermatogenesis, and any disruption to the thermo-regulatory system of the testis may cause problems in spermatogenesis.

Heat stress disturbs spermatogenesis through elimination of spermatogonial germ cells in the seminiferous tubules and degeneration of Leydig and sertoli cells. It is thought to be due to hypoxia-induced oxidative stress and consequently germ cell apoptosis and DNA strand breaks (Perez-Crespo et al. 2008) in pachytene spermatocytes and round spermatids (Lue et al. 2002). Germ cell apoptosis may involve reactive oxygen species, p53–the tumour suppressor protein, nitric oxide synthase, the translocation of the proapototic factor Bax from the cytoplasm to a perinuclear position, the release of cytochrome-c from mitochondria and several caspases. Spermatocytes and spermatids are relatively susceptible to heat compared to spermatogonia due to the fact that spermatogonia are less active and their number remains unchanged and the morphological characteristics are less sensitive to heat exposure (Yin et al. 1997; Lue et al. 2000). Additionally, the testis is able to be repopulated with germ cells following a relatively brief or mild temperature exposure (Lue et al. 1999; Yin et al. 1997). The effects of heat on the spermatogonia seem to be dependent on the method, temperature, duration of heat application and the livestock species. In rams, thermal stress reduces the expression of sperm surface protein PH20 between 17 and 31 days after insulation of the scrotum for 24 h, although there were minimal effects on the distribution of the activity on the sperm head (Fleming et al. 2004).

3.3.2.3 Seminal Attributes

Changes in the testicular temperature will not bring an instant change in semen characteristics because damaged spermatogenic cells take some time to enter the ejaculate following heat stress. The changes in seminal attributes appear between 7 and 14 days after heat exposure, and the values would return to normal between 30 and 42 days post-treatment (Dutt and Hamm 1957; Moule and Waites 1963; Smith 1971). Heat stress is usually followed by seminal degeneration and leads to reduced output of sperm, decreased sperm motility and an increased percentage of morphologically abnormal spermatozoa in the ejaculate and ultimately cessation of spermatogenesis (Marai et al. 2006; Maurya et al. 2016). However, reports on the effect of heat stress on the quality of semen are conflicting where a decrease (Hafez 1968; Abi Saab and Sleiman 1986; Abi Saab et al. 2011) or no effects (Degen and Shkolink 1978) of increased temperature on semen quality are reported. Abi Saab et al. (2011) reported that sperm concentration and progressive motility decreased whereas semen volume increased with ambient stress but not testicular heat stress. Sperm abnormalities due to heat stress are restricted in the acrosomal and mid-piece regions, but not the tail (Abi Saab et al. 2011). In addition, several authors have reported seasonal changes in semen production and quality in different breeds of sheep (Hafez et al. 1955; Kumar et al. 2012).

3.3.2.4 Fertility and Fertilization

The effects of heat stress on the fertility of rams are well-known phenomena but the effects would vary widely between individual animals, and in terms of the extent of acclimatization. The ram's fertility may be retained satisfactorily throughout the year; however, breeding the ram in the hot months of the year is associated with depressed fertility (Hafez 1987). A high proportion of rams could remain sterile during the summer, especially under high humid conditions. The reason for conception failure in ewes mated to heat-stressed ram was related more to fertilization failure than to embryonic mortality (Curtis 1983). Fertility of the rams is ascribed by the ability to mate, sex desire, total sperm production and viability, and fertilizing capacity of ejaculated sperm, which are influenced by elevated ambient temperatures.

3.3.2.5 Embryonic Development

Probably the most unforeseen aspect of the effects of heat on the male is the possibility of its effect on the development of embryos, despite ensuring the ova from a normal female. There are a number of scientific studies stating that males exposed to heat can produce sperm which fail to produce normal offspring in unexposed females. This is evidenced by a study on mice exposed to hot environments where sperm bind to ova normally but have less ability to fertilize *in vivo* and *in vitro*, even after selecting the motile sperm by a swim-up procedure, and many of the resultant embryos failed to develop normally. In sheep, Dutt and Simpson (1957) reported that embryonic mortality dropped by 27% when rams were maintained in air-conditioned chambers during the summer months. Mieusset et al. (1992) stated that ewes inseminated with frozen-thawed semen which was collected from rams 4 days after the beginning of scrotal insulation showed a greater loss of embryos between day 17 and day 65 of pregnancy, although the loss became more evident when the semen was collected 11 or 18 days after the start of scrotal insulation. This may be due to the fact that epididymal spermatozoa as well as cells developing in the testis may be affected in such a way as to affect the developmental capacity of the embryos they produce, as the mating achieved after a few days of insulation would involve spermatozoa already in the cauda epididymis. The development of IVF-derived sheep embryos using semen from scrotal-insulated rams was slightly less than those obtained with control semen, and there was significant degeneration at the blastocyst stage (Ekpe et al. 1992, 1993).

3.3.2.6 Testosterone Concentration

Heat stress causes decline in circulating concentrations of testosterone; however, the concentrations are restored within two weeks even in cases of continued heat stress. The level of testosterone in testes fell from 1.1 to 0.4 μg/gm and spermatic vein plasma content from 8.2 to 1.9 μg/dl when rams were exposed to an average environmental temperature of 30 °C for 14 days (Curtis 1983). The low serum testosterone level was also reported during hot environmental conditions in Ossimi rams (El-Darawany 1999) and during experimentally controlled heat stress in Malpura rams (Maurya et al. 2016). However, direct exposure to high ambient temperature had no significant effect on testosterone production in growing ram lambs during non-breeding season (Rasooli et al. 2010). The above studies may reveal the sensitivity of Leydig cells to heat stress in mature rams.

3.4 Effects of Nutritional Stress on Sheep Reproduction

Adequate nutrition is required for the functional integrity of the endocrine and reproductive system. It has been shown that chronic and acute starvation, decreased quantity and quality of protein, calorie restriction, and also vitamin and mineral deficiencies induce nutritional stress and alter endocrine gland function and reproductive performance of sheep. Reproductive performance of growing animals appears to be more susceptible to nutritional stress than that of the adults, and severe restriction in feed may even result in permanent damage to gonadal and neural tissue. In general, the effects of nutritional stress are reversible as re-feeding the previously under-fed adult animals usually restores reproductive function.

The level of leptin in blood decreases in nutritional deficiency. This acts on the appetite control centre in the brain and increases neuropeptide Y (NPY) which acts on the hypothalamus and brings change in the responsiveness of the GnRH pulse generator to the negative feedback through mechanisms that are independent of the opioidergic neurons. The nutritional factors exerting these effects have not been fully identified. Candidates include the volatile fatty acids and intra-hypothalamic insulin, both of which affect GnRH pulse frequency, thereby affecting all the reproductive organs that control specific events of reproduction. However, changes in glucose supply do not seem to be involved in controlling the responsiveness of the GnRH pulse generator.

3.4.1 Effects of Nutritional Stress on Ewe Reproduction

The sheep is a well-known seasonal breeder, and its reproductive activity is clearly controlled by photoperiod and is further modulated by nutritional status. In a given season, sub-optimal nutrition is associated with decreased reproductive performance: delayed onset of puberty, anovulation or delayed post-partum ovulation, and increased embryo mortality (Robinson 1996; Abecia et al. 1999). This is particularly relevant in extensive farming systems, like in arid and semi-arid climatic conditions, where the animals seasonally experience under-feeding because of wide variations in natural feed resources.

3.4.1.1 Folliculogenesis, Oestrus Response and Duration

Development of ovarian follicles slows down on subjecting the ewe to undernutrition and negative energy balance (Yaakub et al. 1997; O’Callaghan et al. 2000; Rae et al. 2001; Pitta et al. 2005), ultimately affecting oestrus response and duration in sheep (Maurya et al. 2004; Sejian et al. 2014). However, Borowczyk et al. (2006) did not notice any effect of under-nutrition on the number of visible follicles.

Restricted feeding of 30% less *ad lib* intake significantly reduced the duration of oestrus (15 vs 26 h) and increased the oestrus interval (31.5 vs 18.6 days) in Malpura sheep (Maurya et al. 2004), but the effect was more pronounced at restricted feeding of 40% less *ad lib* intake (Sejian et al. 2014). Vinoles et al. (2005) suggested that the mechanism by which short-term nutritional supplementation affects follicle development may involve responses to increased concentrations of glucose, insulin and leptin, acting directly at the ovarian level. It was further found that short-term nutritional supplementation does not involve increase in concentration of follicle stimulating hormone (FSH). The effect is acute, since concentrations of all three substances decrease after reaching peak values on the third day of supplementation. The status of follicle development at the time of maximum concentrations of glucose and metabolic hormones may be one of the determining factors to conclude whether ovulation rate increases or not.

3.4.1.2 Oocyte Quality and Embryo Development

Under-nutrition, resulting in lower body weight and body condition scoring (BCS), has a negative impact on quality of oocyte, which results in lower rates of cleavage and blastocyst formation in ewes (Robinson et al. 2002; Borowczyk et al. 2006). However, the total number of oocytes, number of healthy oocytes, number of cleaved oocytes and morula formation remain unaffected by under-nutrition (Borowczyk et al. 2006). In agreement, low-energy diets decreased cleavage rates compared with supplementation of high-energy diets (Papadopoulos et al. 2001). In contrast, a positive effect of under-nutrition on oocyte quality and embryo development in superovulated ewes has been reported due to increased progesterone concentration (McEvoy et al. 1995).

Nutritional status has also been correlated with embryo survival in ewes (Abecia et al. 1995) and has been documented as a key factor influencing the efficiency of animal reproduction technologies (Armstrong et al. 2003; Webb et al. 2004). Abecia et al. (1995) reported that reduced embryo survival in under-nourished ewes was not attributed to a reduction in LH secretion, inadequacies in follicle growth and development, or the capacity of corpus luteum (CL) to synthesize and release progesterone. Feeding of 50% less diet of maintenance requirement reduced follicular fluid concentration of insulin-like growth factor-1 (IGF-1), and increased follicular fluid concentration of progesterone and abnormal oocyte morphology such as premature activation of cumulus expansion and vacuolation of the nucleolus and increased frequency of detachment of interchromatin-like granules from the nucleolar remnant in superovulated ewes (O'Callaghan et al. 2000).

Deficient maternal nutrition during the periconceptional period can lead to modifications in the gene expression involved in the metabolic activity of the oocyte (Pisani et al. 2008). Ewes that fed 50% of their maintenance requirements for two weeks had reduced expression of glucose transporter 3 (SLC2A3), sodium/glucose co-transporter 1 (SLC5A1) and Naþ/Kþ ATPase mRNA in oocytes, while expression of PTGS2, HAS2 and the leptin receptor in granulosa cells was upregulated (Pisani et al. 2008). Reduced expression of SLC2A3 is potentially relevant in the light of its significant role in post-implantation embryonic development (Schmidt et al. 2009).

3.4.1.3 Fertility

Nutrition is one of the major factors affecting ovulation rate and sexual activity in sheep (Forcada and Abecia 2006; Naqvi et al. 2011). However, no effect of under-nutrition has been reported on conception rates (Abecia et al. 1999; Edwards et al. 2005; Debus et al. 2012). Ewes with the highest periconceptional weight loss had fewer twin pregnancies, confirming a negative effect of weight loss on multiple births (MacLaughlin et al. 2005). The difference in sex ratio in the singleton pregnancies in the under-fed group might be explained by sex-related differences in embryo tolerance to under-feeding (Debus et al. 2012). Lower lambing rates in ewes having 2.5 BCS compared to 3.0 BCS have been reported in various Indian sheep breeds (Maurya et al. 2009, 2010a; Sejian et al. 2010, 2015).

Under-nutrition in ewes before and after mating increases the embryonic mortality, which consequently reduces the lambing rate (Rhind et al. 1989; Smith and Knight 1998; Abecia et al. 2006). Further, under-nutrition during late pregnancy or in early post-natal life can irreversibly reduce the lambing rates of ewes (Gunn et al. 1995). In Romney ewes, under-nutrition leading to a 15% body weight loss from 60 days before to 30 days after conception was shown to induce premature delivery and accelerated foetal hypothalamic-pituitary-adrenal axis maturation (Bloomfield et al. 2003). Further, it has been demonstrated that factors other than foetal exposure to excess glucocorticoids may be important for this effect of periconceptional under-nutrition (Bloomfield et al. 2004). In contrast, maternal periconceptional under-nutrition (50% of their dietary needs from −15 to +30 days post-conception) in a hardy breed does not significantly affect pregnancy rates, prolificacy, lamb birth weight and growth rates, in contrast to earlier finding in other breeds, suggesting that caution must be taken when extrapolating programming data between breeds and breeding conditions (Debus et al. 2012).

3.4.1.4 Hormones and Metabolites

The relationship between nutrition and reproduction is complex, and it is reported that energy balance (positive or negative) is regulated by a series of complex interaction of metabolites and hormones (Scaramuzzi et al. 2006). The impact of nutritional stress on the circulating concentrations of the reproductive hormones and other nutrient-sensitive metabolites essential for the physiological function has been highlighted (Robinson et al. 2006). Changes in dietary intake would promote variations in concentrations of metabolic (insulin, leptin and IGF-1) and reproductive hormones (Polkowska 1996); consequently, this would affect the developing ovarian follicle and/or the composition of reproductive tract secretions, which provide histiotrophic nutrition to early embryos.

The levels of nutrition and peripheral progesterone concentrations are inversely related in ewes (Parr 1992). Under-fed ewes had maximum progesterone concentrations compared to normally fed ewes (Debus et al. 2003). A similar increase in progesterone concentration in under-fed ewes has been reported by other authors

(Lozano et al. 1998; Sosa et al. 2006; Wallace et al. 1997; Lekatz et al. 2010). The increased progesterone concentrations throughout pregnancy in under-fed ewes may be due to initial deposition in adipose tissue and subsequent release of the lipophilic steroid hormones (Lamond et al. 1972; Hamudikuwanda et al. 1996). Alternatively, the metabolic clearance of progesterone might have been decreased, as demonstrated in non-pregnant ewes (Parr et al. 1993a, b; Abecia et al. 2006).

Kiyma et al. (2004) reported that serum concentration of oestradiol was lower in under-nourished ewes. Decreased concentration of estrogen may result from diminished ovarian follicular development caused by suppressed peripheral concentration of gonadotropins (Gougeon 1996). Adams et al. (1994) contradicted this finding and established that food restriction is clearly associated with higher plasma concentration of oestradiol 17- β concentration in ewes. The association between heat stress and increased secretion of cortisol, the principal glucocorticoid hormone in small ruminants, is well documented (Ali and Hayder 2008). Further, glucocorticoids are capable of enhancing the negative feedback effects of oestradiol and reducing the stimulation of GnRH receptor expression by estrogen (Adams et al. 1999; Daley et al. 1999).

3.4.1.5 Gestation

The effects of under-nutrition on gestation are conflicting. Debus et al. (2012) reported prolonged gestation in under-fed ewes while Bloomfield et al. (2003) observed reduced gestation length and Cleal et al. (2007) found no effects on gestation length. The variation in the intensity of gestational effect of under-nutrition has been observed. The gestational and neonatal effects of periconceptional under-nutrition observed by Debus et al. (2012) in Merinos d'Arles ewes were much less as compared to other studies (Bloomfield et al. 2003; MacLaughlin et al. 2005; Jaquiery et al. 2006; Cleal et al. 2007) using different breeds, slightly different under-nutrition protocols and animals with different nutritional histories over several generations.

3.4.2 Effects of Nutritional Stress on Ram Reproduction

It is an established fact that the influence of nutrition on reproductive processes is mediated via effects of dietary constituents on the hypothalamic-pituitary axis, although there is some indication that dietary changes may affect the testis directly. Nutrients might directly supply substrates for the seminiferous tubules or the interstitial cells, but the absolute requirement of protein or energy for production of hormones and germ cells is small, and current indications are that the endocrine function of the testis of mature animals is poorly related to nutrition. Some nutritional regimes imposed on animals can alter volume of ejaculate and testosterone activity without necessarily affecting spermatogenesis, suggesting that certain constituents of the diet can differentially affect the production and/or the release of LH and FSH.

A series of experiments conducted in different sheep breeds in our laboratory clearly showed that nutritional stress significantly affected the sexual behaviour, scrotal and testicular measurements, sperm concentration, seminal volume, mass activity and computer-assisted sperm analysis-derived sperm motion characteristics of ram semen samples (Kumar et al. 2015). In addition, the effects of excesses and overnutrition can be as deleterious as under-nutrition. Emphasizing the importance of maintaining optimum BCS of breeding rams, Maurya et al. (2010b) reported that sexual behaviour, scrotal volume, scrotal circumference, testicular width, testicular length and scrotal skin thickness were significantly reduced in the lower (2.5) BCS group than the moderate (3.0–3.5) and higher (4.0) BCS groups. The semen volume, mass motility and progressive sperm motility were significantly higher in the moderate (3.0–3.5) BCS group and lowest in the lower (2.5) BCS group. However, the sperm concentration did not differ significantly between the groups. The mean plasma testosterone concentration differed significantly between the lower BCS group and the higher BCS groups.

The effects of nutritional stress on sexual activity of rams are generally observed only after prolonged under-nutrition resulting in marked loss in body weight. Restricted feeding of rams for 3 months resulted in a reduction of body fat to less than 12% of live weight compared with 25–49% in well-fed controls. Restricted feeding also produced a decrease in testis weight, smaller seminiferous tubule diameters and a lower number of sperm in the epididymis than in well-fed control rams (Setchell et al. 1965). The relative reduction in testicular weight was more severe than the decline in body weight. The volume of ejaculate and the motility and concentration of spermatozoa (Comstock and Brady 1937; Parker and Thwaites 1972; Oldham et al. 1978) were also markedly reduced in rams on restricted feed intake. Restricted energy intake in adult rams appears to have more of an adverse effect on accessory sex gland function, and therefore on androgen activity, than on spermatogenesis, while protein deficiency generally reduces both accessory gland secretions and semen quality.

On the basis of results from supplementation trials, Schoeman and Combrink (1987) concluded that testicular size and ram fertility are significantly influenced by the level of nutrition, and they suggested that rams should be supplemented with nutrition during the breeding season, particularly if it coincides with the summer season. Mukasa-Mugerwa and Ezaz (1992) reported significant differences in both scrotal circumference and age at puberty between Menz lambs fed on a higher plane versus those fed on a lower plane of nutrition. Naqvi et al. (2010) and Kumar et al. (2014) reported that improved nutrition was associated with increased scrotal circumference, testicular volume and semen production, and reduced age of puberty in Malpura ram lambs.

3.5 Effect of Multiple Stresses on Sheep Reproduction

The effect of two or more stresses occurring simultaneously can summate together and total impact may be severe on reproductive functions (Moberg 2000; Sejian et al. 2012; Maurya et al. 2016).

3.5.1 Effect of Multiple Stresses on Female Reproduction

In ewes, multiple stresses (heat + nutritional + walking) had a highly significant influence on oestrus duration, oestrus cycle length, oestradiol and progesterone concentration in the hardy Indian sheep breed Malpura (Sejian et al. 2011, 2012). Oestrus duration and oestradiol concentration were decreased, while oestrus cycle length and progesterone concentration increased in stressed animals. The decrease in oestrus duration could be related to the high plasma progesterone concentration in multiply stressed ewes. Presumably, therefore, the longer oestrus cycles were due to a slower rate of follicular maturation after CL regression. These authors have also observed that combined stress (heat + nutritional) had a relatively higher detrimental effect on the conception rate. The probable reason for this is reduced sex steroid receptors and altered sex steroids concentration. This view is supported by the fact that there is evidence for an inhibitory effect of under-nutrition on the number of uterine sex steroid receptors, which will in turn affect conception rate (Sosa et al. 2006). Lambing rate also showed results similar to conception rate in the combined stress group. The probable reason for low conception rate in the combined stress group is the sub-optimal progesterone concentration to maintain pregnancy as the thermal and nutritional stress were withdrawn after mating at the end of the experimental period.

3.5.2 Effect of Multiple Stresses on Male Reproduction

In rams, combined stress (heat + nutritional) had more severe effects on testicular measurement and semen production than heat stress and nutritional stress alone (Maurya et al. 2016). Maurya et al. observed that scrotal width, scrotal circumference, plasma testosterone concentration, semen volume and mass motility were significantly decreased while testicular length increased in Malpura rams exposed to combined stress.

3.6 Conclusion

The changing trend in climate due to the increasing environmental temperature affects the reproductive performance of sheep in multiple ways. Even though the sheep is a relatively thermo-tolerant species, many studies have indicated the harmful impact of heat stress on reproductive functions in both ewes and rams. Oestrus duration and percentage are decreased along with increased embryonic mortality in ewes exposed to heat stress. Likewise, in rams, there was significant reduction in testicular volume, improper spermatogenesis and altered semen production. Apart from heat stress, when the animals were subjected to nutritional stress, the ovulation rate, pregnancy rates, prolificacy, lamb birth weight and growth rates were decreased, indicating the significance of optimum nutrition for normal reproductive performance in sheep. Further, in rams, nutritional stress altered sexual behaviour and affected both the quantity and quality of the semen produced. In addition, the cumulative stress impacts, which are very common in the extensive system of rearing, were found to have negatively affected reproductive performance in both ewes and rams. It was observed that when heat stress was coupled with nutritional stress, a multifold negative impact was established in the reproductive performance of sheep as compared to individual stresses. These findings indicate that amelioration strategies involving both heat stress management and nutritional supplementation need to be developed to optimize the economic return from this wonderful species. These measures will ensure the livelihood securities of poor and marginal farmers in hot, arid and semi-arid tropical environments.

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Climate Change Impact on Immune Response in Sheep

4

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Abstract

Sheep are considered one of the most resistant species with respect to climate change and high environmental temperatures. Most studies have focused on the effects of heat stress on the physiological mechanisms of adaptation in dairy cows; few studies have dealt with dairy sheep physiology and, above all, with sheep immunological responses. This chapter will focus on the complex network of mechanisms activated by heat stress as affecting immune responses in sheep. In particular, heat stress will be discussed as an attempt to animals' homeostasis, thus affecting immune system and inducing activation of inflammatory processes. In particular, it will present a synopsis of the knowledge of the sheep immune system, and the changes induced by heat stress on both innate and adaptive immunity. Recent data suggesting a role of heat stress on perturbation of oxidative balance and the consequent effects on the immune system will be discussed. Finally, a discussion on the effects of heat stress on sheep mammary immunity will be presented.

Keywords

Sheep • Heat stress • Immune responses • Heat shock proteins • Oxidative stress

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Contents

4.1 Introduction: Heat Stress and Activation of Stress Physiological Response

Thermal fluctuations in the environment have induced organisms to acquire well-developed defense and adaptation mechanisms in order to deal with natural selection. Sheep are believed to be one of the most resistant species to climatic extremes, especially to high ambient temperatures. Nevertheless, sheep activate a number of physiological mechanisms with a compensatory intention to cope with high environmental conditions and to maintain vital functions. As a result of exposure to high environmental temperatures, and in order to dissipate heat load, animals display an increase of respiration rate due to a direct stimulation of temperature receptors into the hypothalamus (Habeeb et al. 1992; Silanikove 2000). In particular, the presence of wool coat in sheep prevents sweating, thus increasing respiratory rate as the principal way of heat dissipation (Marai et al. 2007). Severe heat stress in sheep arises when maximum air temperature exceeds 30 °C and the temperature–humidity index is over 80 for several days (Sevi et al. 2001). Lactating ewes under heat stress show increase of respiration rate and rectal temperature, and an enhancement of mobilization of body fat reserve for thermoregulation; these events suggest an impairment of animal welfare (Caroprese et al. 2012; Ciliberti et al. 2016). Subsequently, a physiological response of animals to the increased ambient temperature is the reduction of feed intake and the increase of water intake (Bernabucci et al. 2009), followed by an alteration of protein and energy metabolism, mineral balance, enzymatic reactions, and hormonal secretions (Sevi et al. 2006; Marai et al. 2007). Heat stress can activate the hypothalamic–pituitary–adrenal (HPA) axis and increase plasma cortisol secretions to make available glucose for the enhancement of energy demand to cope with heat load (Matteri et al. 2000). The glucocorticoid secretion during heat stress playss the role of stimulating hepatic gluconeogenesis by the conversion of noncarbohydrate molecules into glycogen to increase blood glucose levels. Moreover, besides the activation of the HPA axis, the thyroid gland shows hypofunctioning during heat stress with a consequent reduction of the secretion of thyroid hormones that sustain the productive performance (Todini 2007). As a result, the plasma concentration of triiodothyronine (T3) and thyroxine (T4) decreases in sheep under heat stress (Bertoni et al. 1991) in the attempt to thermoregulate.

The alteration of hormonal secretions and normal physiological functions of sheep can lead to the consequent alterations of the immune system responses and to the increased incidence of udder health problems in sheep during summer (Caroprese et al. 2012; Sevi et al. 2002). It has been demonstrated that corticosteroids can bind to DNA (Deoxyribo Nucleic Acid) and inhibit the expression of genes involved in immune responses (Sgorlon et al. 2012). In particular, it has been suggested that corticosteroids exert anti-inflammatory effects on immune responses (Rosen et al. 2001). The influence of glucocorticoids on immune responses can also occur through the release of cytoplasmic heat shock proteins (HSPs) 70 and 90, which represent the first line of defense against thermal stress and are bound to the glucocorticoid receptor (Collier et al. 2008). The effects of severe heat stress on cellular responses induced by HSPs are well known; on the contrary, there is little information regarding the effects of mild heat stress on cellular responses (Park et al. 2005). The alterations in immune responses induced by heat stress are also connected to alterations in oxidative imbalance at the cellular level (Sordillo 2013). Welfare and production performance of lactating animals under high ambient temperatures can be sustained by management and nutritional strategies. Feeding-time changes can positively affect sheep welfare under heat stress; feeding dairy sheep in the late afternoon reduced their heat production during the warmer hours of the day, when thermal balance through conduction and radiation mechanisms is less efficient, and sustained their cellular immune responses (Sevi et al. 2001). Furthermore, the protection from direct solar radiation contributes to enhanced cellular immunity by sustaining sheep thermoregulatory mechanisms (Sevi et al. 2001). Supplementation of polyunsaturated fatty acids (PUFA) in sheep diet has been investigated as a strategy to help dairy animals to cope with the negative effects of heat stress, and a large number of positive effects on thermoregulatory, physiological, and immunological mechanisms has been found (Caroprese et al. 2011, 2012, 2014). PUFA supplementation as flaxseed is able to interfere with endocrine secretions by increasing the levels of plasma cortisol in sheep under heat stress (Caroprese et al. 2012, 2014). On the contrary, nutritional stress associated with heat stress further reduces the thyroid hormone levels in sheep, suggesting the important role played by energy balance in the diet affecting thyroid gland activity and plasma hormone concentrations (Sejian et al. 2010). The complex network of changes induced in sheep homeostasis caused by heat stress and affecting immune responses is depicted in Fig. 4.1.

4.2 Sheep Immune System: A Synopsis

An understanding of the immune system structure and function in sheep is of great importance to provide information in relation to the changes induced by stressful events on immune functioning. The immune system is divided into two general compartments: innate immunity and adaptive immunity, which, however, cannot be considered independent compartments, but strictly connected. Innate immunity is responsible for defense mechanisms which are nonspecific and arise immediately

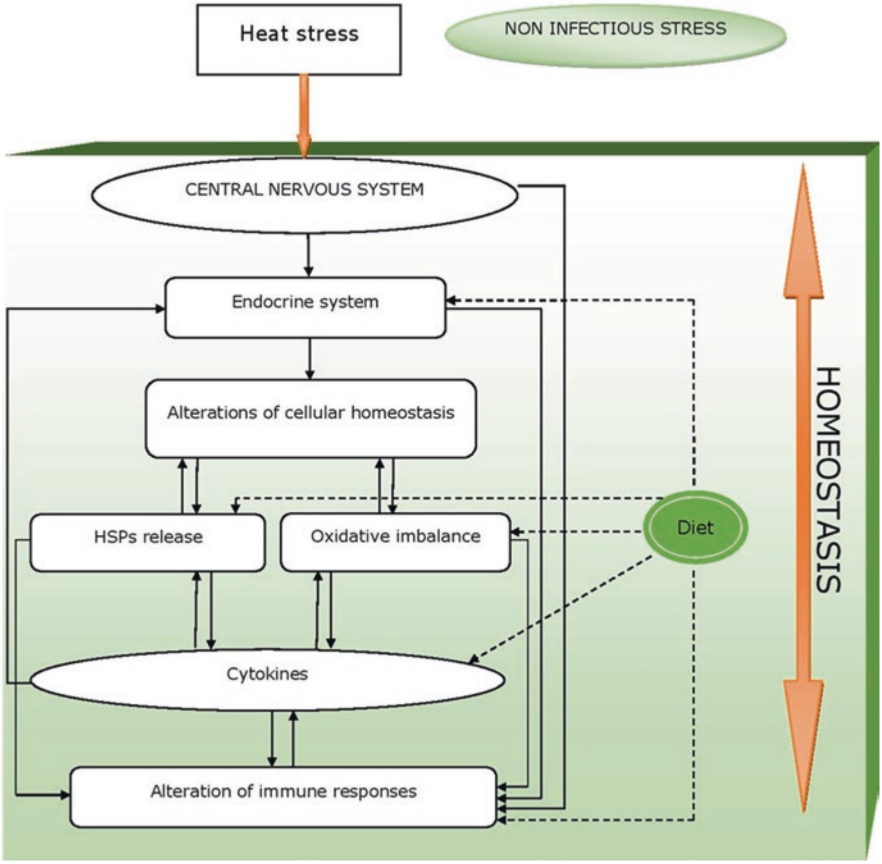

Fig. 4.1 Network of changes induced in homeostasis by heat stress and affecting immune responses

or within hours of an antigen's appearance in the body. On the contrary, adaptive immunity is characterized by defense mechanisms which are specific and based on the recognition of a specific antigen, and by the induction of responses to eliminate specific pathogens or pathogen-infected cells, and the development of immunological memory. Innate immunity includes physical barriers, soluble factors, and cells such as macrophages and neutrophils, which possess receptors for bacterial molecules. Macrophages and neutrophils play an important role in innate immunity by producing nitric oxide, synthesized by inducible nitric oxide synthase and prostaglandin E_2 synthesized by cyclooxygenase, which are some of the inflammatory mediators. Agents that are able to enter the immune barriers meet macrophages and cells possessing key molecules which recognize molecules of microbial agents named pathogen-associated molecular patterns (PAMPs). The receptors of immune cells, known as pattern recognition receptors (PRRs) include several families of molecules of which the most studied are toll-like receptors (TLRs). Each TLR is an alert signal for the immune system able to activate the induction of proinflammatory mediators as a result of the activation of the innate immune system and to initiate the adaptive immune responses. Different TLRs can tailor different responses based on the observation that different cell populations and tissue can express distinct PRRs, and the panel of PRRs expressed in different cells is also responsible for the differences in the responses of adaptive immunity (Iwasaki and Medzhitov 2004). Sheep patterns of PRRs are similar to those of humans and are quite different from those of mice. Nalubamba et al. (2007) identified all ten members of the TLR family in sheep tissue and leukocyte subsets. Furthermore, those authors found that sheep monocytes express the widest panel of PRRs, suggesting that they are the key to recognize PAMPs and to drive appropriate immune responses. Natural Killer (NK) cells play an important role in the immune system. NK cells are closely related to T-cells, but they do not express conventional T cell receptor (TCR) (or Ig) but express two classes of receptors that allow them to recognize features associated with virally infected cells or tumor cells. NK cells are found in abundance during placentation (Jabrane-Ferrat and Siewiera 2014). In sheep, a population of $CD16^{+ve}/CD14^{-ve}/perforin^{+ve}$ cells in peripheral blood was identified as putative NK cells (Elhmouzi-Younes et al. 2010). The cells of adaptive immunity are B lymphocytes (B-cells) and T lymphocytes (T-cells), which are able to recognize 10^{11} different antigens. In general, B-cells are responsible for the secretion of specific antibodies and for adaptive immunity; the antibodies secreted enable phagocytes to recognize microorganisms and destroy them by binding to antigenic sites on both extracellular microorganisms and toxins. In sheep, B-cells express PRRs, which is consistent with the hypothesis that B-cells are involved both in innate and adaptive immunity (Nalubamba et al. 2007). T-cells, which are responsible for cell-mediated immune responses of adaptive immunity, identify and destroy intracellular viruses and microorganisms. The majority of T-cells express cell-surface receptors (TCRs) consisting of α and β chains. A second group of T-cells expresses cell-surface receptors characterized by γ and δ chains. In sheep, the T19 molecule, now known as WC1, was used to phenotype subsets of cells now identified as γ/δ T-cells (Makay et al. 1989; Lund et al. 1993). The genes encoding γ and δ T-cell receptor chains exhibit lower variability than those encoding α and β T-cell receptor chains, thus suggesting that γ/δ T-cells may represent the link between innate and adaptive immunity in sheep (Hein and Griebel 2003). Though the functional significance of this event is not known yet, it may reflect the need of a quick response to particular pathogens for ruminants (Entrican et al. 2015). In contrast to other animal species, sheep display a large number of γ/δ T-cells in the blood (Hein and Mackay 1991). In perinatal and young lambs they may vary from 50 to 60% of blood mononuclear cells, and are prominent in other recirculating lymphocyte compartments; however, their number is lower, about 1–14% of resident leukocytes, in solid peripheral lymphoid organs (Hein and Peterhans 1998). In the jejunum, which are free of Payer’s patches, γ/δ T-cells are about 18% of intraepithelial lymphocytes (Gyorffy et al. 1992). Among the α/β T-cells there two different sublineages: the first one expresses coreceptor molecule CD4 (cluster of differentiation), are named T-helper cells (Th cells), and neutralize intracellular microorganisms, fungi, and parasites by interacting with other immune cells, and activating an antigen-specific immune response; the second one expresses coreceptor molecules T-CD8 and recognizes and neutralizes virus-infected cells. Th cells are further divided into two different subsets: T-helper cells type 1 (Th1 cells) and T-helper cells type 2 (Th2 cells), which are differentiated by the cytokines they produce. Cytokines are signaling molecules, and they can regulate immune responses, inflammation, trauma, and host responses to infection. Cytokines can be both secreted and restricted to the membrane of cells. The primary mechanism of cytokine action is through the upregulation of gene expression by the activation of intracellular signal transduction pathways (Gouwy et al. 2005). Cytokines have multiple functions, and they frequently have effects that overlap with those of other cytokines; furthermore, cytokines are highly potent and can elicit biological responses, even in small concentrations, due to the high affinity of their receptors (Wahl et al. 1988; Hall et al. 1989). One of the factors controlling intracellular signal transduction pathways is nuclear factor kappa B (NF-κB), a protein complex that regulates transcription of DNA, cytokine production, and cell survival, and is involved in cellular responses to stimuli such as stress, cytokines, free radicals, ultraviolet irradiation, oxidized LDL (Low-Density Lipoproteins), and bacterial or viral antigens. Although cytokines exert a central role in the host response to infection, they can possibly have deleterious effects on the host. There is a strict balance between the positive and negative effects of cytokines on the host driven by the duration, amount, and compartment of their expression (Bannerman 2009). The most studied cytokines in sheep are reported in Table 4.1.

The characterization of sheep cytokines has rapidly increased in recent years. Th1 cells including Th1 cytokine responses, mainly IFN-γ, have been associated with intracellular microorganisms, thus including the mechanisms of microbial killing and increased phagocytosis. In addition, Th1 cytokines induce the expression of adhesion molecules and chemokines, which attract mononuclear cells altering the recruitment of monocytes/macrophages and T-cells in the site of infection. Th2 cells and related cytokines, such as IL-4, IL-5, and IL-13, activate the production of neutralizing antibodies (IgG) and the mast cell/eosinophil degranulating antibody known as IgE. Besides Th1 and Th2 cells, Th17 cells are involved in the control of extracellular bacteria and fungi, and have a role in autoimmunity and chronic inflammation during pathological conditions. In sheep, recent investigations demonstrate the importance of monitoring Th-17-type response in order to understand disease pathogenesis and vaccine design (Wattegedera et al. 2015).

Table 4.1 Description of source and biological effect of sheep cytokines

Sheep cytokine	Biological effects	Source
IL-1	The IL-1 (interleukin) is a proinflammatory cytokine that plays a critical role in the host defense against infection; dysregulation of its expression can have deleterious consequences for the host. In sheep, increased IL-1β levels occur after both physiological and psychological stressors (Caroprese et al. 2010).	Monocytes, macrophages, dendritic cells, lymphocytes, endothelial and epithelial cells, and fibroblasts (Barksby et al. 2007).
IL-4	The IL-4 has variable effects on upregulation of Th cell proliferation (Estes et al. 1995). Peripheral blood mononuclear cells from both pregnant and nonpregnant ewes produced IL-4 in response to mitogen stimulation (Wattegedera et al. 2008). Sheep under heat stress display a reduction in IL-4 (Caroprese et al. 2014).	Depleting CD4^{+}cells, produce high levels of IL-4 (King and Mohrs 2009).
IL-6	Interleukin-6 modulates both innate and adaptive immunity via its ability to provoke fever, B-cell differentiation and corresponding immunoglobulin production, T-cell activation, and enhanced proinflammatory responses of neutrophils (Biffl et al. 1996; Keller et al. 1996). The anti-inflammatory properties of IL-6 are its ability to inhibit expression of proinflammatory IL-1β and TNF-α and to stimulate expression of IL-1-receptor antagonist and soluble TNF (Tumor Necrosis Factor) receptor. In sheep, increased IL-6 levels occur after physiological stressors connected with lambing and parturition (Caroprese et al. 2010).	Lymphocytes, monocytes, macrophages, neutrophils, endothelial cells, epithelial cells, and fibroblasts; its expression is induced by bacteria and viruses, as well as by cytokines, such as TNF-α and IL-1β (Biffl et al. 1996, Poll and Deventer 1998).
IL-8	Interleukin-8 is a chemotactic cytokine (i.e., chemokine) with a longer-lasting effect for its resistance to proteolytic degradation (Baggiolini and Clark-Lewis 1992). IL-8 is upregulated in response to infection to attract neutrophils, and T lymphocytes (Harada et al. 1994; Kobayashi 2008). In ewes with subclinical mastitis, the levels of IL-8 in milk samples are related to the level of somatic cells and to the presence of phytogenic bacteria (Albenzio et al. 2012).	IL-8 is produced by cells of monocytic lineage, endothelial and epithelial cells, fibroblasts, neutrophils, and T lymphocytes, and can be generated in any tissue (Matsukawa et al. 2000). Its expression is induced by both exogenous (e.g., bacteria, viruses, fungi, parasites, and products derived from these pathogens) and endogenous (e.g., TNF-α and IL-1β) proinflammatory stimuli (Matsukawa et al. 2000; Mukaida 2003).

(continued)

Table 4.1 (continued)

Sheep cytokine	Biological effects	Source
IL-10	Interleukin-10 exerts anti-inflammatory effects on monocytes, macrophages, and neutrophils by reducing their production of proinflammatory cytokines, chemokines, and eicosanoids (Moore et al. 2001). IL-10 is able to suppress the production of IFN-γ (Interferon gamma) and IL-12, which promote a Th1-type response, thus shifting the adaptive immune response to humoral responses (Moore et al. 2001; Conti et al. 2003; Mocellin et al. 2004). In heat-stressed sheep, the IL-10 secretion increases when fat supplementation is included in the diet, with a direct suppressive effect on the Th1 cell response through the reduction of the IFN-γ secretion (Caroprese et al. 2014). In addition, flaxseed supplementation enhances the IL-10 levels in sheep until 2 weeks postpartum (Caroprese et al. 2015).	IL-10 is produced by different cells such as T lymphocytes, B cells, eosinophils, mast cells, and monocytes (Asadullah et al. 2003).
IL-12	IL-12 modulates the host immune response to bacterial and parasitic intracellular pathogens. IL-12 also contributes to the activation of macrophages (Gately et al. 1998; Trinchieri 2003), and stimulates the production of IFN-γ by T-cells and natural killer cells; IFN-γ can, in a positive feedback loop, induce the production of IL-12 by phagocytes. IL-12 plays a crucial role in shifting the balance between Th1/Th2 responses by stimulating the differentiation of T-cells into IFN-γ-producing Th1 cells (Langrish et al. 2004); moreover, IL-12 alters antibody responses by affecting the production of immunoglobulins involved in mediating Th2 humoral immune responses (Gately et al. 1998). During heat stress, sheep increase IL-12 secretion, in particular when feeding on flaxseed, with the concomitant enhancement of cell-mediated immune responses and IFN-γ production (Caroprese et al. 2014). In an in vitro study, the addition of recombinant ovine IL-12 enhances IFN-γ production and has a small effect on sheep cell proliferation (Wattegedera et al. 2004).	IL-12 is produced by monocytes and dendritic cells (Langrish et al. 2004). The production of IL-12 by neutrophils has a pathophysiological role (Trinchieri 1998).
IL-13	IL-13 induces the production of immunoglobulin isotype E in human B-cells (Punnonen et al. 1993), and suppresses inflammatory cytokine production in both human and mouse systems (Malefyt et al. 1993; Doherty et al. 1993). In heat-stressed sheep, the IL-13 plasma secretion decreases, in particular in sheep supplemented with PUFA rich in EPA (eicosapentaenoic acid) and ALA (alanine); the IL-13 levels found are responsible for the impairment of humoral immune responses (Caroprese et al. 2014).	IL-13 is produced principally by activated T-cells and its expression is primarily associated with the Th2 cells (Zurawski and Vries 1994).

(continued)

Table 4.1 (continued)

Sheep cytokine	Biological effects	Source
IL-17	Th17 cells play an important role in host defense against extracellular bacteria and fungi (Chung et al. 2003; Happel et al. 2005; Huang et al. 2004), and can promote tissue inflammation and autoimmunity (Noack and Miossec 2014). In sheep, recent investigations demonstrated that IL-17 could be useful to understand diseases pathogenesis and vaccine design (Wattegedera et al. 2015).	IL-17 is produced by α/β T-cells ($CD4^+$and $CD8^+$), innate cells such as γ/δ T cells, neutrophils, NK cells, epithelial cells, and mesenchymal cells (Miossec and Kolls 2012).
TNF-α	Tumor necrosis factor-α is a proinflammatory cytokine that promotes endothelial activation, and the recruitment of leukocytes to the site of infection (Brouckaert and Fiers 1996). TNF-α provokes the induction of fever and the synthesis of acute phase proteins. In bovines, subclinical mastitis due to *S. aureus* infection is responsible for an increase of TNF-α levels (Oviedo-Boyso et al. 2007); furthermore, intermediate levels of TNF-α are registered in caprine milk when an isolation of *P. aeruginosa* is found (Albenzio et al. 2016).	Multiple cell types produce TNF-α including macrophages, lymphocytes, neutrophils, and epithelial cells (Angelini et al. 2005), but other cytokines such as IL-1 and IFN-γ and complement components are able to induce the TNF-α production.
IFN-γ	Interferon (IFN)-γ is essential for host immunity against intracellular pathogens and links the innate and adaptive immune system. Interferon-γ increases receptor-mediated phagocytosis, respiratory burst activity, and nitric oxide production, thus enhancing the microbicidal activity of cells (Ellis and Beaman 2004; Schroder et al. 2004). Interferon-γ promotes the activation of cell-mediated immunity by the upregulation of the expression of cell-surface major histocompatibility complex class I molecule (Schroder et al. 2004). In heat-stressed sheep the concentrations of IFN-γ in plasma samples decrease, demonstrating an imbalance between Th1 and Th2 cytokines under high ambient temperature (Caroprese et al. 2014).	Lymphocytes, natural killer cells, and cells of monocytic lineage (Ellis and Beaman 2004; Schoenborn and Wilson 2007) produce IFN-γ.

4.3 Sheep Immune Responses to Heat Stress

4.3.1 Heat Stress and the Intersection Between Innate and Adaptive Immunity

Stress can affect the immune system by inducing alteration of inflammatory processes. The host's inflammatory response is a survival mechanism to cope with pathogens or nonpathogenic challenges. When the induction of inflammatory response is not connected with the presence of pathogens it is termed "sterile inflammation" (Rock et al. 2010; Fleshner 2013). Inflammation in response to nonpathogenic challenges is activated by the release of tissue alarm signals named damage associated molecular patterns (DAMPs), which are host-derived molecules, normally recognized as self molecules by the innate immune system but identified as danger signals when in the extracellular space. The interaction of DAMPs with DAMP receptors, among them TLR and cytokine-1 receptor (IL-1R), leads to the activation of a number of cell signal pathways, such as transcription of NF-κB, which orchestrates the inflammatory response. The DAMP-induced signal transduction pathways control the gene expression activation of different cytokines, cell adhesion molecules, and immunological components to trigger inflammation. Cox et al. (2014) demonstrated in rats subjected to tail shock that glucocorticoids secretion is responsible for IL-1β stress-induced increase in rat subcutaneous adipose tissues. Stressors of different natures and intensity can induce production of extracellular and intracellular mediators to modulate cell responses. Cells during heat stress activate a response to provoke the increase of signal pathways and the reprogramming of gene expression as a homeostatic mechanism (Park et al. 2005). Farmed animals are subjected to different types of stressors, i.e., those caused by management procedures or environmental conditions. In sheep, both physiological and psychological stressors have been found to augment proinflammatory responses by increasing in vivo plasma secretions of proinflammatory cytokines, such as cytokine-6 (IL-6) and IL-1β (Caroprese et al. 2006, 2010).

Heat stress, being responsible for an alteration of the host's homeostasis, can be considered a form of sterile inflammation the animals have to cope with, and can affect their immunological responses, differently influencing both cellular functioning and cells interactions. Dairy animals, when exposed to increase in ambient temperatures, often display a depression of the immune system (Lacetera et al. 2005). During heat or other stress stimuli there is a cascade of protein activation able to alter gene expression of immune cell mediators and to activate heat shock response at cellular levels. Heat shock transcription factor 1 (HSF1) plays a central role in inducing numerous heat shock response proteins (HSPs) that activate the protection of cellular homeostasis during heat stress (Collier et al. 2008). The HSPs are identified according to their molecular weights; those of approximately 90, 70, and 27 kDa are referred to as HSP 90, HSP 70, and HSP 27 (Guerriero and Raynes 1990). The endocrine system can alter HSPs' expression and activity by acting at intracellular level through the inhibition of cell proliferation and protein synthesis, and at extracellular level by supporting innate immunity (Collier et al. 2008). During hyperthermic stress, very high concentrations of inducible HSP 70 were found on the membranes of immune cells, such as monocyte-derived dendritic cells, which contain high concentrations of proinflammatory cytokines (Oosterveld and Rasker 1994). Furthermore, cultured sheep lymphocytes have been demonstrated to produce HSP 90 and HSP 70 in response to thermal stress (Guerriero and Raynes 1990). A 3.5-fold increase of HSP 70 mRNA expression has been registered in skeletal muscle of sheep under heat stress (Chauahan et al. 2014). The increase of the expression of HSP 70 during heat stress has been explained as a mechanism induced to enhance thermotolerance in terms of cytoprotective effects and protein reinfolding (Collier et al. 2008). However, production of HSPs may be influenced by a number of factors, such as cytokines and in particular IL-13; both heat stress and IL-13 can enhance the production on inducible HSP70 (Martin et al. 2009).

Concentration of HSP70 from cultured blood mononuclear cells subjected to heat stress changes according to different sheep breed; Romero et al. (2013) found higher concentrations of HSP70 in Pelibuey sheep than in Suffolk sheep, suggesting that the higher the levels of HSP70, the more efficient the mechanism of adaptation of sheep to hot environment. Diet has been demonstrated to alter HSP expression and secretion in dairy sheep. High doses of antioxidants, such as vitamin E and Se, cause a 5.2-fold increase in the expression of HSP70 in the skeletal muscle of sheep under heat stress, suggesting a possible enhancement of thermotolerance (Chauahan et al. 2014). On the contrary, in flaxseed-supplemented sheep a reduction of concentrations of HSP 70, measured in lysated blood cells, was registered together with a reduction of IL-13 plasma levels (Caroprese et al. 2014). The secretion of glucocorticoids can release the preformed cytoplasmic HSP 70 and 90, which are bound to the glucocorticoid receptor, thus immediately acting to avoid protein denaturation inside the cells (Collier et al. 2008). The glucocorticoid–receptor complex can enhance expression of HSP genes in the nucleus (Vijayan et al. 2003). Besides this, evidence has been provided for reduction of secretions of HSPs induced by glucocorticoids. A hormone-activated transcription factor induced by glucocorticoids, named GR, that acts to regulate specific gene expression against stress in cells can attenuate the heat shock response through an inhibition of the transcription enhancement activity of HSF1 by a mechanism of cross-talk (Wadekar et al. 2001). The role of HSP 90 has not been thoroughly investigated, in particular in sheep under heat stress. The basal expression of HSP 90 can be influenced not only by heat stress events, but also by polymorphisms found at the promoter region of the gene encoding for the protein. In sheep, differences in the expression rate of HSP 90 due to both genotypes and acclimatization processes have been observed in similar climatic conditions, suggesting that those genotypes that display higher expression levels under heat stress also display higher protein amounts (Salces-Ortiz et al. 2013). Diet in heat-stressed sheep can also affect HSP 90 expression and production at protein level. The addition of supranutritional doses of vitamin E and Se increases the expression of HSP 90 in skeletal muscle, whereas the addition of flaxseed and the seaweed *Ascophyllum nodosum* reduces the protein production in the blood cells (Chauahan et al. 2014; Caroprese et al. 2014).

HSPs have been suggested as potent activators of the innate immune system, being able to stimulate the monocyte–macrophage system to produce proinflammatory cytokines and the activation and maturation of dendritic cells via the toll-like receptor 2 and 4 signal transduction pathways. Sheep under heat stress display an increase in the expression of TNF-α and NF-κB expression in skeletal muscle (Chauahan et al. 2014). However, the regulation of immune responses at cellular level by HSPs depends on the magnitude of heat stress; in case of mild heat stress there is a positive regulation of cell cycle and differentiation, whereas in case of severe heat stress the cell cycle is arrested and apoptosis occurs (Park et al. 2005). The induction of T-cell reactivity to HSP 70 involves the induction of Th2 cells producing the regulatory cytokines IL-4 and IL-10. Ewes subjected to heat stress exhibit an impairment of their cellular immune response after the intradermal injection of mitogens (Sevi et al. 2002; Caroprese et al. 2012). Further studies highlighted that hyperthermia can suppress cell-mediated immunity with a down-regulation of Th1 cytokines in favor of the secretion of Th2 cytokines (Murzenok et al. 1997; Elenkov and Chrousos 1999; Webster et al. 2002). Animals' ability to selectively produce Th1 (IFN-γ, and IL-12) or Th2 cytokines (IL-10, IL-4, IL-13) cells is temperature dependent, indeed, and environmental conditions can regulate Th1/Th2 cytokine balance (Park et al. 2005). Cytokines produced by Th2 cells are able to sustain humoral immunity; IL-4 and IL-10 stimulate the differentiation of B cells into antibody-secreting B-cells and can inhibit macrophage activation, proinflammatory cytokine production, and T-cells proliferation. The balance between proinflammatory and anti-inflammatory cytokines seems a mechanism to balance the ongoing proinflammatory mediators during an immunological challenge and to avoid excessive tissue damage resulting from inflammation. Therefore, the maintenance of the proper Th1/Th2 balance could be a critical factor to face immunological challenges, in particular during the summer season. Both IL-4 and IL-13 play an important role in combining their effects to ensure the activation of Th2 cells and the development of humoral immune responses (Zurawski and Vries 1994; McKenzie et al. 1998). In sheep, a reduction of both IL-4 and IL-13 has been found during heat stress, thus supporting the hypothesis of a reduction of Th2 responses during hot weather (Caroprese et al. 2014). Mckenzie et al. (1998) reported that when IL-4 and IL-13 reduce, the Th2 responses diminish, and concomitantly Th1 response appears inappropriate. Similar changes in IL-4, IL-13, and cellular immune responses were found in heat-stressed sheep in Caroprese et al. (2014)'s study, and are shown in Fig. 4.2. The administration of a combination of PUFA from flaxseed and seaweed *Ascophyllum nodosum* in sheep diet under heat stress registered a synergistic negative effect on the immune system reducing IL-13 productions, and, as a

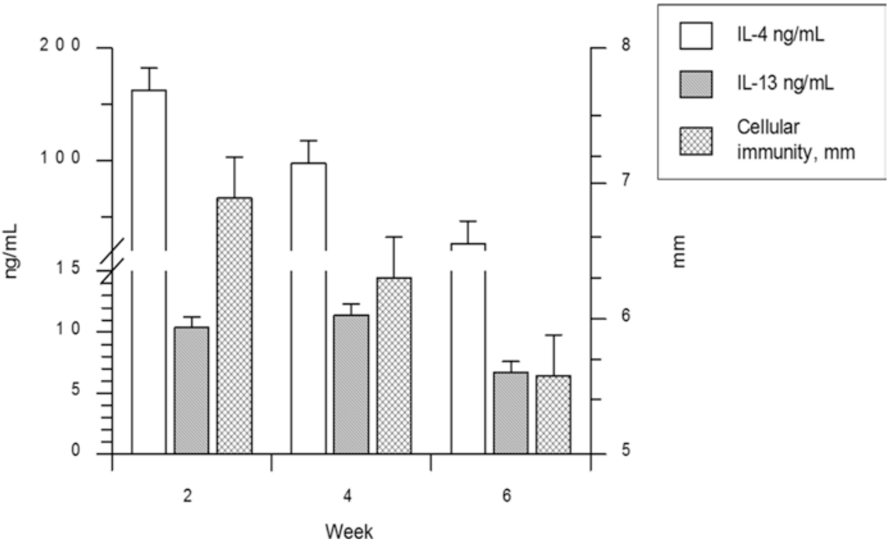

Fig. 4.2 Temporal changes in IL-4, IL-13, and cellular immune responses in heat-stressed sheep

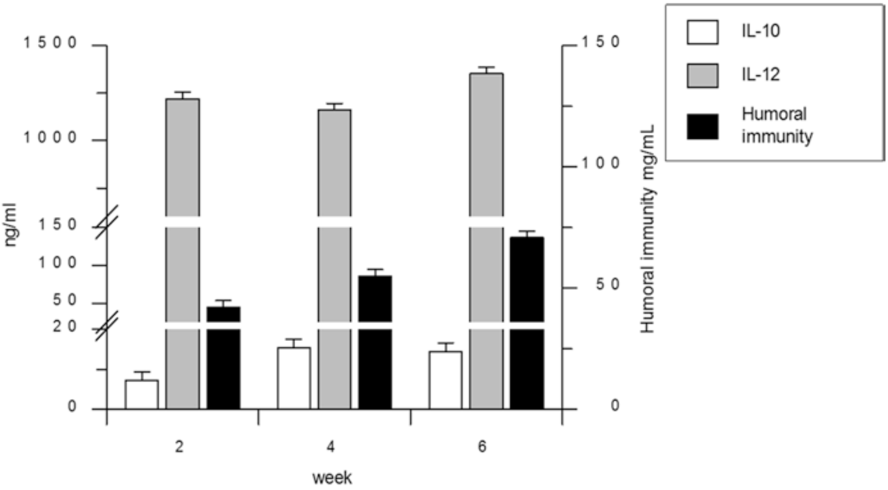

Fig. 4.3 Temporal changes in IL-10, IL-12, and humoral immune responses in heat-stressed sheep

consequence, Th2 responses, by decreasing anti-OVA IgG production. As previously reported, this was also associated with a reduction in Th1 responses, as suggested by the decrease in IFN-γ production (Caroprese et al. 2014). Previous findings suggest the pivotal role of diet in the regulation of immune responses during heat stress response, probably by altering the expression of different genes involved as reported in Chauhan et al. (2014). The key antagonist of Th1 response acting on posttranscriptional mechanisms and regulating cytokine production is the IL-10 that is produced by different cells such as T lymphocytes, B-cells, eosinophils, mast cells, and monocytes (Asadullah et al. 2003; Moore et al. 2001). IL-10 secretion by T-cells can be upregulated by glucocorticoids (Elenkov and Chrousos 1999). In sheep, an increase in plasma IL-10 production has been observed when under heat stress (Caroprese et al. 2014) (Fig. 4.3). As a result, a direct suppressive effect on Th1 cell response is registered, as demonstrated by the reduction in plasma INF-γ concentrations and the decrease in cellular immunity after intradermal injection of the induced delayed-type hypersensitivity by mitogen phytohemagglutinin.

4.3.2 Heat Stress, Oxidative Stress, and Immune Responses in Sheep

Oxidative stress is considered an imbalance between oxidant and antioxidant status (Celi 2010). Oxidative stress can be induced by heat stress as a result of a reduction of antioxidant status and a concomitant increase in production of reactive oxygen species (ROS), lipid peroxidation, or inactivation of antioxidant defense systems (Saker et al. 2004). Furthermore, a concomitant decrease of the markers of antioxidant capacity, with the reduction of enzymeactivities such as superoxide dismutase, catalase, and glutathione peroxidase is registered in the blood of heat-stressed animals (Miller et al. 1993; Bernabucci 2012). Oxidative stress is considered one of the key factors causing the impairment of immune responses in animals under heat stress. Several studies suggest that exposure to heat results in oxidative stress, thus promoting cytotoxicity (Mujahid et al. 2005), and cellular damage (Beckman and Ames 1998). It is worth noting that a cross-talk between oxidative stress and inflammatory reactions has been found (Sordillo and Raphael 2013). The production of low or moderate concentrations of Reacting Oxygen Species (ROS) is a basal mechanism for the activation of a number of innate and acquired immune responses, i.e., the phagocytosis processes involved in the production of toxic ROS by NADPH oxidase localized within phagosomal membrane to protect invading pathogens (Sordillo 2013). Moreover, some ROS are involved in the signal transduction pathways implied in the expression of cytokines, and of immunoregulatory molecules essential during infection (Asehnoune et al. 2004), such as NF-κB, which is activated and translocated into the nucleus in response to ROS accumulation (Gloire et al. 2006). Sheep under heat stress display an increase in the production of reactive oxygen metabolites (ROM) and a decrease in antioxidant defenses, measured as biological antioxidant potential (Chauhan et al. 2014). The uncontrolled increase in ROM production can also be considered responsible for the increase in plasma concentration of advanced oxidation protein products (AOPP), which is a marker of protein oxidation, suggesting increased damage to proteins in heat-stressed sheep. The increased AOPP has been implied in the regulation of proinflammatory responses and is also considered an indicator of acute inflammation in dairy cows (Celi et al. 2011). Nevertheless, in sheep an upregulation of TNF-α and NF-κB expression in skeletal muscle is observed during heat stress, demonstrating the concomitant increase of oxidative damage and proinflammatory responses. Previous findings demonstrated that heat stress can exert a modulating action on the expression of genes implicated in the inflammatory responses connected to the imbalance of oxidative status. The nutritional intervention with antioxidants at elevated doses, defined as supranutritional doses, can reverse the negative effects of high ambient temperature on oxidative stress by improving some of the physiological responses of sheep to heat stress, as demonstrated by some authors (Rhoads et al. 2013). Chauhan et al. (2014) hypothesize that antioxidant supplementation (vitamin E and Se) mitigates heat stress in sheep by increasing HSP mRNA expression and by reducing proinflammatory cytokine and NF-κB transcription factor expression. The integration of antioxidants into the diet contributes to maintaining a continuous feed intake, with a negative feedback mechanism; the authors suggest that neutralization of oxidative species by antioxidants in the diet reduces the release of cytokines and prostaglandins, implicated in the activation of systemic responses including the reduction of feed intake (Bradford 2012). The health benefits of Se are related to Se-containing antioxidant enzymes that reduce oxidative stress producing less reactive molecules, and restoring redox potential of cells (Spears and Weiss 2008; D'Rourke 2009). The addition of flavone glycoside named narginin in the diet of lambs under heat stress positively affected the antioxidant status in terms of superoxide dismutase and glutathione peroxidase, with a positive improvement of the immunological responses measured as antibody production and cellular immunity (Alhidary and Abdelrahman 2016). All of the mechanisms mentioned earlier contribute to protection of the animal against hyperthermia and the resultant oxidative stress.

4.3.3 Heat Stress and Sheep Immune Responses in the Mammary Gland

The incidence of udder health problems in sheep increases during summer as a result of two mechanisms. Firstly, normal physiological and immunological functions of sheep are altered by heat stress. Secondly, the warm and humid environmental conditions which occur in the Mediterranean basin during summer can promote the proliferation of microorganisms responsible for clinical or subclinical infections of ewe mammary gland. As a consequence, both enhanced bacterial colonization of ewe udders and the reduced mammary defense capacity due to heat stress negatively affect the hygienic quality of milk, as demonstrated by the increase in bacterial load in terms of coliforms, staphylococci, and milk neutrophils found by Sevi et al. (2001). As an example, the microbial species isolated from bacteriologically positive milk samples from ewes exposed to heat stress register a prevalence of environmental pathogens (Sevi et al. 2001). A proper ventilation regimen in dairy sheep houses during the summer months can sustain udder health by a reduction of the total coliform counts, the mesophilic and psychrotrophic bacteria load, and somatic cell count in milk also strengthened by an enhancement in cell-mediated and humoral immune responses (Sevi et al. 2002, 2003; Albenzio et al. 2005). The greater bacterial load in sheep udder, as a result of hot and humid conditions, leads to increased somatic cell count (SCC), leukocyte infiltration in the alveoli being one of the main defense mechanisms of the udder against invading bacteria (Burvenich et al. 2000). Recruitment of neutrophils into the udder in response to bacterial penetration can be responsible for tissue damage of the secretory epithelium (Sevi et al. 1999). The consequent increase in capillary permeability and the disruption of the blood–milk barrier cause an enhancement of drainage of lipolytic and proteolytic enzymes into milk (Kehrli et al. 2000). In addition, enzymes produced by the invading bacteria may act as activators of plasminogen (PG) (Fajardo-Lira and Nielsen 1998) and induce the production of prostaglandins and cytokines. The activation of plasminogen activator (PA)–plasminogen (PG)–plasmin (PL) enzymatic system in the mammary gland generates a fragment (f) (1-28) of β-casein (CN) which exerts a negative feedback regulatory control on milk secretion, as reported by Silanikove et al. (2009) in conditions of acute heat stress. In cows, the downregulation exerted by the β-CN (1-28) on milk production during heat stress is induced by blocking the potassium channel of mammary epithelial cells. Furthermore, heat stress increases the responsiveness of the potassium channels to the action of the blocker β-CN (1-28) (Silanikove et al. 2009). An increment of SCC and a concomitant increase in PL activity is found in late lactation milk from sheep during summer, connected to worsening of the coagulating properties of milk (Albenzio et al. 2004). In particular, the enhanced PL activity is linked to the increased levels of macrophage cells in sheep milk (Albenzio et al. 2004). Under heat stress an increase of plasmin concentration in sheep milk after *Ascophyllum nodosum* supplementation is found, with detrimental effects on coagulating properties of milk (Ciliberti et al. 2016). However, the exact mechanisms controlling the relation between heat stress and mammary immunological state have not been thoroughly investigated in sheep. Recently, an additional mechanism has been defined in relation to the regulation of the expression of the Janus kinase/signal transducer and activator of transcription (JAK/STAT) pathway, which regulates the expression of genes associated with cell proliferation, differentiation, and lactogenesis in the sheep mammary gland. Photoperiod seems to influence the expression of the suppressor of cytokine signaling-(SOCS-)3, which is a modulator of the JAK/STAT pathway via prolactin secretion (Szczęsna et al. 2015). Previous results suggest a role of photoperiod in regulating seasonal fluctuations of mammary gland immunity in sheep.

4.4 Conclusion

Heat stress is responsible for alterations in animals' homeostasis and activates physiological compensatory mechanisms driven by the activation of the central nervous system to cope with changed environmental conditions and to maintain vital functions. In sheep, during heat stress a cascade of protein activation able to alter gene expression of immune cell mediators and to activate heat shock response at cellular levels occurs. In particular, numerous heat shock proteins play a central role in activating the protection of cellular homeostasis during heat stress, and they are considered potent activators of the innate immune system, capable of inducing the production of proinflammatory cytokines. Furthermore, during heat stress an alteration of the proper Th1/Th2 balance is observed, which could be a critical factor when faced with immunological challenges. Cytokines play a central role in the cross-talk between altered homeostasis and reassembling and balancing of the immune responses passing through signals of oxidative imbalance. Very few studies have investigated the relation between increased heat load and oxidative stress in sheep, and the consequent impact of oxidative stress on the immunological responses. However, a tentative description of the effects of heat stress on oxidative status, and the intersection among oxidative imbalance, immune, and physiological responses of sheep, has been presented. The incidence of udder health problems in sheep during summer has been discussed. Further studies are required to clarify the role of each compartment in the regulation of the complex network of immune responses activated by heat stress. Nevertheless, in sheep a pivotal role of diet in the regulation of immune responses during heat stress, probably by altering the expression of genes involved, is suggested. The biological mechanisms behind sheep immune reaction to heat stress by the detection of molecular biomarkers for heat stress taking into account the omics approach remain to be studied further.

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Adaptive Mechanisms of Sheep to Climate Change

5

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Abstract

Sheep rearing is the most integral part of animal production particularly in tropical regions. Climate change is observed to have devastating effects on sheep farming through constraints such as heat stress, lower grazing lands, water scarcity and higher pest and disease incidences. These environmental constraints may lead to compromised productive functions in sheep. The cumulative effects of heat, nutritional and walking stress occurring in the hotter parts of the year compromise the productive and reproductive performances of the sheep through reduced feed intake, modified endocrine profile, lower rumination and nutrient absorption and higher maintenance demands.

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Indigenous sheep breeds particularly in the tropical region are found to have better adaptability to hot climates than exotic and crossbreds. Sheep try to cope with these adverse environmental stressors through morphological, behavioural, endocrine, blood biochemical and cellular adaptations. Sheep indigenous to tropical and subtropical regions are observed to have carpet-type wool which helps them in eliciting cutaneous evaporative cooling mechanism to dissipate extra heat load during summer. Exposure to higher ambient temperature triggers all behavioural and physiological mechanisms in sheep to cope with the existing condition. Similarly, their endocrine mechanisms also play a major role in their adaptive processes. Cortisol being the primary stress-relieving hormone initiates various physiological modifications in these sheep to adapt to the adverse thermal conditions. Further, heat stress-induced hyperthermia also decreased thyroid gland activity and thyroid hormone levels in the blood to control metabolic heat production. Higher expenditure of energy along with lower feed accessibility altered blood biochemical parameters such as glucose, protein, cholesterol, globulin and albumin in sheep. The activation of cellular and molecular mechanisms is considered to be the most important responses by which the animals survive the heat stress condition. The activation of these pathways may help to identify various thermotolerant genes to quantify heat stress condition in sheep. It has also been found that respiration rate, rectal temperature, plasma cortisol, thyroxin, triiodothyronine and heat shock protein 70 are established to be the ideal biological makers for environmental stress in sheep.

Keywords

Adaptation • Behaviour • Climate change • Cortisol • Heat stress • Heat shock protein • Sheep • Thermotolerant genes

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5.1 Introduction

Weather and climate of the specific region are widely believed to have stamping impact on biota of this planet. Weather is a short-term day-to-day fluctuation in meteorological parameters at a particular location, and climate is an average of weather conditions over a longer duration in a given geographical location. “Climate change” is defined to be emerging when there is a statistically significant alteration in climate variables occurring for a long period of time, i.e. at least for a period of 30 years (Wallington et al. 2004). Climate change has emerged as a major threat to the peaceful existence of mankind on this earth. In fact, developing countries are recognized to be more sensitive to the climate change disasters compared to the developed countries due to their heavy reliance on weather-sensitive economies such as agriculture, inadequate budget for mitigation measures and poor early warning systems (Fischer et al. 2005). Livestock production is also vulnerable to climate change, since apart from a single trait, it also influenced by indirect characteristics such as adaptation, disease resistance, body indices and reproductive traits. Livestock production based on extensive system of rearing is expected to be more susceptible to climate change than the intensive system. In rural areas, livestock act as livelihood source for poor and marginal farmers through multiple economic, social and risk management functions (Shinde and Sejian 2013). Besides the increasing deleterious effects of climate change, the livestock production system is further influenced by indirect factors such as abnormal population and economic growth and higher demand for animal products (FAO 2007).

Small ruminants essentially play an immense role in the progress of sustainable and ecologically viable production systems (Sejian et al. 2016). They are able to thrive well in seasonal climatic variations than the large animals particularly in both higher altitudes and latitudes, where the fluctuations are expected to be maximum. The livestock reared in the temperate regions are observed to be vulnerable to daily photoperiod and ambient temperature fluctuations, while precipitation changes and the associated feed availability are the major concern in tropical regions (Rosa and Bryant 2003). Sheep rearing acts as the most important source of economic income for poor farmers, particularly in tropical areas (Sejian et al. 2016; Maurya et al. 2016). The crucial role of sheep for socioeconomic uplifting of shepherd communities in the rural regions is expected to be elevating in the coming decades (Ben Salem and Smith 2008; Sejian et al. 2016). Sheep can make use of low-quality biomass in times of scarcity and transform it into useful products, such as milk, meat and wool. Native sheep breeds in arid and semiarid areas demonstrate better performance under harsh environmental conditions than their non-native counterparts. Hence, proper breed selection is a useful tool which can be adopted in breeding programmes to maintain optimal production in the changing climate scenario (Silanikove 1992; Inˇiguez 2005).

Irregular variations in the climatic variables are expected to have higher economic impacts on poor and marginal sheep farmers and on the related sheep inputs in which they rely on. Indirect impacts of climate change can cause deleterious effect on feed and fodder availability both in terms of quality and quantity, reduced water availability and variation in the incidence and spread of sheep diseases. Therefore, in order to enhance the productive and reproductive efficiency of the sheep in the vulnerable regions, appropriate cost-effective management practices must be adopted. Further, the adaptive capability of the livestock species to the thermal environments also plays a vital role in determining the quantity and quality of food production. With these background information, the current chapter is attempted to capture and generate information relating to climate change and its impact on sheep. Efforts are made to present information pertaining to salient adaptation and mitigation strategies to improve sheep under the changing climatic condition.

5.2 Climate Change Impact on Sheep

The cardinal weather variables demonstrated to impose significant effects on the livestock production are temperature, humidity, wind velocity, direct and indirect solar radiation and photoperiod, and among these ambient temperature is proved to be most crucial (Rashwan Ali et al. 2004). Direct impacts of climate change may result in higher surface temperature, atmospheric CO_2 levels and modified precipitation pattern, and all these consequences eventually lead to impaired crop and livestock productivity (Hatfield et al. 2008; Sejian et al. 2012). In the changing climate scenario, the fate of sheep husbandry in many parts of the world raises serious questions. It is expected that climate change may cause shifting of sheep from one region to another, change in breed composition, change in livelihood and nutritional security of farmers, shifting trend of sheep breeds from wool to mutton type, emergence, re-emergence of newer diseases, etc.

Climate change impairs the livestock production potential directly by altering temperature, humidity, solar radiation and wind velocity and indirectly by influencing the feed digestibility, feed availability and quality, pest and disease incidences, etc. Fundamentally, climate change disturbs the sheep production efficiency in several ways including (a) deleterious effects on forage availability and quality, (b) modified pest and disease distribution and (c) direct impacts of fluctuating weather on animal production performances (Smith et al. 1996). Table 5.1 illustrates the direct and indirect effects of environmental stresses on sheep production.

5.2.1 Availability of Feed and Fodder and Its Quality

Extensively reared animals are expected to be mostly influenced by climate change consequences than the industrialized animals. Climate change which resulted in increasing temperature, CO_2 levels and modified rainfall pattern can cause

Table 5.1 Sheep production as affected by both direct and indirect effects of climate change

Growth	Meat production	Reproduction	Availability of feed and water	Distribution of livestock diseases
Reduced average daily gain	Transport-related mortality	Reduced intensity and duration of oestrus	Reduced pasture availability	Altered patterns diseases in animals
Reduced body weight	Reduction in overall meat quality	Reduced LH level	Reduced quantity of feed and fodder	Emergence of new diseases
Reduced BCS	Decrease in protein and marbling	Reduced oestradiol	Reduced micronutrient content in feed	Variations in the predominance of existing diseases
Reduced birth weight	High cooking losses in meat	Low progesterone	Reduced water quantity and quality available for livestock	Variations in distribution and the abundance of disease vectors
		Decreased quality of oocytes		
		Increased embryonic mortality		
		Reduced fertility rate		

detrimental effects on both the feed quality and quantity in multiple ways: (a) through altered herbage growth; (b) variations in pasture composition like grass-to-legume ratio; (c) reduced herbage quality, with modified concentrations of water-soluble carbohydrates and N levels per unit dry matter (DM) yields; (d) increased drought occurrences and related DM production losses; and (e) grater precipitation intensity and enhanced N leaching (Hopkins and Del Prado 2007). Reduced rainfall availability due to climate change further hampers the fodder production efficiency and also elevates the marginal operating costs (Madzwamuse 2010). However, according to IPCC (2007) projections, slight increase in surface temperature (1–3 °C) may have positive impacts on crop productivity in mid- and higher latitudes depending upon the crop varieties, while relative narrow increment of temperature potentially hampers the crop productivity in lower latitudes.

Further, climate change-induced global warming also impairs the grass land productivity by varying the rangeland species distribution, composition and pattern (Hanson et al. 1993). The projected increase in temperature is expected to alter the southern hemisphere environments and the growth and distribution of flora in tropical regions and also deteriorates the grazing capacity in some regions up to 50%. In addition, higher temperatures also lower the dry matter digestibility and degradation rates due to enhanced lignification of plant tissues (Minson 1990) and which can ultimately lead to below par genetic production potential of the animal. Although global warming is expected to reduce the nutritional composition of the tropical grasses, C_4 plants have evolved an unconventional photosynthetic pathway to cope with the climate change challenges. However, higher photosynthetic rate generated more fibre content, and reduced leaf-to-stem ratio and lower digestibility and intake made them less favourable for animal production (Leng 1984). Consequently, ruminant species are assumed to be significantly influenced by climate change in the coming decades (Blackburn and Mezzadra 2006).

5.2.2 Direct Effects on Animal

Farm animals try to keep their body temperatures within narrow limits over a broad range of ambient temperatures through efficient thermoregulatory mechanisms (Cabanac 1975; Mount 1979). During high-temperature periods, productive performances in the sheep are compromised by lower feed intake, redistribution of blood flow and altered endocrine profile (Abouheif and Alsobayel 1983; Eltawil and Narendran 1990). Moreover, drastic change in sheep productivity due to various environmental stresses results in massive economic constraints to the sheep industry. However, vulnerability of the sheep to extreme temperature condition is depending upon various factors such as type of breed, nutritional availability, etc. In this particular case, tropical breeds are observed to be better adapted to thermal environments with low feed requirements and high thermotolerance. Long exposures of livestock to heat stress for long time periods significantly affect their productivity and in extreme cases question their survivability.

Heat stress-induced lower feed intake, modified endocrine profile, reduced rumination and nutrient absorption and higher maintenance requirements in livestock lower the energy availability for production and thereby hamper the productive reproductive performances in them (Collier et al. 2005). Cattle exposed to heat stress showed significant loss of body weight which can be partly explained by the lower nutritional status resulted in negative energy balance in them (Baumgard and Rhoads 2007).

5.2.2.1 Effect on Growth

Growth is defined as the irreversible positive changes in the measured dimensions of the body. Body growth is affected by factors such as nutrients, hormones, enzymes and temperature. The significant influence of thermal stress on growth gain could be directly attributed to lower feed intake associated with reduced anabolic activity (Marai et al. 2007). Further, thermal stress causes reduction in the body condition score (BCS) due to negative energy balance. Factors such as greater maintenance requirements during hot weather, poor appetite and low-quality forages during summer months contribute to the slower growth and reduced body size (West 2003). This reducing body weights can be partly explained by the lower dry matter intake of these animals during hotter parts of the day. In addition, elevated production of catecholamines and glucocorticoids during thermal stress condition may lead to increased tissue catabolism which occurs principally in fat depots and/or lean body mass of sheep. Studies conducted in heat-stressed animals showed redistributed blood flow to the body surfaces (Ooue et al. 2007; Leon 2008) to facilitate heat dissipation to the surrounding environment (Horowitz 2003) which may also lead to earliest gastrointestinal ischaemia and hypoxia in them (Hinnebusch et al. 2002). This leads to improper food assimilation and thereby results in subnormal growth.

5.2.2.2 Effect on Meat Production

Climate change is observed to have significant effects on meat industry by altering both meat quality and safety. Heat stress influences the meat quality mainly in two ways. Exposure of the animals to hotter environments directly affects the organ and muscle metabolism, for example, increased ultimate pH and dehydration rate are seen in heat-stressed livestock, and the effects appeared to be persisting even after slaughter. In addition to the former effects, revised management practices during stressed periods further modify the meat quality of livestock and poultry indirectly. Adoptions of various management strategies like selection of thermotolerant sheep breed for production purposes may lead to altered mutton characteristics such as increased toughness, less juiciness and less marbling. Additionally, changes in ambient temperature may also lead to altered microbial burdens on carcass and meat, especially in animals that carry more enteric pathogens. Apart from slaughter and post-slaughter changes, climate change can also affect preslaughter parameters by increasing the chances of transport mortality (Gregory 2010).

5.2.2.3 Effects on Reproduction

Reproduction is considered as pleasure for farm animals, and at the same time, it is an energy-consuming process. Hence, climate change-induced negative energy balance in farm animals during summer significantly hampers their reproductive efficiency. The probable harmful consequences of thermal stress established in other species can be extrapolated to reproduction in sheep that includes the following: in females, the oestrus incidences, follicular dynamics, embryo development, fertilization, conception rate, lambing rate and birth weight of lambs were found to be adversely effected by heat stress (Jordan 2003; Sejian et al. 2011), while in males, the sexual behavioural pattern, scrotal and testicular measurements, seminal attributes, process of spermatogenesis and spermiogenesis and ability of sperm to fertilize the ovum were affected by heat stress (Hansen and Arechiga 1999; Wolfenson et al. 2000).

5.2.2.4 Distribution of Livestock Diseases and Pests

Climate is proved to have direct relation with the incidence and spread of infectious animal diseases. Climate change which resulted in increase in temperature and relative humidity may lead to higher pathogen and parasite development rates and may cause larger pathogen populations (Harvell et al. 2002). Higher exposure of the animals to pathogens increases their vulnerability to disease incidences. In addition, impacts of climate change also cause emergence of new disease outbreaks including variations in vector populations (Summers 2009; Tabachnick 2010). Hence, increased susceptibility of animals to infectious diseases further hampers their production performances (Herrero et al. 2008).

5.3 Climate Change and Different Environmental Stressors

Sheep produced in the tropical region are challenged with multiple stressors and are widely known to hamper the production performances such as growth, production and reproduction in them (Sejian et al. 2016). Various cardinal weather variables that are observed to have significant impacts on sheep productivity are environmental temperature, humidity and wind, and among these variables, ambient temperature is observed to be the most crucial factor (Shelton 2000; Koubková et al. 2002). In addition, cumulative effects of high temperature along with relative humidity further increase the heat stress impacts. Further, various adaptive responses elicited in these stressed animals are also found to be harmful to their performances (Rivington et al. 2009; Sejian et al. 2014a).

Sheep subjected to heat stress tend to show altered biological functions which are very much evident through reduced productive and reproductive traits (Marai et al. 2007). Sheep produced in warmer regions show low animal performance and productivity in all stages of their development, as they are exposed to higher temperatures in almost all part of the year. Effects of heat stress in sheep are decreased feed intake, growth performance, milk production, higher sweating rate, panting, rectal temperature, respiratory rate and water intake (Sejian et al. 2010a). Apart from these, there are also changes in haematological parameters, electrolytes, metabolites, increased mortality and morbidity and reduced immune function (Sejian and Srivastava 2010a).

Thermal stress is a crucial factor affecting the animal performances in the extensive production system particularly in arid and semiarid regions. Heat stress impacts on livestock productivity and welfare are well documented in various parts of the world. In addition to the compromised production performances, livestock exposures to extreme heat stress condition impair their biological functions and lead to death of the animals. Globally, heat stress is mainly classified into three types including acute, chronic and cyclic. Among these, chronic heat stress is observed to be non-lethal, and the animals are able to cope with this stress condition for a long period of time with limited production losses. However, exposures of the animals to acute stress hamper their thermoregulatory mechanisms and cause hyperthermia. Moreover, prolonged acute heat stresses can also lead to animal morbidity and mortality. Cyclic heat stress generally involves thermal exposures for short time periods, and such occurrences improve the animal's adaptation to particular environment. Heat stress associated with lower growth and reproductive efficiency is well noticed in sheep (Abouheif and Alsobayel 1983). In addition, thermal stress-induced decrease in feed intake, average daily gain and increased sudden death rates are reported in sheep (Abdel-Hafez 2002). Indigenous breeds, reared and developed in the hotter regions of the world, are observed to have increased adaptive capacity to high environmental temperatures (Srikandakumar et al. 2003; Soleimani et al. 2011). Reports showed even slight variations of the ambient temperatures can have negative effects on the digestive processes by decreasing the blood flow to rumen (approximately 76% under severe stress and 32% under moderate stress) and lowering the rumen motility and rumination (Christopherson 1985). Moreover, heat stresses also lead to altered biological functions in sheep including lower feed intake and utilization, impaired water metabolism, disturbed enzymatic reactions and protein, energy and mineral imbalances (Habeeb et al. 1992; Marai et al. 2000).

In addition to heat stress, nutritional stress also proved to be detrimental to the animal productivity particularly in arid and semiarid regions (Sejian et al. 2010c; Maurya et al. 2010; Naqvi et al. 2013). The reduced pasture quality and availability in these regions may lead to significant production losses especially in grazing animals (Linington 1990; Sejian et al. 2014a). Sheep also are subjected to walking stress particularly in developing countries where extensive system of rearing predominates (Sejian et al. 2012). It has been established in Malpura ewes that the locomotory action in search of less pasture during the summer months proved to be an added environmental stress to these animals (Sejian et al. 2012). Water scarcity is a growing problem in arid and semiarid regions with global warming and changing patterns of rainfall, which limit water resources and affect feed quality and quantity in addition to increasing heat stress. This challenging situation causes a wide array of physiological responses in sheep with a negative impact on production, immunity and welfare (Barbour et al. 2005; Jaber et al. 2011).

5.4 Different Adaptive Mechanisms of Sheep to Climate Change

In order to sustain the productivity, animals must maintain their body temperature within physiological limits (Marai et al. 2007). Farm animals are known to show their maximum production level within environmental temperature range between 4 and 24 °C (McDowell 1985). Frequently elevated ambient temperatures in tropical and subtropical regions signified the importance of rearing superior adaptive breed in these areas to adapt to the adverse climate change impacts (Linington 1990). Animals exposed to heat stress environments exhibit various adaptive mechanisms such as behavioural, physiological, endocrine, cellular, metabolic and biochemical for minimizing the stressful condition (Hahn 1999). In addition to the biological adjustments, the animals also show various genetic characteristics for better adaptation in the specific environment (Hafez 1968a). The vulnerability of the animal to heat stress is controlled by various factors such as nutritional and health status, body condition score, genotypic or phenotypic characteristics, extent of exposure and the types of management practices adopted. Compared to large ruminants, small ruminants like sheep and goats are observed to be highly adapted to various climatic regions. Further, greater survivable rates of sheep in extreme weather conditions like drought or famine also signified sheep to be the ideal animal for climate change adaptation in the coming years. Figure 5.1 describes the various organs and the corresponding events associated with sheep adaptation.

5.4.1 Morphological Adaptation

Morphological adaptations are physical changes that occur over many generations in a species that enhances its fitness in a given geographical area. These include allometric body traits like size and shape of the body, design of extremities, skin attributes (colours, thickness, sweat gland distribution) and the hair coat characteristics (colour, thickness, absorption and reflectivity and angle of arrangement of hair to skin). These morphological characteristics further govern the magnitude of heat

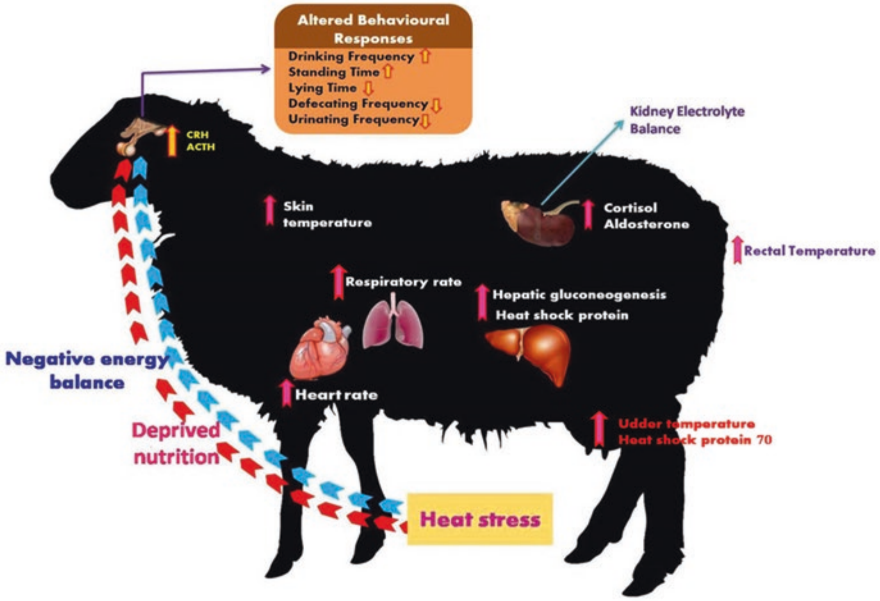

Fig. 5.1 Pictorial representation of various organs and the corresponding events associated with sheep adaptation

exchanges between the animal and the surrounding environment through radiation, convection, evaporation and conduction (Silva 2007). In addition, animal size, shape and surface area are also considered to be dominant morphological traits influencing the thermoregulatory mechanisms in farm animals (Marai et al. 2007). Animals having larger body surface area are found to be highly vulnerable to heat stress. Sheep being a small ruminant having higher surface area can be more susceptible to extreme thermal stress. Moreover, energy transfer in sheep is also depending on skin and coat characteristics such as colour, density, diameter, depth, transmissivity, etc. (Gebremedhin 1985).

Studies have proved that fleece type (Eyal 1963) and colour (Kay 1997) contribute to protection against heat and minimize water loss due to evaporative cooling. Furthermore, a strong relationship between skin characteristics and thermotolerance was also established in animals by Bertipaglia et al. (2007). Indigenous breeds in arid and semiarid areas such as the Marwari (Narula et al. 2010), Omani (Mahgoub et al. 2010), Barbarine (Ben Gara 2000) and Awassi sheep (Gootwine 2011) all have carpet-type wool. This type of wool, as compared with denser wool types, seems to confer protection from solar radiation while at the same time allowing effective cutaneous evaporative cooling (Mittal and Gosh 1979; Rai et al. 1979; Cain et al. 2006). Studies conducted in wool sheep showed a strong positive correlation between wool length and heat tolerance, with minimum stress responses in sheep having larger wool length (20 mm) than those having shorter (8 mm) (MacFarlane et al. 1958). Although, dense fleece obstructs the evaporative heat loss, Thwaites

(1985) defined ideal wool length in sheep to be 40 mm for maximum protection from direct solar radiation. Moreover, exposures of sheep to elevated temperatures (36 °C) also showed considerable amount of heat transfer through ears and legs.

Though earlier scientists opined that hair-type sheep seem to be less thermoresistant under hot conditions when compared with their wool-bearing counterparts (Symington 1960), most of the later studies proved that under tropical conditions of high temperature and high humidity, hair-type sheep were better adapted than wool-type breeds (McManus et al. 2009). Wool sheep are observed to be primarily depending on transpiration-type cooling mechanisms (Silva et al. 2003), while in hair sheep, respiration was found to be the dominant mechanism for heat dissipation (McManus et al. 2011). Additionally, absence of convective heat loss in wool sheep is found to influence the sweat evaporative efficiency and made them more vulnerable to hot environments (Silva 2000). Moreover, drawbacks of both natural and artificial fleece in heat dissipation of sheep were well established in climatic chamber studies conducted by Maia et al. (2009).

With respect to coat colour, a light-coloured fleece allows better reflection of solar radiation, thus keeping the skin underneath relatively cooler compared with darker fleeces (Cain et al. 2006; McManus et al. 2009). Likewise, well-defined variations in heat tolerance traits between groups representing different coat colours (white, brown and black) were established in Santa Inês sheep (McManus et al. 2009). The results obtained from the same study also showed better heat tolerance capacity of white-coloured sheep group compared to other dark-coloured groups through lower heart rates and rectal temperature values. Similarly, according to Pereira (2005), light coat-coloured sheep breeds exhibit more efficient capacity of reflecting solar radiation than dark-coloured breeds, particularly the radiation of larger wavelengths. However, a study conducted in Santa Inês sheep (dark and light coloured) did not show any relation between skin or coat colour and thermotolerance traits. McManus et al. (2009) explained higher heat adaptive capacity of light-coloured animals through morphological traits such as thin skin, short hairs and less pigmented coat and skin. In contrast, least adaptive traits of brown Santa Inês breeds were evident through thick skin, long hairs and few sweat glands. In addition, Yeats (1954) also stated the presence of thin and soft skin in livestock to be connected with the heat adaptation, while the presence of thick skin in animals is observed to be harmful, especially in hot environments with temperature above 40.5 °C. Additionally, reduced evaporative heat loss in animals due to greater coat thickness enhances their metabolizable energy needs for other compensatory heat adjustments and which may further damage their production potential. According to Dyce et al. (1996), pigment granules present in the skin protect the animals from harmful ultraviolet radiation. Increased number of pigmented hairs exhibits both negative and positive effects to animal adaptation in tropical regions. Higher pigmentation helps the animals to protect themselves from ultraviolet radiation, while it also absorbs more heat increment and which in turn increases the heat load in the animal (Maia et al. 2003). Further, light coat-coloured animals reflect more solar radiation with lesser absorbance rate of about 40–50% than dark coat-coloured animals (Shearer 1990). Hence, the ideal animal suitable for tropical region should possess morphological characteristics such as dark skin and light coat colour to resist direct effects of solar radiation (Muller 1982).

Silva (1998) established the importance of high coat hair density for protecting animal body against ultraviolet radiation. However, less hair numbers in animals facilitate more wind penetration into the coat and thereby favour higher heat dissipation to the surroundings (Ni and Hillman 1997). Length of the hairs also affects the heat transfer with shorter hairs assisting more heat transfer to the surrounding environments and thereby minimizes heat stress hazards in animal production. A strong positive correlation between number of hairs and apocrine glands is established in livestock. Animals having more hair numbers showed increased sweat gland density and better heat tolerance. In sheep referencing to the hair morphology, primary follicles differentiate and form the hairs, and heterotypic strands developed following the secondary follicle would transform to wool (Silva 2000). The author also showed sweating rate differences within the individual, between different breeds and group depending upon prevailing climatic condition. Animals having increased sweat gland numbers show better adaptation to hot environments by facilitating higher evaporative cooling mechanisms. Hence, low animal skin temperature was observed to be associated with wider sweat gland distribution and higher coat reflectance. According to McManus et al. (2009), animals having long hair, thick coat and dark skin colour showed increased vulnerability to heat stress challenges with significantly higher rectal temperature, respiration rate and sweating rate.

Another notable morphological characteristic of indigenous sheep breeds from tropical areas is the fat tail. This external localization of the fat allows better heat dissipation from the rest of the body (Degen and Shkolnik 1978), since the body will become less insulated by the fat tissue. In addition, the fat stored in the tail represents an energy store that can be mobilized in times of dietary shortfall (Chilliard et al. 2000; Atti et al. 2004). The concept of the fat tail as a store of metabolic water has been questioned (Epstein 1985), and it is now believed that its main role is to supply energy whenever dietary energy intake is insufficient, which results in some metabolic water formation that could partially help in filling the animal's water requirements. The contribution to water intake that could be derived from metabolic sources was found to be around 8.5% in Yankasa sheep (Aganga et al. 1989), while others reported a contribution of up to 15% in sheep in general (Sileshi et al. 2003). This contribution is affected by the level of reliance on the catabolic mobilization of body fat and protein tissue (Sileshi et al. 2003).

Arteriovenous anastomoses (AVAs) that are present in the limbs, ears and muzzle are another significant anatomical adaptation in sheep (Robinson 2002). These AVAs are bypass channels, which join arteries and veins in both first and second vascular plexus of the skin (Goodall 1955). The AVAs play a significant role in increasing total blood flow to the periphery and therefore play an important role in transport of heat to the outside of the body for dissipation (Rubsamen and Hales 1985) and to prevent thermal damage to the skin (Hales et al. 1985). Figure 5.2 describes the different adaptive mechanisms of sheep to climate change.

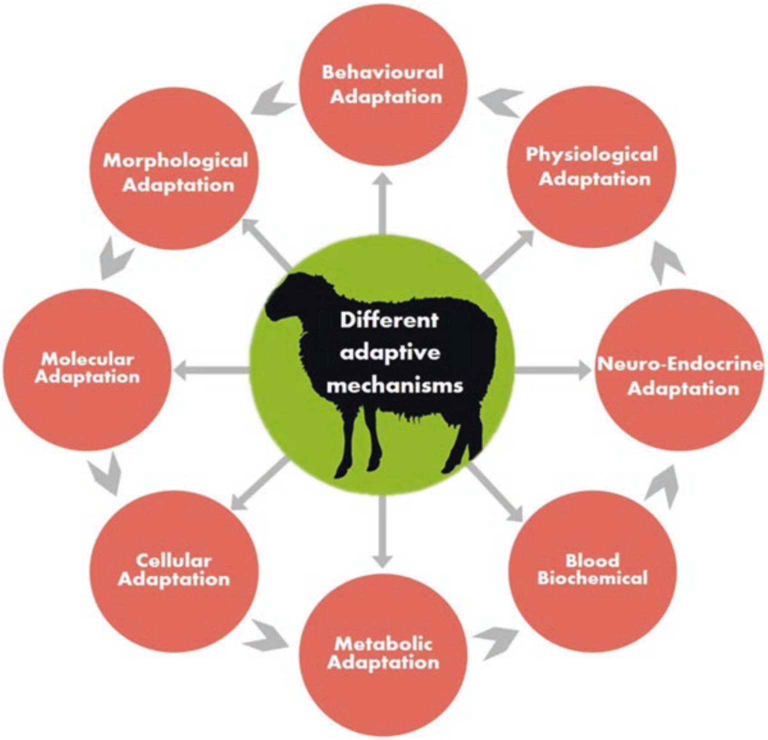

Fig. 5.2 Different adaptive mechanisms of sheep to climate change

5.4.2 Behavioural Adaptation

Behaviour responses also perform a very important role in determining the animal resistance to fluctuations in ambient temperature. Though these behavioural changes seem voluntary, they are directed by internal drives of the animal resulting from certain changes in internal milieu. Combination of behavioural, morphological and physiological adaptation plays a crucial role in livestock for maintaining thermal and water balance (Cain et al. 2008). At the behavioural level, increased night-time feeding was reported in bighorn sheep during hotter periods (Dwyer 2008); by foraging at night, sheep minimize their exposure to high thermal loads and also conserve body water by lowering evaporative cooling requirements. In the same way, sheep seek the protection of shelters and cool microclimates, when available, to hide from solar radiation during the day (Cain et al. 2005). Additionally, animals also try to change their postures according to the orientation of the sun to protect their vital organs from direct effects of solar radiation and also to minimize the heat load of incident radiation (Mount 1979; Bligh 1985).

Studies conducted in sheep showed lower feed intake and higher water intake during heat stress condition (Sejian et al. 2010a). Marai et al. (2007) attributed this reduced feed intake to direct effect of heat stress on the appetite centre in the hypothalamus and associated signalling of the animal to decrease their feed intake. This inappetence of sheep could be an adaptive response to reduce the internal metabolic heat generation. However, Barnes et al. (2004) correlated this decrease in feed intake to individual animal characteristics rather than thermal environment effects, since some animals may eat less irrespective of the outside temperature conditions and vice versa (Barnes et al. 2004).

The higher water intake in heat-stressed animals can be directly attributed to severe dehydration due to increased respiratory and cutaneous evaporative water loss. Sejian et al. (2010a) also reported that the water intake of animals which were subjected to both heat and nutritional stress is significantly higher as compared with heat stress alone. Significantly, higher water intake in sheep during combined stress condition indicates the severity of cumulative effects of heat stress and feed restriction than the individual stress impacts (Hooda and Naqvi 1990; Minka and Ayo 2009). Researchers have also found that thermal stress reduces the intensity of sexual behaviour in ewes and may result in failure of the animal to mate and conceive (Maurya et al. 2005).

5.4.3 Physiological Adaptation

Physiological adaptations are internal systematic responses to external stimuli in order to help an organism maintain homeostasis. The important physiological responses in the sheep are respiration rate, pulse rate, rectal temperature and sweating rate, and the levels of these variables differ with changes in season as an attempt to maintain homeostasis irrespective of the external environmental variations (Indu et al. 2014).

Earlier experiments correlated the level of thermal stress in livestock to core body temperature fluctuations, and significantly increased body temperatures indicated severe heat stress in animals (Monty et al. 1991; Silanikove 2000). Generally in farm animals, rectal temperature is used as a good indicator of core body temperature. Among various livestock species, small ruminants like sheep and goats are considered as hardy animals and are able to maintain their normal body temperatures independent of ambient temperature fluctuations. Though sheep show wider adaptability to fluctuating environmental conditions, significantly increased rectal temperature during summer indicated the severity of the heat stress to which they are exposed to. In normal environmental conditions, sheep maintains the homeothermy through sensible heat exchange mechanisms such as conduction, convection and radiation (Cabanac 1975). As temperature increases above thermal comfort zone, rate of sensible heat loss gets reduced, and evaporative cooling mechanisms are activated. Heat-stressed sheep are found to be primarily depending on respiratory and cutaneous means of cooling adjustments (Mortola and Frappell 2000). In sheep, an enhanced sweating rate is observed to be associated with environmental temperatures above 35 °C and is found to play a secondary role apart from respiratory evaporative cooling with reference to heat transfer (Waites and Voglmayr 1962). Sweat glands in the scrotum are found to be greater in size and number than the general body surface (Waites and Moule 1961) for effective regulation of the testicular temperature, as spermatogenesis in rams is highly sensitive to thermal environments. However, the magnitude of the sweating rate is observed to be decreasing with the progress of time and exposure period (Thwaites 1985). In comparison to cattle, sheep show less dependence on cutaneous evaporative cooling mechanism as only one-eighth of evaporative cooling is through sweating process (Brook and Short 1960).

In addition to rectal temperature, magnitude of changes in respiration rate is also established as a reliable indicator for quantifying heat stress in animals (Gaughan et al. 2002; Brown-Brandl et al. 2005; Sejian et al. 2014b). The increased respiration rate is the first and foremost physiological response documented in heat-stressed animals (Maurya et al. 2007). Compared to cattle, sheep are observed to be primarily depending on respiratory evaporative cooling mechanisms during exposures to elevated temperatures and are also found to have higher respiratory rate than cattle (Hales and Brown 1974; Thwaites 1985). In heat-stressed sheep, approximately 60% of the heat loss can be explained by respiratory evaporative cooling which can even go up to 80% depending upon severity of heat stress (Hales and Brown 1974). Sheep exhibits rapid changes in respiration pattern regarding the magnitude and depth with reference to the severity of heat stress, and in extreme cases, it may reach a response called panting, i.e. respiration rate above 120 breaths/min. Panting in sheep is divided into two phases: initial phase is identified by rapid shallow panting, and final phase is represented by slower deeper panting (Hales and Webster 1967). The second phase of panting involves movement of the thorax, extension of the head and protrusion of the tongue, whereas the first phase involves movement of the diaphragm (Thompson 1985; Hales and Webster 1967).

The quantification of degree of thermal stress in livestock based on respiratory rate was attempted by Silanikove (2000), termed as panting score (low, 40–60 breathes/min; medium, 60–80 breathes/min; high, 80–120 breathes/min; and severe, above 200 breaths/min before second phase panting). However, the above respiratory rate index would not indicate the true condition since it omits the second phase panting effects, though that significantly modifies the acid-base balance and metabolic heat production (Hales and Webster 1967; Hales and Brown 1974; Hofman and Riegle 1977). Moreover, seeing that measuring respiration rate in field condition to be troublesome in a group of animals, panting scores are advised as a substitute to former for evaluating the thermal stress (Mader et al. 2006; Gaughan et al. 2004; Brown-Brandl et al. 2006).

Further, animals exposed to heat stress tend to show significantly higher skin temperature than the control group. In part, this elevated skin temperature in animals could be attributed to the redistributed blood flow and includes increased blood supply to the skin surfaces for enhancing heat transfer to the surroundings (Robinson 2002). Moreover, other studies conducted in sheep identified variations in blood circulation from abdominal viscera to extremities such as ears and limbs (Blaxter et al. 1959; Webster and Johnson 1964). This elevated blood flow to the surface also increases the pulse rate in livestock (Sejian et al. 2010b).

The thermal environment also affects haematological parameters too. The reduction of haematological indices in sheep during summer could be attributed to the haemodilution effect (El-Nouty et al. 1990), destruction of erythrocytes (Shaffer et al. 1981) and depression of haematopoiesis (Shebaita and Kamal 1973).

One of the important challenges for sheep in tropical areas during summer is water availability. At the physiological level, water-stress-adapted sheep show a high capacity to concentrate urine. This is accomplished by the kidney, which has a thick medulla (Schmidt-Neilson and O'dell 1961) that can produce highly concentrated urine of up to 3900 mOsm L^{-1} in the bighorn desert sheep (Horst and Langworthy 1971; Turner 1973) and 3244 mOsm Kg^{-1} in the Awassi sheep (Laden et al. 1987) as compared with values around 3244 mOsm Kg^{-1} in urine of Awassi watered ad libitum (Degen 1977). At the same time, faecal water losses are minimized, as dehydration leads to slower feed transit in the digestive tract leading to greater water reabsorption and dryer faeces (Robertshaw and Zine-Filali 1995).

5.4.4 Neuroendocrine Adaptation

Neuroendocrine adaptations play a significant role in animals regarding the regulation of homeostasis during stressful condition. However, stimulation of endocrine system in livestock is usually found to be associated with compromised production performances such as growth and reproduction (Sejian 2013; Sejian et al. 2013a). Several studies conducted in various farm animals established the specific activity of neuroendocrine responses towards different stress types. During acute stress condition, modification of endocrine responses helps the animals for adaptation and survival, while in chronic exposures, the responses generated may lead to morbidity and mortality (Sejian et al. 2010b). Neuroendocrine responses in livestock are evoked through combination of the immune system, the central nervous system and the endocrine system (Sejian and Srivastava 2010a, b). One of the most important components of the endocrine adaptation is the stress axis – hypothalamic-pituitary-adrenal (HPA) axis. The three main components for the stress include corticotrophin-releasing hormone (CRH) neurons in the hypothalamus, corticotrophs in the anterior pituitary and the adrenal cortex. CRH acts as a primary stimulus for adrenocorticotropin hormone (ACTH) production from the pituitary gland. Consequently, ACTH stimulates glucocorticoid secretion from adrenal cortex. Cortisol is the end product of the HPA axis (Sejian 2013). The cortisol produced from the stress axis initiates various physiological adjustments in the animals to cope with the heat stress conditions (Christison and Johnson 1972). The ACTH synthesis in the animal during stress conditions is primarily initiated by CRH and VP, where the former involves in acute stress phase and the latter regulates repeated stimulation. In addition to these hypothalamic peptides, recently, pro-inflammatory cytokines are also identified to play a significant role regarding HPA axis stimulation. Currently, interleukin-1**,** interleukin-6 and tumour necrosis factor are established as stimulators of the stress axis in animals. Moreover, the role of cytokines in regulating leptin production from adipocytes is also established in animals. Recently, leptin secretion in animals was identified as an inhibitor of stress axis activity, and it is observed to be essential for animal's innate physiological ability to survive periods of nutritional stress associated with climate change-induced feed shortage (Hyder et al. 2013). Hence, both leptin and glucocorticoids contribute to the negative feedback mechanisms to regulate the stress axis activities for maintaining homeostasis. However, supplementary research efforts are needed to identify complete relationship between these hormonal mediators, immune cytokines, brain neurochemicals and stress axis stimulation and to recognize the significance of these responses in livestock production.

5.4.5 Adaptation-Based Metabolic Response

It is a well-known fact that animals exposed to heat stress tend to decrease their internal metabolic heat production for reducing the heat load in them. Heat stress-induced lower feed intake level in livestock is well established through various researches. The decreased feed intake in animals reduces the ruminal microbial digestion and thereby lowers the metabolic heat production (McDowell 1985; Monty et al. 1991). Through various researches, a strong relation between heart and metabolic heat production is well established in livestock (Holmes et al. 1976; Fukuhara et al. 1983; Yamamoto and Ogura 1985; Barkai et al. 2002). Heat-stressed animals exhibited lower heart rate, and Aharoni et al. (2003) attributed this change as an adaptive mechanism in the animal to reduce heat production. However, according to Bhattacharya and Uwayjan (1975) and Sunagawa et al. (2002), significant variations of the heart rate were absent in thermal-stressed animals. Some researchers have shown increase in heart rate in sheep during heat stress (Bianca 1968; Hales 1973).

Results obtained from several studies established a significant inverse relation between ambient temperature and thyroid gland activity. Heat stress-induced lower thyroid gland activity and thyroid hormone productions are observed in various farm animals (Sejian et al. 2010a). Since thyroid hormones are responsible for body metabolism, reduction in their levels also depresses metabolism. Apart from this reduction, there is also a change in the utilization of nutrients for energy purpose since subcutaneous fat is mobilized first, but when energy deficiency is lengthy, native breeds turn to their specialized fat depots such as the fat tail. The fat-tail adipocytes deposit fat when feed is available, and fat mobilization was demonstrated in energy-deficient Barbarine (Atti et al. 2004) as well as the Awassi sheep (Jaber et al. 2011), thus buffering fluctuations in dietary intake. Increased cholesterol levels are another indicator of fat mobilization in water-restricted sheep such as the Awassi (Jaber et al. 2004; Hamadeh et al. 2006) and Yankasa ewes (Igbokwe 1993). This reflects a deficit in dietary energy intake leading to body fat mobilization. Similarly, free fatty acid (FFA) levels were reported to increase in Awassi (Ghanem et al. 2008; Jaber et al. 2011) and the Sudanese desert sheep (Abdelatif and Ahmed 1994) indicating that fat is being mobilized from adipocytes to be used as fuel (Varady et al. 2007). In addition, combination of lower concentration of circulating insulin with reduced systemic insulin sensitivity facilitates hepatic gluconeogenesis and non-esterified fatty acid mobilization (NEFA; Bauman and Currie 1980).

Direct impacts of heat stress on gastrointestinal health and function may cause modified nutrient absorption and distribution pattern in animals. Significantly, higher heat shock protein synthesis in the small intestine (Flanagan et al. 1995) of heat-stressed animals indicated the sensitivity to thermal stress challenges (Kregel 2002). Redistribution of blood flow from viscera to body surfaces (Lambert et al. 2002) may cause oxygen deficiency in the intestine of thermal-stressed animals (Hall et al. 1999). Enterocytes are particularly sensitive to hypoxia and nutrient restriction (Rollwagen et al. 2006), resulting in ATP depletion and increased oxidative and nitrosative stress (Hall et al. 2001). This contributes to tight junction dysfunction and gross morphological changes that ultimately reduce intestinal barrier function (Lambert et al. 2002; Pearce et al. 2013).

5.4.6 Blood-Biochemical Mechanisms

Biochemical response plays a significant role in the attempt of animals to counteract thermal stress. Blood glucose levels decrease with increasing ambient temperature (Ramesh et al. 2013) which may occur due to increased utilization of glucose by respiratory muscle (Sejian et al. 2010b) during panting. Such higher utilization of glucose by respiratory muscle may overcome the hyperglycaemia by glucocorticoids and epinephrine. Additionally, similar reports had been recorded in sheep (Nazifi et al. 2003). Researchers attributed the decline in blood glucose to lowered level of thyroxine in heat-stressed conditions so as to lower the metabolic rate to prevent hyperthermia. Additionally, considering postulation given by Srikandakumar et al. (2003), decrease in blood glucose in response to heat stress can be explained with the lean body condition of experimental animals which is very well evident from mean cholesterol level of control animals. Nevertheless, some researchers have attributed lower gluconeogenesis and glycogenolysis during thermal stress to reduced plasma insulin and thyroxine synthesis (Habeeb et al. 1996), while others identified elevating corticosteroid synthesis resulting in higher gluconeogenesis and glucose utilization (Habeeb et al. 1997). In addition, some researchers explained the reason for hypoglycaemia during heat stress to haemodilution resulted from increased water transport to circulation along with increased glucose utilization for high muscular activity (Rasooli et al. 2004). Contradictory reports also had been observed by some researchers (Srikandakumar et al. 2003; Sejian and Srivastava 2010a).

A study by Ramesh et al. (2013) showed that total protein and globulin decreased with increasing temperature, whereas albumin showed reverse trend under heat exposure. Compared to total protein and globulin, albumin is established as the most sensitive indicator for representing protein status in the animals (Shetaewi 1998). The increase in both serum albumin level and albumin/globulin (A/G) ratio under heat exposure may be due to synergistic effect of increased glucocorticoids and suppressed insulin and thyroxine level (Habeeb et al. 1996) under heat stress. Higher serum albumin production associated with increased osmotic pressure of the blood would cause increased water movement from extracellular and intracellular fluid to vascular spaces, thereby regulating the plasma volume within normal limits (Wilson 1984). Several researchers have identified heat stress inducing lower protein concentration in livestock (Habeeb 1987; Sejian et al. 2008a). The decreased protein concentration during heat stress would initiate hepatic gluconeogenesis through higher glucocorticoids activity to meet energy requirements for adaptive mechanisms (Kamiya et al. 2006; Korde et al. 2007). It also indicates the incapability of protein synthesis to counteract protein catabolism in sheep (Marai and Habeeb 2010). Decreased protein level in thermal-stressed livestock could be due to reduced feed intake associated with lower nitrogen availability (Sejian et al. 2013b).

The serum total lipid concentration was also decreased in the animals exposed to prolonged thermal stress and could be directly attributed to increased hepatic gluconeogenesis or mobilization of fatty acids to meet additional energy requirements for coping to the stress condition (Kamal et al. 1989a, b). Plasma-free fatty acids, total lipids and cholesterol concentration were decreased during prolonged exposure of hot environment. Lower levels of ruminal ammonia and blood urea nitrogen were also reported in Merino sheep maintained at high temperature (35 °C) than those of same animals when kept at low temperature (15 °C) (Todini 2007). Serum cholesterol levels increase due to heat exposure which is attributed to depressed level of thermogenic hormones in heat stress (Ramesh et al. 2013). Similarly, substantiation with variation in thyroidal activity leads to hypercholesterolaemia (Sejian and Srivastava 2010a) under heat-stressed conditions. Some researchers attributed the increased level of cholesterol with enhanced activity of HMG-CoA reductase – the limiting enzyme in cholesterol production in heat-stressed rabbits (Salem et al. 1998; Ondruska et al. 2011). Sejian et al. (2008b) correlated increased cholesterol under heat-stressed conditions with the elevated cortisol secretion to cope with the stressful condition, as cholesterol also acts as an activator for glucocorticoid hormone synthesis. In contrast, decrease in total lipid concentration was also reported (Nazifi et al. 2003; Rasooli et al. 2004) in prolonged thermal stress in which deficiency of glucose due to higher expenditure leads to increased utilization of lipids.

Sheep exposed to extreme thermal stress showed significantly elevated glucose, blood urea nitrogen, uric acid, potassium, chloride and aspartate aminotransferase production (Srikandakumar et al. 2003; Nazifi et al. 2003; Rashid et al. 2013). In addition, prolonged heat stress caused lower levels of plasma potassium which were also found in sheep (Rashid et al. 2013). During heat stress, increased gluconeogenesis controlled by corticoids might also lead to enhanced activities of serum glutamic oxaloacetic transaminase (SGOT) and serum glutamic pyruvic transaminase (SGPT) (Kamal et al. 1989a, b). Singh et al. (1983) reported increased alkaline phosphatase activity in Nali and Nali x Soviet Merino sheep exposed to heat stress. Serum protein concentrations were increased at 35 °C and 40 °C exposure. Blood plasma vitamin A level was decreased as the ambient temperature increased, while atmospheric pressure was decreased in rams, but in ewes it did not show specific trend. Further, the activity of plasma acid phosphates and LDH was comparatively higher during summer than spring season, while GOT, GPT and alkaline phosphates did not change much in ewes.

5.4.7 Cellular Responses of Sheep Adaptation

Earlier in vitro experiments have conformed both sudden and slow natures of cell death in higher temperatures, suggesting different pathways and kinetics of heat stress-associated cell death in farm animals (Vidair and Dewey 1988). Nevertheless, the threshold time at which heat stress triggers the cell death is influenced by various factors such as tissue and cell type; hence, the response of cell to the heat stress depends upon the susceptibility or resistivity of the particular cell (Mertyna et al. 2007). Studies have also proved detrimental effects of heat stress on the pituicytes and hepatocytes, bringing about necrosis (Sritharet et al. 2002). The ratio of neutrophil to lymphocyte (N/L) is widely established to be a simple and reliable tool for assessing stress impacts on farm animals (Minka and Ayo 2008; Minka and Ayo 2011) as under stress environments, particularly heat stress decreases both humoral and cellular immune responses (Kannan et al. 2002; Minka and Ayo 2008), which results in an increase in N/L ratio. Higher N/L ratio during stress conditions clearly indicates the significantly increased glucocorticoid secretions in the farm animals (Kannan et al. 2002). Further, significant reduction in haemoglobin (Hb) and packed cell volume (PCV) was reported in various livestock species as a result of heat stress. This could be attributed to the fact of severe haemoconcentration as a result of thermal stress in these animals (Minka and Ayo 2008; Sejian et al. 2010a).

5.4.8 Molecular Responses of Sheep Adaptation

Responses of the cell to stress follow different pathways including mechanisms that promote its survivability in the particular condition to apoptosis for removing damaged cells. The various defence mechanisms elicited in the cells are influenced by differences in stress type and magnitude. One of such distinctive response is the synthesis of heat shock proteins, and previously it has been characterized as a biochemical response of the cells to minimal thermal stress (i.e. increased temperature of about 3–5 °C from original) (Lindquist 1986). Various studies established effects of heat stress and cold stress on roughly 100 and 20 genes, respectively (Collier et al. 2008).

Heat shock response mainly composed of three components including heat shock proteins (HSPs), heat shock factors (HSFs) and heat shock elements (HSEs). Under normal conditions, HSFs are found to be united with HSPs. However, increased numbers of misfolded proteins in the cells initiate the heat shock responses during heat stress conditions. The HSFs get detached from HSPs and trimerize, hyperphosphorylize and bind with the promoter region of HSEs for further release of HSPs. The HSPs are found to be increasingly bound to misfolded proteins (Saxena and Krishnaswamy 2012) to protect the cells from protein mis-aggregation. Some of the important HSPs identified in farm animals are HSP 27,40,60,70 and 90. Among these, HSP 70 is also established as a confirmatory biological marker for assessing heat stress in livestock.

In addition to HSPs, expression of leptin (Bernabucci et al. 2006) and interleukins, interleukin-2 (Lan et al. 1995) and interleukin-6 (Wang et al. 2000) genes are also found to be changed markedly during thermal stress. Varying expression level of interleukins and leptin during various seasons suggests a link between these genes and environmental conditions. Elevated circulating concentrations of IL-6 have been observed following localized or whole-body hyperthermia in primates (Bouchama et al. 2005). Increased level of IL-2 production by splenocytes under acute heat stress was shown in avian species (Han et al. 2010) which leads to increased lymphocyte proliferation. Additionally, Lacetera et al. (2009) showed enhanced leptin secretion from adipose tissue during thermal stress with subsequent increase in circulating leptin concentration. However, very high temperature was reported to reduce leptin concentration in lymphocytes. Therefore, the downregulation of leptin and OB-R gene expression during heat stress was found to be the mechanisms through which heat-stressed animals compromise the immune functions. This is an indication of the adaptive mechanism to high environmental temperatures, which may culminate in immune suppression in the animals.

5.5 Conclusion

The review highlights the adverse impacts of heat stress on livestock production potential as well as elaborately deals with the various mechanisms by which the sheep survives the environmental stresses. Climate change affects both sheep performance and profitability through its direct and indirect effects. Further, the review addresses the inherent potentials of sheep in terms of morphological, physiological, behavioural, cellular and molecular adaptations to climate change. Though there are several way outs to lower the thermal stress effects on sheep, developing long-term approaches are the need of the hour for adapting to the climate change effectively. Research efforts are still needed for the complete understanding of the interactions of climate system with livestock production along with other drivers of change in wider development trends.

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6

Sheep Genetic Diversity and Breed Differences for Climate-Change Adaptation

Ahmed R. Elbeltagy

Abstract

Numerous factors may affect the resilience and sustainability of global sheep production systems, and climate change will provide new challenges in this regard. In this chapter, the author addresses phenotypic and genetic variations associated with variable climatic conditions, particularly those associated with adaptation to biotic and abiotic stressors. The first section reviews aspects of phenotypic and genetic variations associated with tolerance characteristics, e.g., coat color, tail shape, and body temperature under extreme weather events. The second section examines genomic variation associated with tolerance to climate stress using different genomic approaches. In the final section, the basic information and strategies for the genetic improvement of sheep for climate-stress-tolerance traits, e.g., genetic parameters and genomic tools, are discussed. In all sections, research examples are provided of specific adaptations to certain stresses. The information provided in this chapter should extend the understanding of the genetic architecture of climate-driven adaptation and evolution, genomics, and selective breeding. It should also encourage the application of such results for supporting sheep breeding and production to cope with the stresses resulting from expected global climate change.

Keywords

Sheep • Diversity • Climate • Stress • Adaptation

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Contents

6.1 Introduction

Sheep provide a source of high-density energy (fat), protein (lean mutton), and other livelihood and economic supporting products (milk, wool/hair, hoofs). Sheep are critical for food security and livelihoods, particularly under stressful and diverse environments that are expected to be under severe climate changes. Demand for animal products is foreseen to increase significantly in the future, while competition for resources, e.g., competition between livestock and human for land, for the production of livestock feeds and green fuel, will increase, dictating that livestock systems must increase both productivity and efficiency. Sheep, in their natural habitat and in most production systems in small holdings under stressful condition, are usually not competing for concentrates that demand for biofuel; rather they rely on natural vegetation for grazing. Sheep also require less water than do other livestock species in terms of the amount (liter) of water/kg meat produced and require only 57% of the water required by cattle (8763 L/kg mutton vs. 15,415 L/kg beef) (Mekonnen and Hoekstra 2012).

In the future, climate change is expected to be a major force testing the resilience of global food production systems (Thornton et al. 2009; Renaudeau et al. 2012). Ensuring livestock systems remain productive and efficient under changing climates will be a major challenge. This is unlikely to be achieved with a single strategy; rather it will rely on a complex of adaptation-mitigation strategies, focusing on the individual animal (genetics), and its production system components (housing, reproduction, nutrition, and health care). In the wake of changing climates, phenotypic variations will mainly be the result of genetic adaptation at the genome level and will be a major challenge for utilization in sheep breeding and genetics (e.g., marker-assisted selection and breeding strategies). Therefore, scientists and breeders must identify breeds/populations of sheep that can economically produce and are robustly suited for future climates.

Adaptation for climate stress could be generally defined as an animal's ability to survive, grow, and reproduce in the presence of environmental stressors that include (1) direct abiotic stressors (heat, severe weather events, drought/water unavailability, and intensity of solar radiation) and (2) biotic stressors (indirect stressors of climate change, as they increase due to climate changes) such as existing and emerging diseases and parasites (Thornton et al. 2014).

Genetic improvement of sheep for climate-stress-related tolerance (abiotic)/resistance (biotic) will be a major pillar in the implementation of sustainable sheep production systems, under changing climate with developing stresses. Preparation for such transition will require significant research efforts in three areas: (1) production system vulnerability and resilience under different changing climate scenarios; (2) detection of phenotypic variation in animal tolerance/resistance traits and genetic background responsible for such variation, including use of landscape genomics, signatures of selection, candidate gene, and quantitative trait loci (QTL) studies associated with tolerance performance; and (3) strategies for breeding systems for genetic improvement of tolerance traits including interaction among reproduction, production performances, and adaptation traits. In this chapter, the last two points will be discussed, as the availability, utilization of data, and understanding results of research activities in these two areas would play a crucial role in the genetic improvement for sheep adaptation to climate-change stressors, develop resilience of production systems, and improve the livelihood and food security for sheep breeding communities.

6.2 Phenotypic and Genetic Variations of Sheep Tolerance Traits to Local Climate

6.2.1 Thin Tail and Fat Tail

One of the most basic phenotypic characteristics in sheep, which is linked to adaptation, is the tail shape. Almost 25% of the world sheep are recognized for their fat tails or rumps (Fig. 6.1). These sheep are expected to be more adapted and able to survive in the challenges of desert life and other extreme climatic conditions. They are therefore predominantly located in most of the climate-stress areas of the Middle East, North, East and Southern Africa, Iran, Pakistan, and some parts of Central Asia and China, where climate is characterized by heat, rain seasonality, and the existence of periods of prolonged droughts, and therefore poor pasture. The shape and size of the fat tail vary considerably among breeds and populations.

Adipose tissues accumulating in the tail are mobilized during periods of food scarcity and correspondingly tend to decrease in size during seasonal periods of weight loss. The uneven distribution of body fat in the tail has a thermoregulatory effect as an appendage favoring heat dissipation. The tall and slender "low-volume" types of bodies of fat-tailed sheep are also important adaptation characteristics to periods of heat stress in dry climates, and along with the longer legs, they are particularly suitable characteristics for walking long distances in search of pasture and water as in the nomadic lifestyles of herders in most arid dry regions of the

Fig. 6.1 Different fat tail and rump shapes in sheep breeds

world. Identification of genomic regions that have been associated with selection for phenotypic adaptation traits, such as tail fat deposition, is important and challenging areas of research in sheep genetics. Moradi et al. (2012) performed a small genome-wide scan using 50K SNP (single-nucleotide polymorphism) Chip in an attempt to identify selective sweeps associated with fat deposition, in a comparative study of two Iranian breeds: one thin-tail (Lori Bakhtiari) and a fat-tail (Zel) breed (47 animals from each breed). In a separate analysis, they analyzed genotyping data of seven sheep from the sheep HapMap (http://www.sheephapmap.org) breed data repository. These included four thin-tail breeds – Deccani, Scottish Blackface, Bunder Oberland, and Gulf Coast Native; and three fat-tail breeds – Karakas, Norduz, and Afshari, looking for selective sweeps associated with tail fat deposition. Population differentiation using F_{ST} statistics in the two Iranian thin- and fat-tail breeds revealed seven chromosomal regions on sheep chromosome (*Oar*) 5. Almost all of these regions overlapped with QTLs that had previously been identified as affecting fat and carcass yield traits and, above all, mechanisms of stress tolerance in bovine. For instance, the *TCF7* gene on *Oar* 5 plays role in T cell receptor V(D)J recombination, alpha-beta T cell differentiation and cellular response to interleukin-4 (immunity function).

Selective sweeps detected using the F_{ST} approach with the sheep HapMap – four thin- and three fat-tailed breed – data revealed that three of these regions were located on *Oar 5*, O*ar 7*, and *Oar X*. Increased homozygosity in these regions was detected favoring fat-tail breeds on *Oar 5* and *Oar X*, and was in favor of thin-tail breeds on *Oar 7*. This preliminary research reflected the association between fat-tail deposition genes and climatic-stress-tolerance performance. However, further investigations are still needed from this point. Table 6.1 summarizes some of the orthologous areas in bovine and ovine species and published bovine genes and QTLs.

Table 6.1 Orthologous genes possibly related to fat deposition in the bovine genome identified using the BLAST (Basic Local Alignment Search Tool) genome search with UCSC (University of California Santa Cruz) Genome Browser

Chromosome	Location on Ovine genome	Location on Bovine genome	Gene	QTL associated
Oar-2	2:55859169-56302905	8:62601056-63034390	*NPR2*	Fat depth
			*SPAG*8	Carcass weight
			HINT2	Body weight (birth)
			TMEM8B	
Oar- 2	2:73628609-73861345	8:45226663-45415081		Fat depth
				Fat thickness
				Carcass weight
				Body weight (birth and mature)
Oar-3	3:146615284-146676235	5:33981017-34041987	*CACNB3*	Meat tenderness
			DDX23	Hot carcass weight
				Birth weight
Oar-5	5:47146900-47332222	7:44936435-45113988	*PPP2CA*	Fat thickness
			SKP1	
			TCF7	
Oar-7	7:30510065-30587784	10:29363930-29441529	na	Milk fat yield
				Carcass weight
				Hot carcass weight
				Body weight (birth)
Oar-7	7:46639859-46910155	10:45312778-45581699	*PTGDR*	Milk fat yield
				Hot carcass weight
				Body depth
X	X:59192476-60151772	X:51751347-52712765	na	

Source: Edited from Moradi et al. (2012)
na not available

In the same context of investigating the association of polymorphism of genes, regulating functions related to tolerance, reproduction, and production performance, with the fat-tail characteristics, Chelongar et al. (2014) studied the association of genetic polymorphisms within the insulin-like growth factor 1 (*IGF1*) and pituitary transcription factor 1 (*PIT1*) genes with fat-tail sheep. The association was tested in the Iranian Makooei sheep breed, using the conventional single-strand conformational polymorphism (SSCP). Results showed a significant statistical association between fat-tail measurements and genotypes of both genes. For the *PIT1*, the P3 genotype was found to be associated with superiority of both tail length and width ($P < 0.01$), while the P4 genotype showed an association with significant superiority of fat-tail thickness ($P < 0.01$). Meanwhile, the AA, AG conformational patterns of *IGF1* had a significant effect on fat-tail thickness ($P < 0.05$).

The association of SNP polymorphisms in both growth hormone (*GH*) and leptin (*LEP*) genes with fat-tail measurements (dimensions) in the same Makooei sheep breed was also investigated by Hajihosseinlo et al. (2015) using an SSCP (single-strand conformation polymorphism) denaturation approach in 100 ewes. The authors reported significant statistical associations between all fat-tail measurements studied and the *GH* and *LEP* genotypes. Individuals with the G4, L4 genotype of *GH* and *LEP* genes, respectively, had shorter tail length, less tail thickness, and width compared to individuals with other genotypes ($P < 0.05$). The results also demonstrated that individuals with the G5 and L5 genotypes of *GH* and *LEP* genes were associated with superiority of tail length and thickness ($P < 0.05$), while individuals with the G2, L2 genotypes showed superiority in tail width ($P < 0.05$).

6.2.2 Coat Color, Body Measures, and Mass

Coat color is a qualitative trait and an indicator of adaptability to heat stress (Fadare et al. 2013; McManus et al. 2011a). Coat color is an important trait of biological, economic, and social significance. The genetic cause of domestic white and black sheep involves a tandem duplication affecting the ovine *agouti signaling protein (ASIP)* gene and two other neighboring genes, *AHCY* and *ITCH* (Norris and Whan 2008). Sheep coat color is regulated by a combination of copy number variation (in *ASIP)* and deregulated gene expression (*AHCY* and *ITCH* promoter). Norris and Whan (2008) identified some white sheep with up to four copies of the *ASIP* allele, while the black sheep have a nonduplicated *agouti* allele and the silenced promoter that mutes its expression. Li et al. (2014), conducting a GWAS (genome-wide association study) of sheep coat colors using Illumina 50K SNP BeadChip in the Finn sheep population, identified 35 SNPs associated with all the coat colors in the studied breed, which cover genomic regions harboring the pigmentation genes including the previously identified *ASIP*, in addition to TYRP1 and MITF. The signals detected around the *ASIP* gene were explained by differences in white versus nonwhite alleles.

McManus et al. (2009) found distinct differences between color groups (white, brown, and black) in Santa Inês sheep in some major physiological parameters indicating animal stress. White color individuals showed lower heart beat rate (HPR), respiration rate (RR), and rectal temperature (RT) than the other color groups, indicating better adaptation to heat stress. The brown Santa Inês sheep was the least adapted with thicker skin, longer hairs, and fewer sweat glands. Pereira (2005) stated that light coats (white or cream) were more efficient in reflecting radiation especially higher wave lengths. Meanwhile, several publications (Silva 2000; Gebremedhin and Wu 2002; Pereira 2005) confirmed that animals with more pigmented skin were more resistant to ultraviolet rays, in spite of the fact that such high pigmentation leads to absorbing more thermal energy, increasing surface skin temperature and therefore causing more heat stress. However, sheep with light-colored coat is not accompanied by a dark-colored skin.

Fadare et al. (2013) studied the effect of coat color on some physiological and blood parameters that are associated with climatic-stress-tolerance traits, including rectal temperature (RT), respiration rate (RR), pulse rate (PR), packed red cell volume (PCV), red blood cell count (RBC), white blood cell count (WBC), plasma sodium (Na^+) and potassium (K^+), in addition to a heat-stress index (HIS) in four sheep color categories of West African Dwarf sheep. The studied measures were recorded before sunrise and sunset during both late dry season (January–March) and early rainy season (April–June). Animals with a black coat showed the highest significant ($P < 0.05$) measures of RT, RR, PR, and HSI, respectively, followed by brown mouflon and brown with extensive white, while the Badger Face sheep had the lowest mean values. Coat color also had a significant effect on blood parameters (RBC, WBC, Na^+ and K^+). These results indicate that selection for white-coat-colored sheep to attenuate heat stress is desirable in the hot humid tropics.

In an attempt to assess the relationship between genetic variability in coat-color traits of the same West African Dwarf sheep with heat-stress tolerance, Decampos et al. (2013) studied the coat-color genotype effect on skin and rectal temperatures, pulse and respiratory rates, white blood cell count (WBC), red blood cell count (RBC), hemoglobin (HGB), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin cell (MCHC), red cell distribution width (RDW), platelets (PLT), mean platelet volume (MPV), platelet distribution width (PDW), and plateletcrits (PCT). The major coat-color gene variations observed included the white/tan (A^{wt}), black (BB), spotted brown (Bb), gray/mouflon (A^{gt}), and badgerface (A^{b}). Results showed that the genotype for coat-color genes had a significant ($P < 0.01$) effect on body temperature and pulse rate, with the gray/mouflon (A^{gt})-color animals having the highest body temperature (38.90 °C ± 0.22 °C) and Bb had the lowest (37.20 °C ± 0.35 °C). White/tan (A^{wt}) had the highest pulse rate (28.90 ± 0.66 beats/min) and Bb had the lowest (20.00 ± 2.00 beats/min). The coat color had significant ($P < 0.01$) effects on RBC and MPV with brown (Bb) color having the highest RBC counts (18.20 ± 0.00) and badgerface (A^{b}) having the lowest (11.50 ± 0.62). The Bb genotype had the highest value for MPV (5.60 ± 0.00 fL) and A^{b} had the lowest (4.70 ± 0.15 fL). It was therefore concluded that sheep with Bb and A^{b} genotypes tolerate heat stress better than other coat-color genotype groups. These results confirmed the recommendation to consider the genotype of coat color in the selection for climate stress and changes.

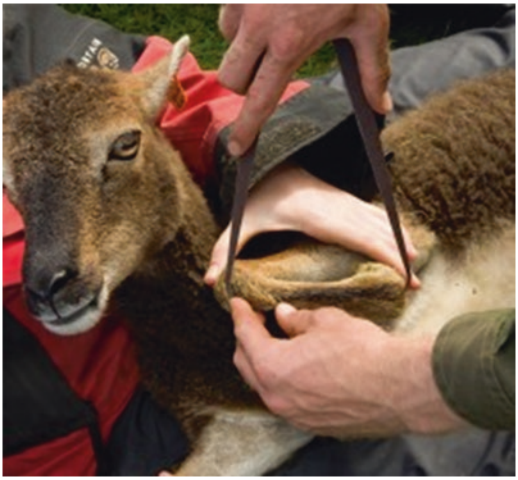

Fig. 6.2 Body measures being recorded for a Scottish Soay sheep animal

Scottish Soay sheep is a breed raised on an isolated island in Hebrides, where the mean minimum and maximum daily ambient temperatures near the islands had significantly increased in the period between 1985 and 2007 (Maloney et al. 2009) (~22 years or 7 generations considering the generation interval of around 3 years). It was recently reported that the proportion of dark-color sheep in the Hebrides has decreased, along with larger-sized animals, while smaller-sized lighter-colored Soay sheep (Fig. 6.2) have been increasing. It was therefore concluded that an apparent genetic linkage between loci for the coat-color polymorphism and loci with antagonistic effects on body size resulted in such a decrease. It could be suggested that while in the past a dark coat has offset the metabolic costs of thermoregulation by absorbing solar radiation, the selective advantage of a dark coat became invalid as the climate became warmer in the North Atlantic. In parallel, Bergman's rule which states "populations and species of larger size are found in colder environments, and species of smaller size are found in warmer regions" may also be operating there, reducing the selective advantage of large body size in warmer environments, and "smaller-sized and lighter-colored sheep could be favored by their lower gross energy demand."

6.2.3 Parasite Resistance

Gastrointestinal nematode infections are one of the main health issues in grazing sheep and have a great impact on their production. They are often affected by climate change. Selection for nematode resistance has mainly been based on the use of indicator traits, such as fecal egg count (FEC) (Bishop and Stear 2001). Concerning the phenotypic difference among breeds in their resistance to gastrointestinal nematodes, Baker and Gray (2003) indicated that most sheep breeds identified as resistant are tropical indigenous breeds that are usually characterized as "genetically unimproved small breeds," while exotic (improved) breeds are considered as poorly resistant. Baker (1998), based on a 6-year study in coastal Kenya, concluded that Red Maasai sheep was more resistant to *Haemonchus contortus*, with two to three times more productive, than the exotic Dorper sheep, in the subhumid Kenyan environment. Bishop and Morris (2007) concluded that breed differences in resistance to nematode infections were documented, particularly for tropical or subtropical sheep facing *H. contortus* challenge and the existence of good evidence of relatively good resistance in Barbados Blackbelly, St. Croix, Florida Native and Gulf Coast Native breeds (Caribbean and southern United States), Garole (India), and Red Maasai (Africa) sheep breeds. However, collecting and quantifying such indicator traits is a costly and time-consuming process and usually requires the animal to undergo parasitic challenge. Therefore, investigating resistance-associated molecular markers would be very advantageous, under stressing environment. To date, several studies have reported QTL for nematode resistance in different sheep breeds (e.g., Crawford et al. 2006; Davies et al. 2006; Sallé et al. 2012). However, little overall consensus across the sheep breeds studied has been reported, which might be due to the genetic complexity of the trait, diversity of the studies conducted as involving a variety of sheep breeds, nematode species, and experimental approaches followed. Moreover, it has been shown that standard additive genetic studies may fail to explain most of the known genetic variation influencing such complex disease resistance traits (Manolio et al. 2009; Kemper et al. 2011) suggesting the presence of missing undetectable additive genetic variance using conventional GWAS.

Riggio et al. (2014) aimed to (1) identify loci underlying variation in FEC as the most appropriate measure for nematode resistance, both within and across four sheep populations (Scottish Blackface lambs, $N = 752$; Sarda-Lacaune backcross ewes, $N = 2371$; Martinik Blackbelly-Romane backcross lambs, $N = 1000$; and Texel lambs, $N = 64$); (2) evaluate the accuracy of genomic estimated breeding values (gEBV) for FEC trait within and across the four populations; and (3) explore nonadditive genetic variation (i.e., epistasis and heterozygote advantage) for the FEC trait. Phenotyped animals were genotyped using the Illumina 50 K SNP BeadChip. Recorded phenotypes were FEC for *Nematodirus* and/or *Strongyles* at different ages. Results indicated several genomic regions of interest, both intra- and inter-sheep populations studied. gEBV had moderate to good intrapopulation predictive accuracy, whereas interpopulation predictions had accuracies close to zero. Epistasis analysis identified two significant pairwise SNP interactions for *Strongyles*. Heterozygote advantage analysis identified some significant SNPs. In conclusion, genetic prediction for nematode resistance could be valuable for intrapopulation studies but not for the interpopulation level, which encourage investigation of individual populations.

6.2.4 Body Temperature Under Extreme Weather Events

Projection of climate-change effects includes the frequent occurrence of severe climatic events, e.g., droughts and heat waves. One of the pioneer studies investigating animal variation in response to severe heat waves was by Elbeltagy et al. (2015),

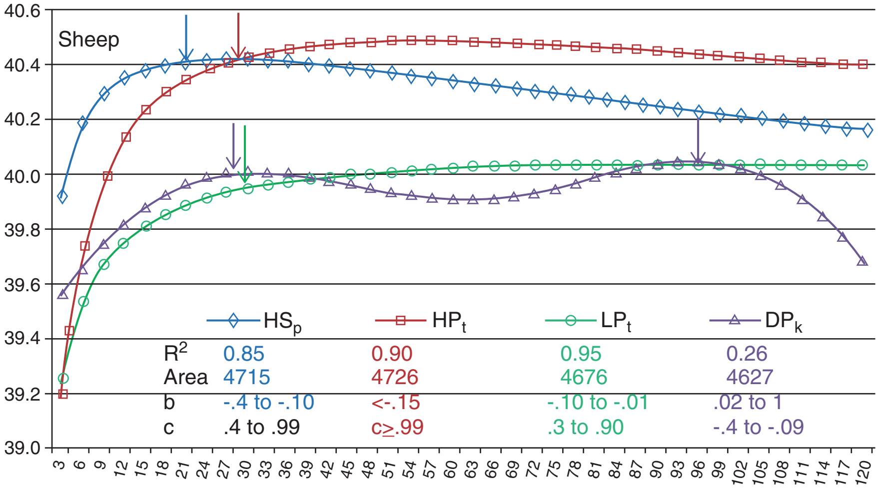

Fig. 6.3 Classification of sheep according to their rectal temperature response to acute heat stress resembling severe heat waves under expected climatic change

where the methodology relied on assessing variation in body thermal response to acute heat stress (AHS). In this experiment, 68 desert Barki ewes were confined in a climatic chamber at >41 °C for 120 min, and their RT was measured at 3-min intervals. Individual sheep records were fitted to a linear mathematical model: $y = a + b \ln(x) + c (\ln(x))^2$. Mathematical fitting of RT resulted in the classification of the sheep into four groups according to the value of two main parameters of the curve: peak value (rectal temperature) and post-peak slope (Fig. 6.3). The four sheep groups were high peak with post-peak plateau (HPt, $n = 13$), low peak with post-peak plateau (LPt, $n = 11$), high peak with post-peak slope (HSp, $n = 8$), and dual-peak (DPk, $n = 8$). The LPt sheep were proposed to be the most tolerant, while the HPt sheep were considered the least. Until now, no interbreed variation or transcriptome analysis has been conducted to link RT performance variation to gene expression; more investigation in this regard is needed.

6.3 Genomic Variation Associated with Tolerance/Adaptation to Local Stressors

Local and/or regional climatic conditions, e.g., temperature, humidity, and precipitation, influence the spatial distribution of phenotypic and genetic variations in all livestock species. The detection of climate-stress-mediated signatures of selection and QTL are potential approaches to interpret the genetic basis of adaptation to changing climates (Joost et al. 2007; Lv et al. 2014; MacCallum and Hill 2006). The identification of genomic adaptive variation could also provide insights into functional variants playing major roles in the adaptation process. Indigenous sheep breeds have a population history characterized by domestication and human selection for favorable economic production traits (mutton, dairy, and wool). Most of the populations raised under severe stresses, e.g., in hot, arid desert environments, have not been exposed to stringent artificial selection or objective genetic improvement plans. Their current genetic makeup is mainly due to natural selection along with absent or limited human-mediated selection. SNP-based genomic comparisons among divergent breeds have successfully identified many genomic regions and genes that have undergone selection sweeps (Gu et al. 2009; Qanbari et al. 2010; Stella et al. 2010; Amaral et al. 2011; Lv et al. 2014; Kim et al. 2016). Most studies have been based on variation in allele frequency (F_{ST}-based approach), genotyping of homozygote regions (ROH), extended haplotype pattern (iHS for intrapopulation and iES/R_{sb} or hapFLK for interpopulation variations). However, most of the published research on sheep, so far, has neglected the integration of genomic and environmental data (Kijas et al. 2012; Fariello et al. 2014). The linkage among signatures of selection and genomic patterns associated with environmental differences was missed in such trials. One of the most recent research efforts in this regard was performed by Kim et al. (2016) in which signals of natural selection were investigated in hot-arid-adapted Egyptian desert Barki sheep and goats, using genotype data from the *ovine* and *caprine* Illumina 50K SNP BeadChips. Several candidate regions under selection were identified. The majority of the identified genes were those involved in multiple signaling and signal transduction pathways in a wide variety of cellular and biochemical processes, including traits for adaptation to hot, arid environments, such as thermo-tolerance melanogenesis (FGF2, GNAI3, PLCB1), body size and development (BMP2, BMP4, GJA3, GJB2), energy and digestive metabolism (MYH, TRHDE, ALDH1A3), and nervous and autoimmune response (GRIA1, IL2, IL7, IL21, IL1R1). Most importantly, eight common candidate genes under selection in both *ovine* and *caprine* were also identified, representing shared selection signature of a conserved syntenic segment on sheep chromosome 10 and goat chromosome 12, which could most likely be evidence for selection in a common environment in two different, but closely related, species.

Pioneer research activities, which involved the spatial analysis method (SAM), to detect candidate loci for natural selection in a step toward the landscape genomic approach were represented (Joost et al. 2007, 2008; Pariset et al. 2009). More recently, other approaches were developed to investigate the genomic landscaping to detect basics for genomic adaptation to various local climates and therefore expected climate-change effects on the genomic makeup of indigenous livestock, and to test the associations among SNP alleles (candidate QTL) and climate variables in various organisms. The two most well-known approaches in this stage were BayEnv (based on using environmental correlations to identify loci underlying adaptation to local environments), (Coop et al. 2010) and the "latent factor mixed model," LFMM (which implements fast algorithms using LFMM, based on a variant of Bayesian principal component analysis (PCA) in which residual population structure is introduced via unobserved factors) (Frichot et al. 2013). Joost et al. (2013) gave a good presentation of such approaches. Although these approaches had their weaknesses due to different implicit assumptions in the models, several studies have succeeded to investigate genetic adaptation to different climatic pressures by scanning the genome for environmental correlations in several organisms (Hancock et al. 2010 in human, Meier et al. 2011 in Fish, and Shimada et al. 2011 in the marine three-spined stickleback).

In sheep, evidences for phenotypic variation due to genetic adaptation to different local climates have been reported. Nielsen et al. (2013) studied the association between lamb autumn body mass and a number of climate-related measures, including snow depth (of the previous winter), spring and summer (August) temperatures, and precipitation in August, in 38,587 lambs representing both the Norwegian white sheep (NWS) and Spel sheep breeds for the period 1992–2007. These two breeds that were studied largely differed in digestive anatomy and diet composition. Results indicated positive relationships between lamb autumn body mass and the three climate measures in both breeds. Meanwhile, there was a negative relationship between lamb autumn body mass and the spring precipitation in the Norwegian white sheep breed.

The first attempt at conducting an integrated approach for the coanalysis of geographical coordinates, environmental data, and genome-wide SNP genotyping was reported by Lv et al. (2014). In this study, 49,034 SNPs were genotyped in 32 indigenous sheep breeds, from 18 countries, that are adapted to a wide spectrum of climatic variation. The countries and corresponding agro-climatic zones included Southern Europe: Italy, Spain, and Cyprus; Central Europe: Germany and Switzerland; Northern Europe: Finland and Norway; Western Europe: Ireland, United Kingdom; South Asia: Indonesia, India, Iran; West Asia: Turkey; East Africa: Kenya; South Africa: South Africa; the Pacific: New Zealand; Caribbean islands: Trinidad and Tobago; and the United States of America. Nine environmental variables included in the study were mean diurnal temperature range (DTR, °C), number of days with ground frost, average monthly precipitation rate (PR, mm/month), the coefficient of variation of monthly precipitation (PRCV, %), relative humidity (RH, %), percent of maximum possible sunshine (SUN, %), mean annual temperature (°C), number of days with >0.1 mm rain per month (RDO), and altitude (ALT, m). Principal component analysis (PCA) was performed on the basis of climatic variables and the analysis of genetic relationships among the 32 breeds studied to identify a set of distantly related breeds adapted to extreme environments. The aim of this approach was to enhance the resolution of signatures for "climatic adaptation" and suppress any possible misleading signals due to common origins of some breeds. Results indicated that the PCA clustered the 32 native sheep breeds, according to the environment they are adapted to. PC1 represents a synthetic parameter that principally summarizes the information of three climatic variables: RDO (18.49%), SUN (17.89%), and DTR (15.91%). PC2 and PC3 did not reveal a clear geographic divergence associated with environmental variables. PCA plotting revealed that eight breeds, belonging to climatic zones of high values of precipitation and days of rainfall, have positive extreme PC1 values: four breeds from the United Kingdom (Border Leicester, Boreray, Scottish Blackface, and Soay sheep), two from Switzerland (Swiss Mirror and Valais Blacknose), one from Norway (Spael colored), and one from Finland (Finnsheep). Six breeds have PC1 values at the negative extreme mainly because of the high values of temperature, sunshine, and distribution of precipitation (TMP, DTR, SUN, and PRCV). These included one each from Iran (Afshar), Turkey (Karakas), Cyprus (Cyprus Fat-Tail), India (Indian Garole), South Africa (Ronderib Afrikaner), and Kenya (Red Maasai) (Fig. 6.4).

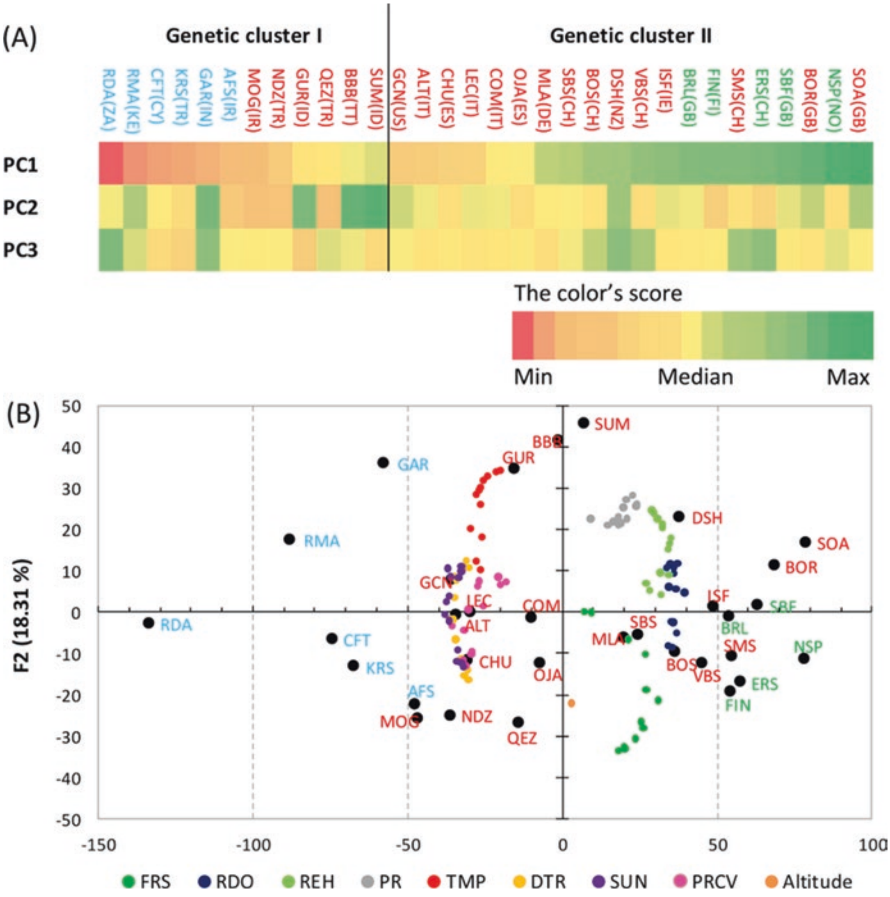

Fig. 6.4 PCA clustered of environmental variables and 32 native sheep breeds. (a) Heat strips for each of the first three PCs are shown for the 32 sheep breeds assigned to the two genetic clusters (I and II); the two letters before the breed codes indicate the country of origin: *CH* Switzerland, *CY* Cyprus, *DE* Germany, *ES* Spain, *FI* Finland, *IE* Ireland, *ID* Indonesia, *IN* India, *IR* Iran, *IT* Italy, *KE* Kenya, *NO* Norway, *NZ* New Zealand, *TR* Turkey, *TT* Trinidad and Tobago, *UK* United Kingdom, *US* United States, *ZA* South Africa. (b) The score plots of PC1 versus PC2 for the 32 old native sheep breeds and the environmental variables of their geographic origins. The breeds in contrasting environments selected for the selection tests are indicated in *blue* and *green*, respectively. The nine environmental variables are mean diurnal temperature range in °C *DTR*, number of days with ground frost *FRS*, precipitation in mm/month *PR*, the coefficient of variation of monthly precipitation in percent *PRCV*, relative humidity in percentage *REH*, percent of maximum possible sunshine *SUN*, mean temperature in °C *TMP*, number of days with >0.1 mm rain per month *RDO*, and altitude. The *small colored circles* represent the altitude or the yearly mean and monthly parameters of one of the eight climate variables across all the 32 breeds

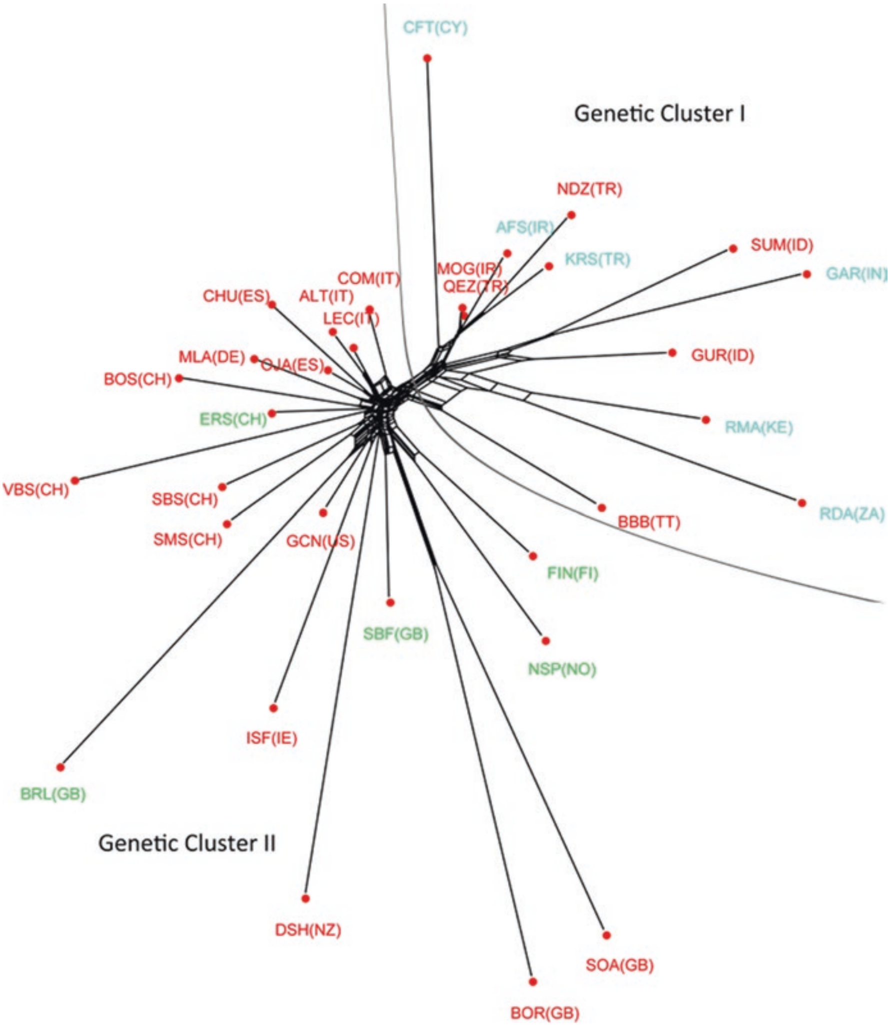

Fig. 6.5 A neighbor-net graph of pairwise Reynolds' genetic distances (D_R) genomic relationship among the studied 32 breeds (Source: Lv et al. 2014)

The results of the PCA were confirmed by the pairwise Reynolds' genetic distances, D_R (Reynolds et al. 1983), as the breeds were grouped into two main clusters (Fig. 6.5). Cluster I included breeds from South Asia, the Middle East, Africa, and South America, and cluster II had breeds from Europe, New Zealand, and the United States. Resulted grouping was in agreement with the phylogeography of Kijas et al. (2009, 2012). All the breeds in cluster I were those showed negative PC1 values based on environmental variables, and all the breeds with positive PC1 values were classified into cluster II (Figs. 6.4 and 6.5). In addition, a variety of selection detection tests, genetic differentiation of SNPs (using F_{ST}), haplotype structure, and genetic-environmental correlations were also performed. A set of candidate SNPs, genes and core haplotypes under climate-driven adaptation, that were related to the biological processes of energy metabolism and endocrine and autoimmune regulation were also determined. A total of 230 SNPs showing evidence for selection, due to "climate-mediated pressure," were identified. Allele frequency of 189 (82%) of them were significantly ($P < 0.05$) correlated with climatic variables. Gene-ontology analysis of genes harboring the 189 significant SNPs identified 17 candidate genes related to GTPase regulator and peptide receptor activities in the biological processes of energy metabolism and endocrine and autoimmune regulation. Results also indicated high linkage disequilibrium (LD) and significant extended haplotype homozygosity (EHH) for the core haplotype TBC1D12-CH1 of TBC1D12 (encode signaling molecule involved in GTPase (guanosine triphosphate hydrolases) activator and regulator activities, e.g., the regulation of Ras protein signal transduction). The global frequency distribution of the core haplotype and allele of OAR22_18929579-A showed a geographic pattern and significant ($P < 0.05$) correlation with climatic variation. In conclusion, the results reflect that adaptation to local climates can shape the spatial distribution of genomic variation and candidate genomic regions resulting in adaptive variation in sheep. Results from such initial research approaches in sheep have extended our understanding of the genetic architecture of climate-driven adaptation and evolution and potential applications of such data in functional genomics, selective breeding, and genomic selection for coping with the expected global climate change on sheep.

6.4 Genetic Improvement for Tolerance/Resilience Traits for Climate-Change Stressors

6.4.1 Sheep Breeding and Diversity and Their Effects on Stress Tolerance

Domestic sheep populations have been subjected to many generations of man-directed selection pressures for increased productivity with progressive elimination of individuals that were less productive for traits of economic importance and therefore led to a reduction in genetic diversity. The gains from this selection have resulted in the nowadays highly productive sheep breeds like the Merino, Leicester, and Lincoln for wool; the Dorset, Dorper, Hampshire, and Suffolk breeds for lamb/mutton; and the East-Friesian and Lacaune as dairy breeds. Genetic diversity provides the raw material for population change through selection, as it increases the chances that sheep populations could be selected to suit the present and future environmental changes. Reduction in diversity reduces the potentiality for future genetic change toward adaptation to climate stressors. The challenge of climate change will require adapted production systems that support the existing levels of superior productivity merged with adaptation to novel stressful environments. The need for genetic diversity to accommodate these changes is of great concern. Increasing productivity and efficiency will be fundamental, but maintenance of genetic diversity and adaptation performance will also be of high priority. Having diverse farm AnGR will allow for more opportunities to match breeds to a changing climate or to replace populations affected by severe climatic events such as heat and droughts. Within breeds and populations, broad genetic diversity will allow for greater opportunities for selection for adaptation. Kim et al. (2016) reported a higher level of genetic diversity in the desert-adapted Barki sheep breeds (0.37 for both H_o and H_e), and shorter ROH stretches (4.4 Mb) in comparison to temperate sheep breeds (Romney, Texel, and Corriedale). Evidence from data from wild populations emphasized that increased genetic diversity is selectively advantageous on the individual level (Fourcada and Hoffman 2014). Therefore, it could be expected that adaptive-traits-based selection strategies could result in maintaining genetic diversity. Therefore, there is alarming concern over the growing rate of loss in genetic diversity in farm animal genetic resources (Hoffmann 2010). It is now more obvious than ever that strategies for maintaining genetic diversity would help ensure the sustainable use of animal genetic resources in changing climates and allow wide-enough genetic pools that secure sheep productivity and support the livelihood of smallholder farmers and producers.

6.4.2 What Information Is Available and What Is Needed?

There is currently a shortage of specific genetic information explaining why certain sheep breeds are more or less adapted to certain environmental stressors and therefore to climate change under such stresses. For climate-change adaptation, the breeds of greatest interest would be those prevailing for centuries under harsh environmental conditions, e.g., arid and cold desert and high altitudes. In the last decade, many sheep populations have been genetically characterized using recently developed tools based on genome-wide SNP genotyping, either using single-marker (Pariset et al. 2006a, b; Pariset et al. 2011) or haplotype-based approaches (Kijas et al. 2012; Fariello et al. 2014; Kim et al. 2016). The value and use of these data for the study of adaptation are still in progress. Several studies have addressed certain breeds from developed countries, where climate-stress-selection pressure has major footprints (Joost et al. 2007; Lv et al. 2014; Kim et al. 2016). The rapid development of genomic tools now allows analysis of functional genomic variants and regions with potential associations with adaptation (e.g., Elbeltagy et al. 2016). The study of adaptation suggests the use of a “genomic landscape approach” (Lv et al. 2014). This requires detailed information describing the production system (e.g., FAO 2012), including socioeconomic information (e.g., Drucker 2010) and indigenous knowledge about the management of the breed in its environment as well as geographic coordinates to incorporate climatic data and soil, vegetation, and water resources (Osman et al. 2012). Past studies have focused on pure indigenous breeds that are already tolerant to domestic stresses, while others promote crossbreeding as a valuable strategy for merging productivity and adaptability (Shinde and Sejian 2013). Utilizing crossbred populations requires phenotypic and genotypic characterization of the crosses. Phenotypic characterization still needs harmonization and more in-depth description. One example of such well-planned experiments is the Goat AdaptMap (Huson et al. 2014). Similar programs and data and sampling collection approach need to be developed for *ovine* populations. The challenge that will remain is the complexity of measuring adaptation phenotypes and determining which should be included and how they should be weighed in the breeding goals. A practical approach would be to select for traits associated with superior productivity under stressful conditions.

6.4.3 Genetic Relationships Between Adaptive and Productive Traits

One of the major concerns for livestock production, including sheep, is the relationship between adaptive ability and productive traits. In other words, "Is the more adapted animal, is also more prductive one?". Until now, scientific literature has only a limited number of estimates of genetic correlations among various adaptive and production traits. Knowledge of these genetic correlations is essential for the development of effective breeding objectives and implementing genetic improvement plans for sheep production under changing climate stress.

Interpretation of the genetic relationships between resistance and production traits has sometimes been misunderstood (Bishop 2012), with incorrect inferences being drawn from observations that indigenous adapted sheep breeds tend to be smaller in size with poor production, whereas high-performing exotic breeds often have poor disease resistance. Some authors have concluded that such breed differences are likely to reflect breed selection history rather than genetic antagonisms between resistance and productive traits.

Bishop (2012) reported that anemia scores were negatively genetically correlated with FEC and positively correlated with live weight in sheep (as decreasing FEC resulted in increased PCV and heavier body weight), strengthening the evidence for a lack of genetic antagonisms between productive and adaptive traits in breeding programs. It was also reported that most heritability estimates for FEC in sheep ranged from 0.2 to 0.4, and resistance to the different *strongyle* parasites was strongly genetically correlated and close to unity. Bishop et al. (2004) also reported that the genetic correlation between *strongyle* and *nematodirus* FEC was at least 0.5, indicating that FEC was a useful indicator of susceptibility.

6.4.4 Genetic Parameters for Adaptation Traits

Initially, breeding schemes to improve adaptation should be based on the selection of appropriate breeds that are adapted to the local environmental conditions, before undertaking within-breed selection programs to improve resistance (Burrow et al. 2001; Burrow 2006; Bishop 2012) or involving the breed in an introgression scheme (crossbreeding). Based on recent reviews of the literature, genetic tolerance/resistance to environmental stressors usually follows polygenic patterns of inheritance, as do production traits (Bishop 2012; Burrow and Henshall 2014). When population-wide genomic testing becomes cost-effective in the near future, tests for tolerance traits will need to be fully integrated into quantitative genetic evaluation programs.

Practically, to genetically improve tolerance traits through breeding practices, the traits must be under direct or indirect genetic control that can be detected by genetic parameters. Mandonnet et al. (2001) and Bishop and Morris (2007) reported that heritability for FEC differed in both sheep and goats, depending on the age of measurement, with FEC tends to be less heritable in kids and does. Bishop's (2012) review also indicated that PCV was heritable in sheep and goats and that Famacha scores (an indicator of anemia in the eyelid) were heritable in sheep. Additionally, the concentrations of various antibodies, eosinophils, pepsinogen, and fructosamine were moderately to highly heritable and often strongly correlated with FEC. It was therefore concluded that breeding to improve resistance utilizing these traits in livestock species is possible. Traits of tolerance to other (a)biotic stresses as measured by changes in rectal temperature have been reported in young calves with a moderate value of 0.19 (Morris et al. 2012) and in dairy cattle (Dikmen et al. 2012), who reported an average value of 0.17, indicating the possibility of genetic improvement of such traits is highly associated with tolerance/adaptation performance of several stressors. Efforts to assess the genetic parameters for adaptation measures (thermal, respiratory, and metabolic) require more research efforts.

An alternative to breeding for specific traits is to target general robustness, the ability of animals to adjust to a range of environmental conditions. The Domestic Animal Diversity Information system of FAO (Food and Agriculture Organization) (http://dad.fao.org) lists numerous breeds, particularly from mountainous and arid areas, that are adapted to extreme ranges in harsh conditions (Hoffmann 2013). Selection for robustness would likely require the development of an index involving multiple traits. Aboul-Naga et al. (2010) suggested a useful index that relied on changes in some biological parameters such as rectal temperature, respiration rate, tidal volume, minute-ventilation volume, and heat production due to both heat and exercise stresses to assess the animal tolerance to grazing stress in the hot, arid desert. Heritability of some of such traits and genetic markers associated with tolerance has been estimated (Elbeltagy et al. 2016). Early results suggest that within-breed (Barki desert sheep breed) variation in response to grazing stress (grazing in hot, arid conditions under direct solar radiation in poor pasture) can be detected in individual heritable traits (e.g., respiration rate) and in the total index (till under improvement). Animals were successfully grouped into three categories according to their response to grazing stress (high-, mid-, and low-tolerance groups), and results were confirmed in several years of testing.

6.4.5 Genomic Tools for Assessing and Improving Climate-Stress Adaptation in Sheep

The use of genomic tools plays a crucial role in the genetic improvement of tolerance/resistance traits. An increased characterization with high-throughput single-nucleotide polymorphism assays or genome sequencing is becoming necessary for interpreting the biological basis for adaptation to climatic stress and climate change. Genomic selection for biotic stresses that are associated with climate change has already been severally investigated, as described for parasite resistance in this chapter. In addition, sheep facial eczema (FE), which occurs in warmer districts in New Zealand during late summer and autumn and could increase with climate change, is responsible for serious production losses. It is caused by a fungus, *Pithomyces chartarum*, which proliferates on dead plant material in pastures under warm, humid conditions. Spores of this fungus contain sporidesmin, which produces severe toxic effects in sheep liver. Growth of the fungus, and its production of spores, is strongly influenced by climate and environmental factors. Phua et al. (2014) found that there was a genetic basis in FE sensitivity in sheep, and this prompted research for a genetic approach to mitigation in the form of a diagnostic DNA test for susceptibility to the disease. High-density SNP genotyping using the Illumina *Ovine* 50K SNP BeadChip resulted in the development of a genome-enabled prediction approach to screen for facial eczema resistance in Romney sheep with an accuracy of .38.

Within the same context for abiotic stresses, Kim et al. (2016) identified signatures of natural selection to hot, dry conditions of arid desert sheep, using SNP genotyping data, based on both allele frequency (Fst) and haplotype mapping (iHS). Using genome-sequencing approach, Jiang et al. (2014) managed to identify major genomic signatures associated with interactions between diet, the digestive system, and metabolism in ruminants using genome-sequencing data.

These two approaches represented valuable steps in understanding the genomic data and its possible utilization in interpreting functional genomics and genetic improvement for adaptation. However, these studies must be expanded to include more breeds and spatial distributions, various agro-ecological zones, and be augmented with more information on production systems, environments, and GIS information to get a global understanding of the term “adaptation” in sheep and to be able to proceed with genetic improvement for such traits.

6.5 Conclusions

Climate-change stressors are expected to affect sheep production systems globally. Climate stress has already expressed clear impacts on sheep phenotypes affecting body color, size, and other phenotypic characteristics. Results obtained from existing research suggest that signatures of natural selection for breeds adapted to certain stresses, e.g., hot, arid desert conditions, could be identified and information probably utilized for future selection and/or introgression strategies for genetic improvement in climate-stress adaptation. It is also obvious that local climates can shape the spatial distribution of both phenotypic and genomic variants for different adaptation traits. On a phenotypic level, indigenous sheep breeds/populations under different ecologies expressed adaptive phenotypes, including coat color, tail shape, heat tolerance, and parasite resistance. These phenotypic differences have been shown to be associated with specific genes and genomic regions, using both high-density genotyping and landscape genomic approaches. Results obtained from sheep have extended our understanding of the genetic architecture of climate-driven adaptation and evolution, genomics, and selective breeding. Applications of such results to support sheep production and breeding under stress will significantly help in coping with the effects of expected global climate change.

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Climate Changes, Water Use and Survival During Severe Water Deprivation

7

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Abstract

The global total water resources available for consumption are only 0.7%. In addition to that, climate change is worsening the situation. In such condition the water availability for livestock is reducing. Water is an essential component for several vital functions of the body such as regulation of body temperature, growth, reproduction, reaction and digestion. Drinking water scarcity is common during summer in tropical environment. Although the native sheep breeds of arid and semi-arid regions are well adapted to the water shortage as well as heat stress, still the insufficiency of water in summer months affect their physiology and compromise their productive performance. The adapted native sheep of arid and semi-arid region endeavour with some anatomical, physiological and behavioural modifications to reduce the demand of water in the body. Livestock loses body water through urine, faeces, respiratory evaporation and sweating. Most of the mammals die when more than 15% water is lost from their body. The water requirements for sheep are met through drinking water, feed water and metabolic water. The water intake of sheep depends on the available feed stuff, environmental temperature, individual animal and its physiological stages, and water quality. The decreased water intake in sheep reduces body weight and feed intake, and increase blood osmolality due to haemoconcentration. The endocrine

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levels especially stress hormone and metabolic hormone levels are also altered with water insufficiency in sheep. The reduced water availability also affects the reproductive events of the animal and ultimately their production performance is compromised.

Keywords
Water • Sheep • Physiology • Adaptability • Immunosuppression

Contents

7.1 Introduction

Now it is confirmed that climate change is real and is becoming worst (IPCC 2013). All the changes will affect the most vulnerable poorest people of the society and will affect the rural poverty. In developing countries, the negative impact of climate change will be more severe for poor people as they depend on natural resources for livelihood. The communities rely mostly on livestock and agriculture which are probably the most climatic sensitive area (IFAD 2007).

Water cycle is a balance of precipitation, evaporation and steps in between. The climate change is affecting the water resources in term of quantity, variability, timing, form and intensity of precipitation (Adams and peck 2008). The rising temperature of earth has a significant effect on fresh water and its supply. The warmer temperature of earth is increasing the rate of evaporation of water into the atmosphere. The higher evaporation may dry some areas and may precipitate (rain) in some other areas (USGCRP 2009).

The water supply resources like river, lakes, ground water basins are already over allocated, suffering degraded water quality and are often not sufficient. Climate change will aggravate these water challenges (NRDC 2010). The arid and semi-arid region is in dearth of drinking water since time immemorial, but since then sheep husbandry has been considered an important livelihood option for the farmers residing in those agro-climatic regions. Probably sheep is the best gift of nature towards these regions by taking less vegetation and water (Naqvi et al. 2015). With the projected climate change and world water resources are predicted to be further at stake, the socio-economic role of sheep in such communities living in those regions will be on rise in future (Ben Salem and Smith 2008).

Adequate water is necessary for optimum livestock production. Water constitutes 50–81% of the mature body weight. The water requirement depends on the species, age, activity, diet, physiological stage and environmental temperature. The livestock meet their water demand by direct intake or from moisture in feed stuff (NDSU 2015).

7.2 Availability of Water

The world's 70% of fresh water resources remain in the form of icecaps in Antarctica and Greenland while only the remaining 30% of the water resources is available for consumption. Among this 30% that is available for consumption, around 67% is being used for agricultural activities (IPCC 2007a, b). Figure 7.1 describes the global distribution pattern of fresh water resources for different activities.

India with 2.4% of the world's total area has 4% of the total available fresh water. Over 70% of India's population, that is, more than one billion live in rural areas depending solely on agriculture for their livelihood and, for those economically weaker sections of population, rivers serve as the only hope to secure their livelihood. Rainfall in India is mainly dependent on the south-west monsoon between June and September, and the north-east monsoon between October and November. The annual precipitation which is considered the main source of water in the country is estimated to be around 4000 km^3. In India there are 12 major river basins with the estimated catchment area of about 10 Mha. Therefore, the river system is considered to be the major contributor (about 60%) to the surface water resources in the country (Pathak et al. 2014). Table 7.1 describes the various water resources in India. Further, Fig. 7.2 represents the various activities that require water in India.

Fig. 7.1 Water use in the world

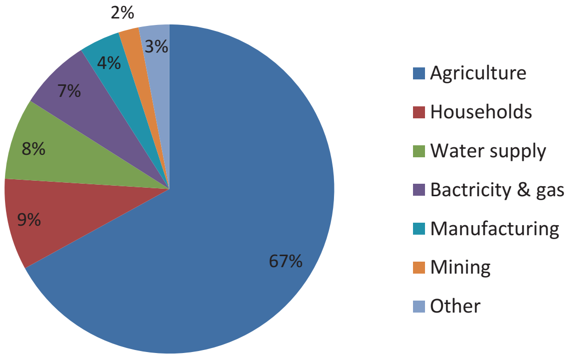
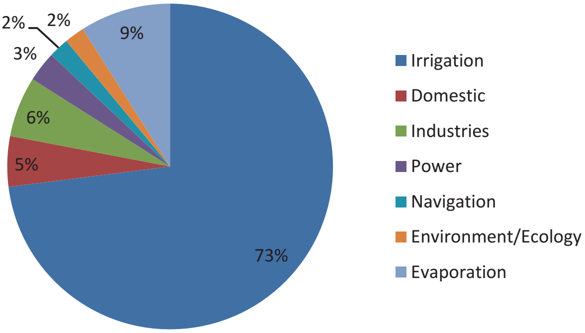


Table 7.1 Water resources of India

Parameters	Amount (Bm^3)
Annual precipitation	4000
Available water resources	1869
Utilizable water	1122
Surface water (storage and diversion)	690
Ground water (replenishable)	432
Present utilization (surface water 63%, ground water 37%)	605
Water use for irrigation	501
Water use for domestic purposes	30
Water use in industry, energy and other sectors	74

Fig. 7.2 India – water requirements for different uses (year 2010)



7.3 Impact of Climate Change on Surface Water

The hydrological cycle of India is expected to be affected drastically by the changing climate. This may result in (1) more rainfall in lesser time; (2) reduction in number of rainy days; (3) increase in precipitation; (4) initial increase in glacial-melt-runoff and later on decrease; (5) less ground water recharge; (6) increase in flood events; (7) increase in drought events; (8) increase frequency of landslide from hilly areas, etc.

7.3.1 Sheep and Water

The high air temperature during summer season is the predisposing factor for water scarcity in the semi-arid tropical region. With the increase of global warming, the water scarcity is in increasing trend with fluctuation of precipitation that's leading to irregular rainfall and limited water availability (Jaber et al. 2013). The adverse environmental variables in the event of climate change remain a challenge which ultimately reduces the productive potential of sheep (Alamer 2009). Sheep remains to be one of the primary means of livelihood option to the resourceless poor particularly in the arid and semi-arid regions of the world (De et al. 2015). Sheep farmers in these agro-climatic regions depend on extensive system of rearing relying solely on pastoral resources for feeding their animals. In such an environment, the animal needs to walk long distances in search of limited feed and water resources during summer season. These events put the animal in extreme stressful condition which jeopardizes their production ability (Casamassima et al. 2008). Although sheep are considered to be extremely adapted, if the non-availability of water prolongs for a longer period it may hamper their survival. Particularly the animals are more vulnerable if their body water resources are depleted by more than 20% (Shkolnik et al. 1980; Al-Ramamneh et al. 2012). In some parts of arid and semi-arid region, the semi-migratory flocks used to migrate to local villages for grazing for continuously 2 days and return to their villages for watering, that is, the sheep are given drinking water in every 48 h (De et al. 2013). Breed differences were established in sheep to withstand drought condition and there are certain breeds (e.g., Awassi) which can withstand drought condition with water available once in 2 days without any significant changes in their production. Further, there are also reports suggesting the survival of sheep with little or no water for up to 1 week (Nejad et al. 2014b; Chedid et al. 2014). However, few authors suggested that the breed like Yankasa can survive without water for up to 5 days but with several physiological changes (Aganga et al. 1989; Igbokwe 1993). Even there are breeds like Australian Merino (MacFarlane 1964) and desert bighorn sheep (Farid et al. 1979; Turner 1979) which can stand without water up for to 10 days and 15 days respectively. In contrast it has been reported in Barki sheep in Egypt which did not cope even for 3 days without water in desert condition (Farid et al. 1979).

7.3.2 Water Intake of Sheep

As per NRC recommendation, supplying sufficient quantity of drinking water is considered to be an appropriate nutritional management in animals (NRC 2007). Particularly in winter season, sheep needs little extra water supply to meet the water requirement in addition to the available water in forages. But hot and drier weather increases their water intake (Naqvi et al. 2015). The water intake must fulfil the total water lost and water retained (Araújo et al. 2010). Sheep can meet their water requirements through drinking water, feed water and to some extent metabolic water through catabolism of nutrients consumed (Esminger et al. 1990). On an average based on availability, the Indian native adult sheep consume around 3–5 l of water daily.

7.3.3 Factors Affecting Water Intake

7.3.3.1 Feed Stuff

Feed stuff is an important source of water to the animal. In arid and semi-arid region, feeding of succulent fodder like cactus, forage watermelon and silage may meet up a large extent of water requirement of sheep (Sahoo et al. 2013). It is the fact that good quality green fodders may meet the entire water requirement for sheep (NSW 2014). Sheep grazed in good green pasture may not need to drink water for many weeks (NSW 2014). NRC (2007) has given an equation as follows: WTI = 3.86 × DMI – 0.99, where WTI is water intake and DMI is dry matter intake. If dry matter intake is 1 kg, then the water intake will be 2.87 l (Araújo et al. 2010).

7.3.3.2 Environmental Temperature

Environmental temperature directly affects the water intake of sheep. The increase in temperature increases the water requirement of sheep to support the evaporative and cutaneous cooling mechanisms during heat stress (NRC 2007; Luke 1987). The water consumption in summer is almost 40% higher than in winter. It has been reported that the testing environmental conditions may increase the water consumption to the tune of around 78% (NSW 2014). The temperature of water may also influence the water intake and further it can alter the functions of rumen microbial population through its buffering capacity in the rumen and reticulum (Araújo et al. 2010). Further, it is observed that the temperature of drinking water also influences its intake and the animals generally prefer to drink water which is below the body temperature during heat stress condition (NSW 2014). During summer, animals need to drink more water for evaporative cooling as well as drier pasture, but evaporation from water resources increases water salinity and reduces availability that cause stressful condition in arid and semi-arid region.

7.3.3.3 Animal

The age of the animals also influences quantum of water in animals and it has been established that older animals' intake was more as compared to younger animals and this difference was attributed to the larger body size and higher requirement for feed digestion and utilization in older animals (Araújo et al. 2010). Pregnant and lactating ewes need more water than the adult animals. In addition the litter size also was found to influence the water intake with larger intake (3.5 times) being reported in animals which gave birth to twins than the ewes with single lambs (NRC 2007). Breed difference also exist in sheep in terms of water requirement. The well-adapted native breeds of arid and semi-arid region require less water than others.

7.3.3.4 Watering Points

Watering point is an important factor determining the water intake by the animals mainly in terms of cleanliness and location of the water source. Animals are sometimes forced to wade through the mud to take the water if the level of water in the earth tank is too low for the animal to reach. Further, the animals are forced to refuse the water that is contaminated with mud and faeces. It should be ensured that the animals know the location of the watering point if they are introduced to a new pasture. Sheep generally graze within a radius of 2.5 km of a watering point in pastoral system (NSW 2014).

7.3.3.5 Water Quality

Surface water is usually more saline than the underground water. Animals increase their water consumption if the water is saline for the better taste and higher water turnover needed for the salt balance in the body. Further, if the water possesses a pH less than 6.5 (acid) or above 8.5 (alkaline), it can lead to digestive problems in the animals, enforcing them to refuse the intake. Sometimes, animals reject the water in case it is contaminated with toxic materials or contain algal growth (NSW 2014).

7.3.4 Metabolic Water

Metabolic water from nutrient catabolism supplies some amount of water to the animal. About 60 g of water is generated when 100 g of carbohydrate is oxidized. Protein oxidation yields 42 g of water from each 100 g of protein. Around 110 g of water is produced when 100 g of fat is oxidized. However, during fat oxidation there would be water loss from the body. Animals increase the breathing rate when water losses from the lungs are higher and reduce the amount of metabolic water available for fat hydrolysis in comparison to the hydrolysis of carbohydrate (Ensminger et al. 1990).

7.3.5 Compartmental Water Management of Sheep

During drought period, dehydration due to intermittent water supply forces the animal to adapt compartmental water management. The fluid loss patterns across different compartments indicate that the intracellular fluid volume compartments resist the fluid loss as the extracellular fluid compartments balance this change in the fluid volume. The plasma volume being a part of extracellular fluid is mostly affected during dehydration. This indicates that as a way to prevent the increasing osmolality, water from the plasma moves to the intracellular fluid compartment (Kataria et al. 2003). Such intercompartmental movement of fluid from extracellular to intracellular spaces may be a way of compensating the water losses (Nose et al. 1988). This movement of water across the compartments is regulated by the mechanisms governing the cellular osmolality (Kataria et al. 2003). The water influx in the cellular compartments immediately after the rehydration was evident from the replenishment of the water losses in the cells (Kataria and Kataria 2007).

7.3.6 Water Balance in Sheep

Water balance defines the difference between the intake and losses of water. Sheep loses water through urine, faeces and transpiration. Urine excretes the water soluble metabolic products. Urine flow increases with the increase of protein and mineral content in the diet. A large amount of water loss occurs through defecation. The water content of sheep faeces is 60–65%. Table 7.2 describes various components of water in sheep.

Table 7.2 Water balance of Yankasa sheep (Aganga 1992)

Water components	Mean	SE
Average live weight (kg)	25.56	0.25
Metabolic mass ($kg^{0.73}$)	10.95	0.08
Water drunk ($ml/kg^{0.73}/day$)	202.53	8.14
Water intake in food ($ml/kg^{0.73}/day$)	3.17	0.03
Metabolic water ($ml/kg^{0.73}/day$)	19.02[3]	0.36
Water loss in faeces ($ml/kg^{0.73}/day$)	16.08[3]	0.84
Water loss in urine ($ml/kg^{0.73}/day$)	45.60	2.07
Evaporated water loss ($ml/kg^{0.73}/day$)	162.40[3]	6.74
Average daily urine production (ml)	501.1	9.16
Daily water intake (ml)	2218.0	68.79
Daily hay intake (g)	500.0	
Average daily faecal output (g)	362.1	10.92

7.4 Adaptability of Sheep to the Water Deprivation

It is a well-known fact that the native breeds of the tropical region are well adapted to the water deprivation than the non-native breeds. To become adapted with water stress, the sheep in the tropical regime takes some adaptive strategies. The sheep in those regions seek shelter or shade during daytime to protect from heat exposure to reduce the need for water loss through evaporation for thermoregulation (Cain et al. 2005). Similarly, they prefer night grazing to avoid solar exposure and minimize water loss (Dwyer 2008). The carpet type wool of Marwari (Narula et al. 2010), Omani (Mahgoub et al. 2010), Barbarine (Ben Gara 2000) and Awassi sheep (Gootwine 2011) protect themselves against heat and minimize water loss due to evaporative cooling. The carpet type wool is a denser wool that protects from solar radiation and allow effective cutaneous evaporative cooling (Mittal and Gosh 1979; Rai et al. 1979; Cain et al. 2006) whereas in tropical environment breeds are of hairy type wool as they don't need protection from solar radiation and evaporative cooling water loss (McManus et al. 2009). The fat tail of arid and semi-arid region sheep helps in metabolic water formation that could partially fulfil the animal's water requirements (Chedid et al. 2014). The water-stress-adapted sheep have thicker medulla in kidney that helps to produce concentrated urine as a water management strategy. Along with that, the adapted sheep have slower feed transit through the digestive tract in order to enhance the water reabsorption from the feed producing faeces with reduced water content (Chedid et al. 2014). In well-adapted sheep the rumen acts as a water reservoir (Silanikove 1994). To prevent water loss for thermoregulation, the adapted breed may increase their body temperature a little during daytime.

7.4.1 Effect of Water Deprivation on Feed Intake and Body Weight

Feed intake is reduced in water-restricted ewes (Kumar et al. 2015). The reason for the restricted feed intake during water scarcity could be probably attributed to the decrease in the postprandial hyperosmolality of the ruminal fluid (Langhans et al. 1991). Hypovolemia and hyperosmolality often take place in the animals after the feed intake due to the saliva and gastric juice secretion. Such mechanisms force the animals to respond either by drinking water along with feed intake or by restricting feed during water deprivation (Jaber et al. 2013; NRC 2007). Weight loss is a usually observed physiological impact during periods of water deprivation. The reduction in weight loss could be due to the water losses and the mobilization of fat to enhance gluconeogenesis as a compensatory mechanism for the reduced feed intake (Jaber et al. 2004; Epstein 1985).

7.4.2 Effect of Water Deprivation on Physiological Responses

Sheep of water scarce regions need to take some adaptive strategies in physiological functions to sustain thermal equilibrium (Maurya et al. 2004). Generally sheep maintain their thermal equilibrium through respiratory evaporative cooling. But the arid-adapted dehydrated sheep tend to reduce evaporative cooling mechanisms like panting and sweating for thermoregulation in order to reserve their body water and to prevent further dehydration (Baker 1989; McKinley et al. 2009). Water-deprived sheep have a slow panting rate (McKinley et al. 2009; Chedid et al. 2014). It has been observed that both respiration rate and pulse rate decreased in water-restricted animals (Kumar et al. 2015). The reduced respiration could be attributed to less energy availability in water-deprived animals. The decreased pulse rate in water-restricted animals could be due to the reduced metabolic rate because of the reduced feed intake in these animals (Kumar et al. 2015). Sheep being homoeothermic animals maintain their body temperature within a range.

7.4.3 Effect of Water Deprivation on Blood Biochemical

Dehydration under warm climatic condition causes haemoconcentration and this could be due to the movement of water from blood to intercellular fluid compartment to compensate for the lost body water (Kataria and Kataria 2007). This mechanism leads to increased haemoglobin and packed cell volume levels (Li et al. 2000; Ghanem et al. 2008; Jaber et al. 2013). The decrease in plasma glucose level after water restriction may be attributed to less feed intake (Kumar et al. 2015). The plasma protein and albumin levels were found to increase in water-restricted ewes (Jaber et al. 2004; Casamassima et al. 2008; Ghanem et al. 2008; Hamadeh et al. 2009) due to decreased blood volume (Cork and Halliwell 2002). But long-time restriction causes dietary insufficiency that leads to reduced protein levels (Hamadeh et al. 2006; Ghanem et al. 2008). The albumin breakdown and synthesis in water restriction happens to supply amino acid (Moorby et al. 2002) and maintaining colloidal osmotic pressure and fluid distribution (Burton 1988). In order to supply energy during scarcity period of water, fat is mobilized from fat tail and subcutaneous source to compensate the energy deficit (Chedid et al. 2014; Atti et al. 2004; Jaber et al. 2011). It is indicated with higher cholesterol levels (Jaber et al. 2004; Hamadeh et al. 2006; Igbokwe 1993). But in some breed, cholesterol levels reduced like other metabolites due to less availability of fat reserve like fat-tailed breed or prolonged dietary insufficiency (De et al. 2015; Kumar et al. 2015). During water stress, kidney prefers slower glomerular filtration and higher urea reabsorption (Silanikove 2000). That raises the urea and creatinine levels in blood (MacFarlane 1964; Igbokwe 1993; Jaber et al. 2004). But in prolonged restriction, urea levels may decline to increase the urea recycling into the gut (Igbokwe 1993; Marini et al. 2004), so that it can be used as a nitrogen source by rumen microflora during less feed intake. The reduced blood volume and increased renal retention leads to an increase in electrolyte concentrations (Qinisa et al. 2011), mainly sodium (Na^+) and chloride (Cl^-) (Rawda 2003; Ghanem 2005; Hanna 2006).

7.4.4 Effect of Water Deprivation on Endocrine Profiles

Blood aldosterone and cortisol level increases in dehydrated animals to maintain the fluid and electrolyte balance (Li et al. 2000). Further, it has been observed that prolonged water restriction can act as an additional stress to the animals with the liberation of cortisol to relieve the condition (Kataria and Kataria 2007; Nejad et al. 2014a, b). In addition dehydration stimulates the release of aldosterone in water-deprived animals in an effort to maintain the fluid and electrolyte balance (Kataria and Kataria 2007). Moreover, aldosterone also increases the renal retention rate to maintain sodium homeostasis in water-restricted animals (Ashour and Benlemlih 2001). Dehydration also increases the plasma vasopressin levels. Also the level of urine flow is reduced in dehydrated animals and this could be correlated to the increased excretion rate of vasopressin (Jaber et al. 2013). Further in water-restricted animals, a balance is established between plasma osmolality and extracellular fluid volume in sheep and this is brought about by the adjustment of extracellular sodium content (Blair-West et al. 1972). The water deprivations have effect on plasma rennin concentration. Water restriction increases the plasma oncotic pressure (Kenney 1949). The increased sodium reabsorption from the renal proximal tubule and reduced sodium load in macula densa in dehydrated sheep could be due to increased oncotic pressure which ultimately increases the renal rennin release for maintaining the fluid balance. Thyroid hormones have a major role in metabolic homeostasis (Chedid et al. 2014). The T3 and T4 levels generally reduced in sheep following water deprivation which may be an adaptive strategy of sheep to reduce general water loss through metabolism. The reduced T3 and T4 in water-restricted sheep are also associated with reduced feed intake (Ward et al. 2008). Prolactin hormone is involved in thermoregulation including fluid balance and distribution (Alamer

2011). Prolactin also has role in maintaining the fluid balance in dehydrated sheep and this effect is brought about by mimicking the aldosterone action to maintain the water balance and sodium homeostasis (Burstyn et al. 1972; Doris and Bell 1984; Becker et al. 1985).

7.4.5 Water Deprivation and Reproduction

The timing of reproductive events may be affected by dehydration. The feed intake reduced during water deprivation leads to retardation of follicular growth (Blanc et al. 2004). Nature has also decided the lambing season between February and April so that food, favourable climate and water remain ample for dam milk production. Reports pertaining to impact of water stress on reproductive activity of sheep are very scanty. However, it has been observed that the estrus response, estrus duration and blood estradiol concentration were found to be decreased in water-restricted sheep (Kumar et al. 2015). This could be attributed to the impaired reproductive hormone status in feed-deprived animals as usually the level of feed intake was reduced in water-deprived animals (Polkowska 1996; Iiker et al. 2010; Sejian et al. 2011). Further, the reduced blood estradiol concentration could be due to suppressed gonadotropin levels in dehydrated animals (Lechner-Doll et al. 1995). In addition the level of blood progesterone was found to be very high in dehydrated animals and this higher level was attributed to the lower metabolic clearance of progesterone rather than the increased secretion rate (Kumar et al. 2015; Forcada and Abecia 2006).

7.5 Conclusion

Water is considered vital for the basic physiological functions of the animal body. In the era of climate change, water scarcity is one of the major crises that negatively influences the sheep production. However, literatures pertaining to this aspect are inadequate. This warrants that concerted research efforts are needed in order to make this species cope up to the changing climate as predicted by several international bodies. Appropriate efforts should be taken to identify the most appropriate breed which can withstand water restriction in the coming years as this is going to be the most crucial factor than any other environmental stress in the coming years. So it is the ideal time to identify appropriate agro-ecological zone specific sheep breeds which can effectively withstand dehydration.

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Projected Impacts of Climate Changes and Sustainability of Sheep Production Systems

8

John Gaughan

Abstract
Sheep production plays a major role in terms of meat, milk and fibre production in countries that are very susceptible to climate change. Climate change will have both direct and indirect effects on sheep production systems and the effects are largely multi-faceted and it is difficult to adequately predict how all of the underlying factors will interact. The indirect effects of climate change on sheep production especially in regard to nutrition may have a greater impact than the direct effect of ambient temperature. The low availability of pastures during summer was found to be the most crucial factor reducing sheep production. Further, exercise stress was found to be an important stress, particularly in extensive system of rearing, which negatively influences the production potential of sheep. Although the production potential of sheep is influenced by climate change-induced sudden disease outbreaks, it remains a largely unexplored area of research. Therefore, developing appropriate strategies involving management of rangelands, disease surveillance and genetic selection of sheep for greater heat tolerance may offer longer term solutions to sustain sheep production in the changing climate scenario.

Keywords
Exercise stress • Genetic selection • Heat stress • Pasture management • Sheep

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Contents

8.1 Introduction

Sheep are an important food and fibre source in many countries and approximately 25% of the global ruminant population is sheep (Marino et al. 2016). The global sheep population was approximately 1.2 billion in 2013 (FAO 2016). China has the largest sheep population (202 million), followed by Australia (72 million) and India (63 million). Sheep production plays a major role in terms of meat, milk and fibre production in countries that are very susceptible to climate change, for example, India (65 million), Pakistan (29 million), Mongolia (23 million) and Afghanistan (13 million) (FAO 2016). Further, there is considerable world trade in live sheep and sheep meat. In 2013, approximately 16 million live sheep were traded around the world. Major exporters included Somalia (2.2 million) and Australia (1.9 million) (FAO 2016). Although live export represents a small percentage of the global sheep population (1.3%), it is nevertheless an important food source for some countries (e.g. Qatar and Saudi Arabia imported 409,000 and 597,000 live sheep, respectively, in 2013). Sheep are an important global food source and like other livestock are potentially vulnerable to climate change.

Climate change will have direct and indirect effects on sheep production systems. Thornton and Gerber (2010) outlined the direct and indirect effects of climate change on grazing livestock. The direct effects were extreme weather events, water availability, drought and floods and productivity losses (physiological stress) due to temperature increase. The indirect effects were fodder quantity and quality, disease epidemics and host pathogen. In this chapter, the primary focus will be on the effects of climate change on grazing sheep production, and secondly on diseases and parasites.

8.2 Impact of Climate Change on Sheep Production

It is well established that climate change will lead to reductions in feed availability (pasture and fodder crops), reduced quality of feedstuff, reduced quality and quantity of water, increased risk of diseases and parasites, and an increase in adverse local weather conditions (heat stress and solar load) (Harle et al. 2007; Thornton and Gerber 2010; Kenyon et al. 2009; Nardone et al. 2010). All of these are likely to have negative effects on sheep production not only in regions where production is already curtailed by harsh conditions but also in currently benign areas such as Europe.

8.2.1 Sheep Production and Climate Change

The relationship between sheep production system and climate change is complex (Thornton et al. 2009). The impact of climate change is multi-faceted and it is difficult to adequately predict how all of the underlying factors will interact. It is unlikely however that sheep will be exposed to only a single climate change-induced stressor. In a recent study, Sejian et al. (2016) demonstrated the effects of multiple stressors (heat, nutrition and exercise) on the physiological, blood biochemistry and the endocrine system of Malpura rams. The exercise component is primarily walking, the suggestion being that sheep will need to forage longer and cover a greater distance to find adequate feed due to the effects of climate change on pasture production and water availability. Therefore, it is conceivable that the indirect effects of climate change on sheep production especially in regard to nutrition may have a greater impact than the direct effect of ambient temperature.

8.2.2 Effect of Climate Change on Grazing

Due to a lack of resources, an already variable climate, and a reliance on grazing, it is likely that sheep production in developing countries will be adversely affected by climate change, especially in areas where rainfall is already decreasing (Rischkowsky et al. 2008). However, this is not just a developing country problem. Sheep production in developed countries such as Australia which is largely rangeland based is also very susceptible to climate change (Harle et al. 2007). Reduced rainfall in the Mediterranean Basin is also likely to have negative effects (Seguin 2008) on sheep production. Interestingly, Harle et al. (2007) also stated that in regions where rainfall is predicted to increase, such as New Zealand and parts of China, there may actually be an increase in sheep production. However, the production modelling shows mixed results. Modelling by Ghahramani and Moore (2016) shows the change in live weight of sheep across various sites in Western Australia × potential climate combinations ranged between −3% and +3%, and gross margin varied between −11% and +6%. So, while modelling suggests that impact of climate change on meat and wool sheep production is mixed, the impacts on milking sheep production are mostly negative, probably because the common milk sheep breeds (especially in Europe) are highly susceptible to heat stress. Finocchiaro et al. (2005) reported a 4.2% reduction in daily milk yield when milk sheep (Valle del Belice breed) in the European Mediterranean Basin were exposed to natural heat stress. Heat stress also results in reductions in feed intake which have implications for growth and reproduction. This suggests a direct effect on the biology of the animal. Genetic selection of sheep with greater heat tolerance from within the susceptible milk breeds is the likely longer term solution.

The growth and quality of pasture and fodder crops may be affected by changes in rainfall amounts and variability as well as higher atmospheric CO_2 concentrations (Harle et al. 2007). Pasture response to climate change is complex due to interactions between direct climate drivers such as CO_2 concentration, temperature and precipitation, and indirect effects such as seasonal productivity and plant–animal interactions (Porter et al. 2014). A number of studies have suggested that an increase in CO_2 concentration coupled with warmer conditions will improve pasture growth via a longer growing season and increased photosynthesis (Anderson et al. 2001; Tubiello et al. 2007; Ghahramani and Moore 2016) of C3 plants. The impact on C4 plants appears to be limited (Thornton et al. 2013). Kenyon et al. (2009) stated that "*The climate in the UK is changing, with a trend towards increased rainfall in the autumn and winter and warmer average temperatures throughout the year. There has also been a 4-week extension of the herbage growing season over the past 40 years*." Potentially, the changes in pasture productivity could lead to increased sheep production in some areas. The modelling by Ghahramani and Moore (2016) suggests that pasture growth in Western Australia would be enhanced by increased CO_2 especially in lower rainfall areas, but gains may be offset by other aspects of climate change such as increased incidence and severity of heat waves. Furthermore the nutrient availability of plants may be negatively affected when plants are exposed to higher temperatures. Minson (1990) reported that increased temperatures increase lignification of plant tissues, which leads to lower rates of degradation in the rumen. So, again potential gains in pasture production for sheep may be offset in this case by reduced digestibility of the plants. Romanini et al. (2008) suggested that the predicted temperature rises of 2–5°C could negatively impact on grazing capacity in Brazil by up to 50%. Although the Romanini et al. (2008) study was based on beef cattle, there is no reason to doubt that sheep production could be adversely affected as well by reductions in pasture quality especially in areas where reductions in rainfall are part of the climate change mix. The capacity for sheep production in tropical highlands cannot be overlooked. Higher temperatures may lead to improved plant productivity in parts of the tropical highlands where cool temperatures currently constrain plant growth (Thornton et al. 2013).

Low soil fertility, land degradation and a loss of palatable plant species are already problems in many of the world's rangelands. These problems have been mostly human-induced via overstocking, poor land management and harsh climatic conditions. Unfortunately, climate change is likely to exacerbate these problems especially in drier climate zones (Ghahramani and Moore 2016). These are the very areas where sheep production is of high importance. However, there are potential solutions. Rischkowsky et al. (2008) stated that although drought-tolerant plant species have been introduced into rangelands in the West Asia and North Africa (WANA) region, there are problems associated with land tenure (communal ownership) and a lack of land management policy. There is little doubt that the potential for increased sheep production in WANA is possible. But for this to be achieved there will need to be structural changes in land management and water policy.

8.2.3 Mixed Farming

Mixed farming (i.e. grazing sheep plus crops production) is already a common and well-established practice in many regions. Mixed farming options are typically less risky in variable climates than cropping alone (Ghahramani and Moore 2015). It is therefore possible that sheep production could expand in areas where cropping is currently in decline or predicted to decline. This is primarily due to the greater potential impacts climate change could have on crop production, e.g. effects of drought on dry-land cropping. Livestock are already used as an insurance against drought in many areas (Seo and Mendelsohn 2006; Rust and Rust 2013). Indeed in a recent study, Ghahramani and Moore (2016) stated that sheep production was more reliable than cropping in drier areas. Mixed farming may therefore serve as a transition from full reliance on cropping to full reliance on sheep production. But there are inherent risks with this strategy especially where water resources are limited. In areas where climate change modelling suggests reductions in rainfall, the risks to sheep production are high.

8.2.4 Diseases and Parasites

A considerable amount of work has been undertaken to investigate the potential impacts of climate change on the spread of diseases and parasites in humans (Thornton et al. 2009). However, similar studies on sheep populations have not been carried out to the same extent. It remains unclear how climate change will affect sheep health. In some instances increased temperatures and rainfall may increase parasite growth, and the opposite may occur if rainfall is lower. Again, it is a complex story.

It is also necessary to keep in mind that importance of a sheep disease/parasite is somewhat dependent on the resources that are available to deal with the problem. Hence a disease of minor importance in Europe may be of major importance for small holders in Africa. This is not because sheep are necessarily more susceptible to the disease in Africa but simply the financial resources may not be available to vaccinate against the disease. Grace et al. (2015) listed the top 15 diseases in Africa that are likely to become more of a problem with climate change. All of these are currently endemic in the regions listed in the Grace et al. (2015) report. The important message here for sheep production is that as animals are exposed to greater stress (due to droughts, heat, etc.) they become more susceptible to diseases/parasites.

Changes in parasite populations show the complexity of climate change and their epidemiology with respect to climate change is largely unknown. Positive aspects associated with longer growing seasons, greater rainfall and warmer temperatures are all favourable not only for pasture production but also ideal for some parasites. It is possible that climate change might alter parasite epidemiology and therefore the effectiveness of current control strategies (van Dijk and Morgan 2008). This has major management implications. The occurrence of outbreaks of sheep parasites such as *Haemonchus contortus, Nematodirus battus, Teladorsagia circumcincta* and *Fasciola hepatica* in southeastern Scotland was associated with warmer wetter conditions, a consequence of climate change (Kenyon et al. 2009). In addition, a study was undertaken by Bosco et al. (2015) in southern Italy to determine the relationship between outbreaks of acute fasciolosis in sheep and weather conditions. These authors showed that that there was a direct relationship between changes in climate (warmer and wetter) and the outbreak of fasciolosis.

However, it remains unclear if changes in parasite populations in sheep are driven only by climate change. Kenyon et al. (2009) state that there is a need to determine the current prevalence of helminth parasitism in the UK and provide a benchmark to measure any future changes. This would be a useful strategy for the control and prevention of diseases and parasites affecting sheep worldwide. Further, there is a need for a better understanding of the parasites themselves, especially in regard to how they adapt to climate change.

As an example bluetongue virus (BTV) which causes bluetongue disease in ruminants that adversely affects sheep, and cattle and goats to a lesser extent. It is a common disease in the tropics and sub-tropics, but also spreads into the temperate regions of Australia. The emergence of BTV in Europe has been put forward as an example of the spread of a disease due to climate change. BTV would occasionally appear in southern Europe when climatic conditions were favourable for its spread from North Africa (Gould and Higgs 2009). However, it has now spread throughout much of Europe including the UK. Gould and Higgs (2009) concluded that the spread of BTV into Europe was only partly due to climate change. Other factors such as wind-borne midges which are the insect vectors for the disease and the transport of infected animals into clean areas also play a role (Gould and Higgs 2009; Grace et al. 2015).

8.3 Conclusion

Climate change is complex and multi-faceted. There is currently (apart from studies done in Australia) a paucity of information on how climate change will impact on sheep production. However, it is likely that only small holder production systems in the developing world, in particular much of Africa, the Middle East, Pakistan and India, which will be adversely affected by climate change. It is also predicted (and to an extent already seen) that there will be less rainfall, higher temperatures and an increase in extreme events (droughts and flooding). Overall, there will be both positive and negative outcomes on sheep production from climate change.

The positive outcomes include:

- Improved pasture production in areas with C3 grasses due to higher concentrations of atmospheric CO_2, which may lead to greater productivity from sheep. And the effect may be greater in dry areas.
- Increased sheep production in tropical highlands as increased temperature and rainfall improve pasture yields.
- Longer growing seasons create a greater biomass, thereby improving sheep productivity.

The negative outcomes include:

- Decreased milk production and overall productivity in milk sheep.
- Increased CO_2 concentration will have little effect on tropical C4 grasses.
- Increased incidence of extreme weather events (droughts, heat waves, floods) could offset the positive outcomes and exacerbate the rundown of already fragile production systems.
- Increased risk of disease and parasites; however, it is largely unknown how changing disease/parasite challenges will impact on sheep production.

Some potential solutions:

- Government strategies to better manage rangelands, especially communal ownership of lands, and better water management.
- Genetic selection of sheep for better heat tolerance within existing sheep breeds (long-term approach).
- Disease surveillance – knowledge of the current scenario.
- Develop better understanding of the genetics and biology of the vectors, viruses, bacteria and parasites that affect sheep.

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Impact of Climate Change on Sheep Disease Occurrences and Its Management

9

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Abstract

Climate change refers to variation in normal climatic conditions and is evidenced through abnormal increase in surface temperature, irregular rainfall patterns, and higher incidence of extreme events. Shift from specific climatic pattern may lead to compromised health, productivity, and immune functions in sheep. Further, pest and disease occurrence in a region is strongly correlated with the prevailing weather conditions and adopted management practices. The varying climatic conditions affect the disease incidences in sheep by influencing their immune competence, virulence of infectious agents, and strength of transmission mechanisms. Elevated environmental temperature due to climate change may lead to increased development rate in certain infectious pathogens and cause higher population size. In addition, climatic factors such as temperature, humidity, and rainfall are established to affect the vector population dynamics and disease transmission potential. Severe water stress along with heat stress can cause immune suppression in sheep during summer. Moreover, studies established a strong positive correlation between frequency of extreme events and pest and disease incidences. Hence to control the spread of disease and pest among sheep population, suitable multiple adaptation and management practices should be

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promoted in arid and semiarid tropical regions. The severe effects of heat stress on the sheep can be reduced by management strategies such as shearing wool prior to the onset of hot weather, providing plenty of cool and fresh water, and stall feeding to prevent direct incidence of solar radiation. In addition, integrated pasture development could be practiced through adoption of drought-tolerant varieties to ensure regular pasture supply. These efforts will improve the immune status and thereby help the sheep to counter disease-causing pathogens. Developing disease-tolerant breeds is a long-term adaptive strategy to tackle climate change impacts. Further, modeling and forecasting of disease-spreading patterns assist the farmers to take proper precautionary measures against the pathogens. Moreover, disease management practices such as isolation of infected animals and vaccination against frequently occurring diseases also prevent the disease outbreaks in a particular region.

Keywords
Climate change • Disease • Heat stress • Pathogen • Pest • Sheep • Vector-borne disease

Contents

9.1 Introduction

Climate change describes a variation in the weather, temperature, and environment over a given period of time, be it manifested through changes in mean temperatures or occurrence of extreme weather events such as lower or higher rainfall, drought conditions, and high or low temperatures (IPCC 2007). Climate change can have adverse effects on the livestock because animals depend on a specific pattern of climate in order to remain healthy and productive. The extreme weather events disturb the physiology of animals and may cause higher disease incidence (Thornton 2009). The environmental changes have direct impacts on the health–disease dynamics of animal population. Many important animal diseases are affected directly or indirectly by weather events. Climate influences the distribution, timing, and intensity of the disease (van Dijk et al. 2010). The changes in the weather patterns determine the balance between the three elements that comprise the ecological triad: the infectious agent, the host, and the environment (King et al. 2006). The current debate among investigators around the globe is to understand how critical global warming could become a threat to human health. However, comprehensive reviews in animal health realms are limited. The broader picture of how climate change impacts the animal disease ecology and transmission dynamics has been studied earlier (Skuce et al. 2013). Sheep farming is an important livestock enterprise in tropical and subtropical regions. Globally sheep population trends remain constant with highest concentration in Asia and Africa. In most parts of the world, sheep are still reared under pastoral and mixed farming systems, which make them predisposed to changes in the negative effects of environmental factors (Nardone et al. 2010). Apart from significantly influencing the availability of pastures/fodder crops, climate change has been found to adversely affect the health and productivity through higher disease incidences in sheep (Marino et al. 2015).

9.2 Relationship Between Climate Change and Sheep Diseases

Environmental factors are long known to influence disease epidemics. Climate change brings greater fluctuations in temperatures, radiation intensity, humidity, and rainfall patterns. Studies have found that long-term climate warming tends to favor the geographical expansion of infectious diseases in animals (Ostfeld and Brunner. 2015; Rodó et al. 2013). The extreme weather events may help to create the opportunities for more clustered disease outbreaks or outbreaks at nontraditional places and time (Epstein, 2000). The geographical and seasonal distributions of infectious diseases including the timing and intensity of disease outbreaks are affected by climatic factors (Kuhn et al. 2005; Wu et al. 2014). The significant association between the weather parameters and incidence of several infectious diseases of sheep has been established. Sheep diseases caused by viruses (bluetongue, orf, tick-borne encephalomyelitis, peste des petits ruminants (PPR), sheep pox), bacteria (foot rot, caprine pleuro-pneumonia, chlamydiosis, listeriosis, fleece rot), and parasites (fasciolasis, infestations by ticks, mites, and lice) were found to have a strong impact in particular seasons, indicating the influence of weather events in disease epidemics (Vallat 2008; de La Rocque et al. 2008; Moenga et al. 2016). The climate change phenomenon significantly influences disease epidemics by affecting the essential components of infectious disease cycle namely the host, pathogens, and mode of transmission (Engering et al. 2013). Apart from affecting infectious disease cycles, climate change also affects sheep farming practice, land use, and establishment of new microenvironments leading to ecological changes, thus influencing the occurrence, distribution, and prevalence of sheep diseases (Hoberg et al. 2008). The relationship between climate change and the occurrence of sheep disease depends on how environmental conditions influence immune competence of sheep, virulence of infectious agents, and strength of transmission mechanisms including role of disease vectors.

9.3 Effect of Environmental Stress on Immune System of Sheep

Climate change-associated extreme weather events lead to stressful conditions altering normal physiology of animals. In general, stress and immune response are negatively correlated. The stress-induced glucocorticoid hormones such as cortisol mediate immune suppression in animals. Stressed conditions significantly affect the immune competence fighting the invading microbes, and the compromised immunity is the major reason for surge in infectious diseases (Padgett and Glaser 2003). Stress has been found to affect the components of both humoral and cellular immune mechanisms. Heat stress reduces cellular immunity by decreasing proliferation of immune cells which may involve altered expression of cytokines and heat shock proteins (Sevi and Caroprese 2012). Ewes subjected to heat stress and reduced ventilation rate display increased cortisol levels which is responsible for the impairment of their cellular immune response after the intradermal injection of mitogens and their humoral response (immunoglobulin G (IgG) production) after antigen injection (Sevi et al. 2002a, b and Caroprese et al. 2012). Late lactating ewes when exposed to higher solar radiation had higher amounts of total fecal coliforms, *Pseudomonadaceae*, as well as the highest number of mastitis-related pathogens in their milk, indicating the suppressed immune system allowing more infections. Similarly, high ambient temperatures caused significant mineral imbalance and increased milk neutrophil levels, thus showing the effect on animal's heath and milk quality (Sevi et al. 2001). Ewes subjected to heat stress showed impairment of their cellular immune response after an intradermal injection of mitogens. It was found that supplementation of flaxseed meal can reduce the impact of heat and solar radiation stress on immune response in ewes by modulating the expression of cytokines (Caroprese et al. 2012).

Water scarcity associated with the changing patterns of rainfall is a growing problem in arid and semiarid regions where sheep farming is predominant. High ambient temperatures combined with water scarcity further amplify the conditions of immunosuppression in sheep. It was found that water restriction significantly affected the humoral antibody response of Awassi ewes to *Salmonella enteritidis* infections (Barbour et al. 2005). Similar immunosuppression effects against polypeptides were visible in water-deprived lactating ewes. Leukocyte profiles (higher neutrophils) and glucocorticoid levels are considered as indicators of animal under stressed conditions. Stress-induced effects on the proliferation and the redistribution of immune cells to target organs where they can defend against infectious agents make animals more susceptible to diseases (Carroll and Forsberg 2007). Further investigations regarding the effects of environmental stress on the expression of genes involved in the immune regulation are required. In particular, the influence of exposure to extreme stress on production of cytokine pathways involved in controlling immune responses of sheep needs future attention.

9.4 Climate Change and Sheep Pathogens

Climate change can directly affect different infectious agents including virus, bacteria, fungi, and parasites through influencing their survival, multiplication, and life cycle. Higher temperatures resulting from climate change may increase the rate of development of certain pathogens or parasites that have one or more lifecycle stages outside their animal host. This may shorten generation times and, possibly, increase the total number of generations per year, leading to higher pathogen population sizes (Harvell et al. 2002). Similarly, infectious agents are sensitive to moist or dry conditions and hence may be affected by any changes in precipitation, humidity, and soil moisture. For example, the germination of *Bacillus anthracis* spores that cause acute infectious disease in all warm blooded animals including sheep depends on temperature, relative humidity, and soil moisture. Outbreaks of anthrax are often associated with alternating heavy rain fall and drought, and high temperatures (Kiel et al. 2000). Similar environmental changes may facilitate clostridia spores—organisms that reside in soil and show higher proliferation and disease-causing potential. These results are significant for important sheep diseases caused by clostridial organisms such as enterotoxaemia type C (bloody scours/ struck), type D (Pulpy kidney disease), and tetanus (Lock jaw). Incidence of peste des petit ruminants (PPR) found more during the onset of rainy season was linked to increased survival of virus in these conditions (Wosu et al. 1990). The survival of eggs and larvae of *Haemonchos contortus* causing severe diseases of sheep has been found greatly influenced by higher temperatures and humidity (Rinaldi et al. 2015). Figure 9.1 describes the direct and indirect effects of climate change on sheep disease occurrences.

9.5 Effect of Climate Change on Biological Vectors of Sheep Diseases

Biological vectors are intermediate hosts that carry and transmit pathogens to the hosts which are the final victims of diseases. Several important vector-borne diseases affect sheep. Viral infections such as rift valley fever (transmitted by mosquitoes), bluetongue (transmitted by culicoides), rickettsial Q fever (transmitted by ticks), and many external parasites (flies, lice, and fleas) and internal parasites (flatworm, tapeworms, and roundworms) themselves cause severe diseases of economic importance in sheep farming. Temperature, precipitation, humidity, and other climatic factors are known to affect the reproduction, development, behavior, and population dynamics of the biological vectors of these diseases. The seasonality and amounts of precipitation in an area can strongly influence the availability of breeding sites for insect vectors and their aquatic immature larval stages. These climatic

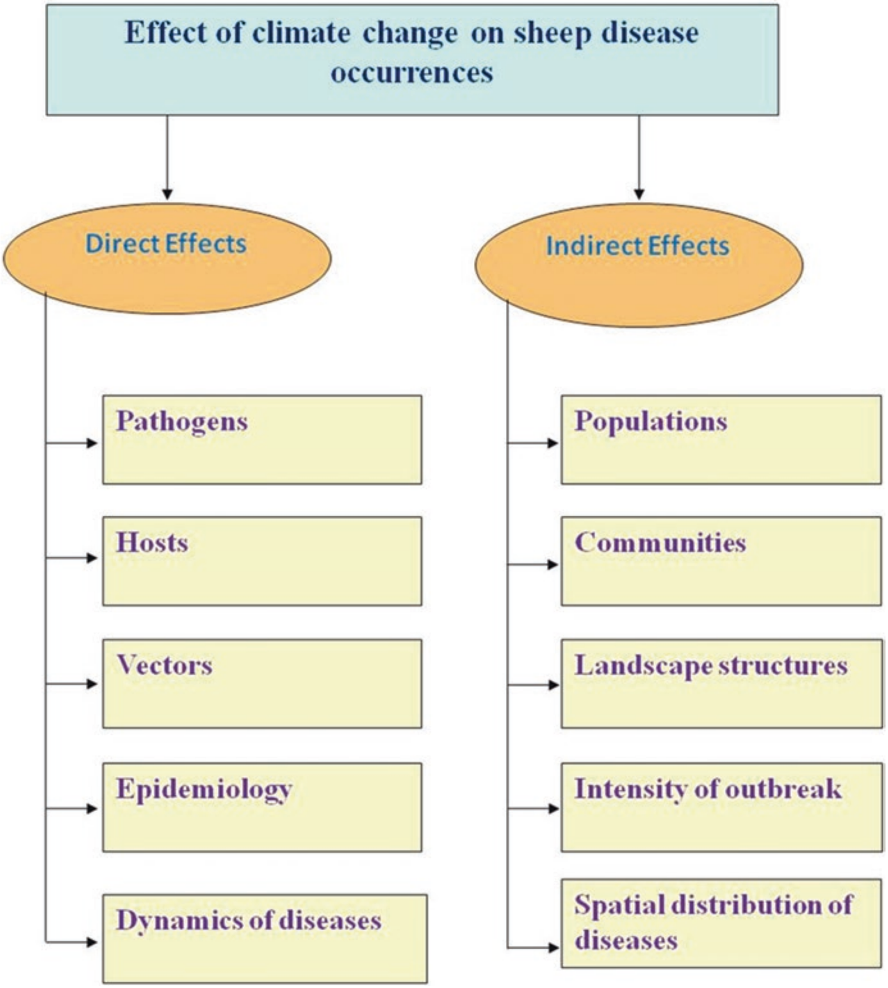

Fig. 9.1 Direct and indirect effects of climate change on sheep disease occurrences

variables can directly affect the vector population dynamics and disease transmission potential (Gage et al. 2008). Further it was found that the feeding frequency of vectors on host is directly influenced by the climatic factors. For example, the vectors of bluetongue disease in sheep, *Culicoide* midges females feed every 3 days at 30 °C but only every ~14 days at 13 °C (Wittmann and Baylis 2000). Bluetongue has been the model disease to study the climate change impact on vector-borne disease ecology and geographical distribution (Purse et al. 2005; Wilson and Mellor 2009). Warming climate has been suggested as the major driver for the spread of bluetongue disease in sheep population (Guis et al. 2012; Samy and Peterson (2016)). Temporal scales of climate data, and vector distribution and abundance have been used to model the bluetongue transmission risk. The results have predicted the spread across the border portions of the European continent and further northward expansion in North America (Zuliani et al. 2015). All these studies have pointed that *Culicoides* vector population may drive bluetongue response to climate change.

9.6 Adaptation and Management Strategies

It is important to improve farmers' perception on the harmful effects of climate change such as heat stress events, frequent drought conditions causing reduced feeds/fodder, and subsequent increase in disease incidence leading to loss of productivity. Promotion of multiple adaptation and management methods among sheep farming community will help overcome the effects of environmental stress on health and disease incidence in sheep.

9.6.1 Feed/Fodder Management

Climate change directly affects the availability of forage and drinking water for grazing sheep population (Pilling and Hoffmann 2011). The contribution of rangelands to the diets of small ruminants is decreasing because of changes in rainfall patterns, soil erosion, and overgrazing (Salem and Smith 2008). Integrated management of crop–livestock systems such as pasture improvement with fodder trees and shrubs that are drought tolerant will be useful for rehabilitating the rangelands. This is combined with supplementary feeding during drought such as the use of feed blocks, pellets, and a range of agroindustrial by-products may contribute as an adaptive strategy to climate change effects.

9.6.2 Heat Stress Management

Heat stress events frequently observed in arid and semiarid tropics affect physiology and immune potential of sheep that severely reduces production and increases disease incidence (Marai et al. 2007; Macías-Cruz et al. 2016). Managemental practices such as shearing of wooly and hairy sheep prior to the onset of hot weather, providing plenty of clean, cool, and fresh water is paramount to prevent heat stress in sheep. Access to appropriate shade with enough ventilation is an important aspect of managing sheep farms in hot weather. During extreme hot summer, stall feeding will minimize the exposure of animals to high solar radiation. Inclusion of nutrient-dense diets is usually preferred as animals generate more body heat when they digest poor quality feed. Inclusion of certain supplements in the feeds may improve the performance during summer stress. The combination of seaweed *Ascophyllum nodosum* and flaxseed has been suggested as an adequate supplementation to sustain milk production and milk fatty acid profile in ewes during summer heat stress (Caroprese et al. 2016). Similarly, betaine supplementation provided improvements in physiological responses of ewes exposed to heat stress and may be beneficial for the management of sheep during summer (DiGiacomo et al. 2016). Further, stocks suspected of heat stress should not be vigorously handled and if any, transportation of such stock should be taken during cooler times of the day. Providing cooling systems and adjusting the diet to reduce metabolic heat production will be able to protect animals from the local-scale effects of climate change. However, these practices may considerably increase additional input costs of sheep rearing and may not be feasible for small-scale production systems.

9.6.3 Climate-Resilient Genetic Resources

Building up of innate genetic resilience in sheep population to environmental stressors may serve as a long-term strategy. Adapted local sheep breeds of tropics and subtropical regions have unique traits such as disease resistance, temperature, and drought stress tolerance (Hoffmann 2013). Promotion of genetic resources will help to fight disease outbreaks and other effects of climate change (LPP et al. 2010). It is important for sheep breeders to exploit and optimize the genetic diversity of resilient traits and high productivity traits available in different sheep breeds. Genomic selection methods may help to build livestock for efficiency, reduced emissions intensity, and adaptation (Hayes et al. 2013). Genetic characterization for resilience and understanding the adaptation mechanisms for stressful environments is important part of conservation including subsequent building of inventories, information on spatial distribution of breeds, and valuable breeding stock.

9.6.4 Modeling and Forecasting Emerging Sheep Diseases

Early warning policy systems that aim to make the sheep farmers aware of future climate variability and potential shocks so that they can take proactive steps to use varying approaches that best fit to different agroclimatic conditions are designed. Climate variability impacts the distribution of parasites and accordingly influences the spatiotemporal dynamics of parasitic diseases of sheep (Peter and Chandrawathani 2005; O'Connor et al. 2006). The distribution of *Haemonchus contortus*, one of the most pathogenic parasites infecting sheep worldwide, is primarily determined by the environmental conditions. Recently, efforts were taken to predict climate-driven changes in the distribution of haemonchosis in sheep using empirical and mechanistic models (Bolajoko et al. 2015; Rose et al. 2016). Application of proper surveillance information and empirical data of disease response to climate variables are essential to develop robust predictions and build geographic information system (GIS)-based risk maps for parasitic diseases in sheep.

9.6.5 Disease Control and Prevention Measures

The disease management in sheep herd involves farm-level biosecurity and quarantining of sick animals and regular use of vaccines against frequently occurring diseases. The application of suitable diagnostic tools to detect disease outbreak in the herd is a strategy to prevent large-scale damages by taking corrective measures for protecting healthy, unaffected animals. Use of proper antibiotics and ethnoveterinary medications will help in treatment of diseases in sheep. Vector control techniques such as use of fly repellents, insect-proof animal housing, and cloud of smoke with dried leaves/wood may keep off *Culicoides* from sheep flock. A "One Health" approach developed by Food and Agriculture Organization (FAO) is effective in prevention and control of sheep diseases as it takes into account every factor associated with animal production.

9.7 Conclusion

Climate change-induced higher pest and disease incidences are well documented through various researches. Increased temperature, humidity, and extreme events lead to higher pest and parasite population in arid and semiarid areas. In addition, heat stress, water scarcity, and nutrition stress caused suppressed immune system in sheep. Further, elevated pathogen population along with immune suppression may lead to severe disease incidences and associated production losses in sheep. Hence, proper disease and pest management strategies should be developed to control higher incidences of disease in sheep during summer.

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10

Enteric Methane Emission in Sheep: Process Description and Factors Influencing Production

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Abstract

Ruminants by virtue of the anatomical structures of the gastrointestinal tract possess a large fermentation vessel known as rumen, where complex feed materials are acted by microbes and are degraded under anaerobic condition to produce volatile fatty acids and fermentative gases. The short-chain volatile fatty acids, namely, acetate, propionate, butyrate and valerate, along with small quantity of branched-chain fatty acids like iso-butyrate and iso-valerate are the main source of energy for the ruminants. Different fermentative gases like carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), etc. are produced in the rumen of sheep during the process of digestion. Enteric CH_4 is one of the important gases which animal nutritionists and environmentalists are concerned owing to wastage of feed energy to the tune 8–12% and also due to the phenomenon of global warming. CH_4 is a potent greenhouse gas (GHG) which is responsible for global warming, and it is about 23 times more potent than CO_2. CH_4 gas which is added to the atmosphere comes from both biotic source and from anthropogenic activity. In the last few decades, there is steady increase in human population, industrialization, urbanization and income of people, and this phenomenon has increased the demand of livestock-derived food like meat, milk and eggs. To cope up with the demand of food of livestock origin, the number of food animals have also increased to several folds. The livestock, especially in developing countries, thrives on poor-quality feed material which is also one of the contributory factors for increased enteric CH_4 production. Sheep is a grazing animal and

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thrives on pastures, grassland and community grazing land. Sheep as a food animal plays an important role in meeting the protein requirement of human population and provides and generates income for the farmers worldwide. In spite of the beneficial effect, sheep inherently produce huge quantity of CH_4 in their stomach and release them to the environment which contributes to the phenomenon of global warming. As sheep is primarily a grazing animal, the quality of pasture may be a determining factor for enteric CH_4 production. This chapter deals with the enteric CH_4 production in sheep; microorganisms involved in the process, metabolic pathways existing in the rumen and factors influencing enteric CH_4 production are discussed in details.

Keywords
Sheep • Enteric methane • Methanogenesis • Rumen microbes • Metabolic pathways • Factors affecting methane production

Contents

10.1 Introduction

The contribution of livestock to enteric methane (CH_4) emission is a much debated topic worldwide, and at the same time it is also a concern for scientists working in agriculture, animal husbandry and environmental sciences because of the deteriorating environmental health. The global warming phenomenon, which everybody is aware, is caused due to release of greenhouse gases (CO_2, CH_4, N_2O, etc.) to the atmosphere because of anthropogenic activity as well as from the enteric fermentation in the ruminants' stomach. With the increase in the global human population, the demands for food of animal origin are increasing very rapidly. The main products from livestock are milk, meat, eggs, hide, etc., and their demands are increasing with the augment in income of the people in both developing and underdeveloped countries. Concomitantly, the livestock population in most of the countries is increasing day by day to meet the ever escalating demand of teeming human population for livestock food.

Because of the anatomical differences, the ruminants unlike simple stomach animal possess a large fermentation vat known as the rumen. The feedstuffs consumed by the ruminants are fermented in the rumen anaerobically by a host of microorganisms and are converted into short-chain volatile fatty acids, namely, acetate, propionate, butyrate and valerate, along with branched-chain fatty acids like iso-butyrate and iso-valerate and fermentative gases. The VFA is the main source of energy for the ruminants and aids the animals in meeting their maintenance requirements as well as for their growth and production. The fermentative gases formed in the rumen are carbon dioxide (CO_2), hydrogen (H_2), CH_4 and nitrous oxide (N_2O).

Enteric CH_4 production in ruminants is a normal phenomenon, and it acts as a sink for the disposal of H_2 gas which is formed in the rumen as a result of anaerobic fermentation. Enteric CH_4 emitted by the ruminants is a wasteful process, and significantly higher amount (10–12%) of the feed energy is wasted as CH_4. If the H_2 gas which is liberated in the process can be channelled for propionate production or for some useful end product(s), then the rumen fermentation efficiency can be increased with lower enteric CH_4 production.

Like all ruminants, sheep also possess four-chambered stomach and rumen; the largest of the four chambers occupies significant portion of the stomach. Sheep are range managed animals and depend on grazing resources for most of their nutrient requirements. Among the domesticated ruminants, they are unique as they can thrive on fallow, barren and waste land where it becomes difficult for other domestic ruminant species to assimilate. Sheep has the ability to sustain themselves on resources even found beneath the soil cover. During scarcity period these animals factually dig the soil cover and unearth the shoots and succulent portion of perennial plant species and consume them (Sankhyan et al. 2010). The small body size and dextrous mouth parts of the domesticated sheep enable them to feed selectively when needed. Sheep differs with other domesticated ruminant species when it comes to feed selection; they normally select feedstuffs that capitalize on pleasant sensory stimuli and minimize unlikeable ones. They select the tender, succulent, readily visible, sweet-smelling and sweet-tasting plant parts over those that are coarse, dry, obscure, obnoxious smelling and tasting (Arnold 1981). Thus by the virtue of the feeding habit, forb consumption by sheep tends to increase as its availability increases (Cook et al. 1967; Bryant et al. 1979; Campbell et al. 2007), and leaves usually are a major constituent of sheep diet (Bryant et al. 1979; Dudzinski and Arnold 1973). It is noteworthy that in the lean seasons they are able to meet their requirement for various nutrients even in the semiarid regions because of their selective grazing habit.

The digestive system of sheep is more efficient for utilizing a wide variety of feedstuffs, and the presence of a diverse consortium of anaerobic microorganisms in the compartmental stomach is unique for this livestock species (Agrawal et al. 2014). In this chapter some light is thrown on the enteric CH_4 production in sheep; their digestive system, metabolic pathways involved in the process, factors influencing CH_4 production involving animal factors, feed factors, feeding system, presence of plant secondary metabolites in the diets of the sheep, etc. are extensively discussed.

10.2 Methane and Global Warming

CH_4 is a potent greenhouse gas (GHG) responsible for global warming and is emitted from natural sources like wetlands and from anthropogenic activities such as leakage from natural gas systems and from the raising of livestock. Global warming potential (GWP) of CH_4 is estimated to be 56 for over 20 years. It is a relative measure of how much heat a GHG traps in the atmosphere and compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of CO_2 (IPCC 2013). It is calculated over a specific time interval, commonly 10, 20 or 500 years, and expressed as a factor of CO_2 (GWP of CO_2 is 1). Natural processes in soil and chemical reactions in the atmosphere help to remove CH_4 from the atmosphere. CH_4's lifetime in the atmosphere is much shorter than CO_2, but CH_4 is more efficient at trapping radiation than CO_2.

CH_4 emission attributed to livestock mostly occurs due to enteric fermentation and from manure management. CH_4 emissions from livestock are estimated at about 2.2 billion tonnes of CO_2 equivalent, accounting for about 80% of agricultural CH_4 and 35% of the total anthropogenic CH_4 emissions. CH_4 emitted from livestock depends on the feeding system on which livestock are reared (Soren et al. 2015). Among the diverse factors associated with enteric CH_4 production in ruminants, nutrition plays an important role. CH_4 production will be lowered only if the feed that is offered to the animal is tailored to the metabolic requirements, with better digestibility, and significant portion of the nutrients are diverted towards production and less towards wastage and CH_4 emissions (Grainger and Beauchemin 2011). For instance, in concentrate-based feeding system, a high-grain diet will result in less CH_4 per unit of intake in ruminants, but feeding system solely on concentrate will have other implications. On the other hand, in pasture-based animal feeding systems in countries with a large agricultural sector (Argentina and New Zealand), the contribution of livestock to GHG emissions is considerably greater (Leslie et al. 2008; O'Mara 2011).

10.3 Methane Emission from Sheep vs Other Ruminant Species

All the ruminant species emit CH_4 by virtue of their digestive system which is adapted for anaerobic fermentation, especially the rumen, the largest of the four chambers. In the developing countries, most of the ruminant species thrive on poor-quality roughages to meet their nutrient requirement, and in the process they contribute significantly to global CH_4. Large ruminants like cattle and buffaloes produce

Table 10.1 Enteric methane emission from different livestock species in the world

Livestock species	[a]Enteric CH_4 emission (kg $\times 10^9$)
Cattle	69.9
Buffalo	10.7
Sheep	6.04
Goat	4.61
Swine	1.08
Camel	1.11
Horse	1.05
Ass	0.42
Mule	0.11
Alpaca	0.063
Total CH_4 production	94.9

[a]Estimated methane emitted by different livestock species in 2010. Adopted from Patra (2014a)

more CH_4 than the smaller ruminants (Table 10.1). Thus, the countries or regions with the largest cattle populations will contribute the most to global CH_4 emissions on a million-metric-tonne basis (Knapp et al. 2014). As per one estimate, by 2025 the total global enteric CH_4 emission (kg$\times 10^9$) from different class of animals will be 105, of which cattle, buffalo, sheep, goat, swine, camel, horse, ass, mule and alpaca will contribute to about 77.3, 12.1, 6.18 and 5.19, 1.29, 1.17, 1.03, 0.45, 0.09 and 0.13, respectively (Patra 2014a).

Smaller ruminants like sheep and goats will produce slightly more CH_4 than non-ruminants like horses and swine. CH_4 emitted by different ruminants depends on host of factors like species of animal, populations, dry matter intake, level of production, quality of pasture, roughage quality, volume of the rumen and other factors (Broucek 2014). CH_4 emissions in dairy cows depend on the body weight, feed intake, diet composition and milk yield. However, there is a wide variation in CH_4 productions when same diets are fed at same level in dairy cows (Bell et al. 2012).

CH_4 production in lactating cows is almost twice the amount as compared to either dry cows or heifers and is mostly due to their increased feed intake, although ration and animal size also have an effect. Sheep and goats on the other hand can produce about 10–16 kg CH_4/year, while cattle can produce about 60 to 160 kg/year, and this depends on their size and dry matter intake of the animal. CH_4 to some extent is also produced by non-ruminant herbivore animals like donkey, horses, mules, etc. as a result of anaerobic fermentation in their hindgut. The quantity of CH_4 produced by the hindgut fermenters is relatively less than that of ruminants because in these animals there is alternative H_2 sink available other than CH_4 (Jensen 1996) and also due to the fact that the digesta entering the hindgut is already digested in the small intestine.

10.4 Digestive System of Sheep

The digestive system of sheep is composed of mouth, oesophagus, stomach (rumen, reticulum, omasum and abomasum), small and large intestines and anus. Various other structures and organs, such as the salivary glands and liver, also help in the digestion process. A few of the key structures are described briefly below.

10.4.1 Salivary Glands

There are three sets of glands that drain saliva into the mouth. The saliva mixes with the feed that is being chewed and is swallowed with the feed. Saliva has a high pH and is very important in maintaining the correct pH balance in the rumen and is a key component of rumen fluid. Therefore, the salivary glands in ruminants are extremely useful. An adult sheep can secrete above 25 litres of saliva per day.

10.4.2 Oesophagus

The oesophagus is a long muscular tube that runs to the stomach. When feed is swallowed, muscles in the oesophagus move the feed to the rest of the system.

10.4.3 Stomach

The stomach of ruminants greatly differs in structure and function compared to monogastrics (dogs, pigs, horses, humans, etc.). Monogastrics have a relatively simple, single-chambered stomach. Sheep, like other ruminants, have three additional chambers (rumen, reticulum and omasum) that feed passes through before reaching the ‘true’ stomach (abomasum). The ruminant stomach occupies most of the left-hand side of the abdomen. In sheep, the rumen holds 75%, reticulum 8%, omasum 4% and abomasum 13% of the total volume of the stomach.

10.4.3.1 Rumen

The rumen is the largest compartment and extends within the left side of the body cavity from the diaphragm to the pelvis. The rumen is a critical site for digestion of feed in ruminants. It has anaerobic complex environment and harbours host of microorganisms (bacteria, protozoa and fungi) which acts upon the feedstuffs and digest them, with liberation of volatile fatty acids and fermentative gases. The rumen contents separate into three zones based on their density and particle size: gas (fermentation by-product) rises to the top; small, dense particles sink to the bottom (grain, well-digested forage); and lighter, longer particles form a middle layer on top of the rumen fluid. Feed remains in the rumen until the particles are small enough to pass into the next chamber.

The main sources of energy for the sheep are volatile fatty acids, namely, acetate, propionate, butyrate and valerate with small amounts of branched-chain fatty acids (iso-butyrate and iso-valerate). Approximately 70% of the energy requirements of the animal are supplied through microbial activity in the rumen. The feed proteins on the other hand are first degraded by the rumen microbes to ammonia, and subsequently this ammonia is used for synthesis of microbial protein. The microbial protein takes care of the maintenance requirement of the sheep. Some types of proteins will be completely dissolved and utilized by the microbes, while other types pass from the rumen intact, and these are known as bypass proteins.

10.4.3.2 Reticulum

The reticulum is a blind pouch of the rumen that acts as a holding area for feed after it passes down the oesophagus. The reticulum receives material coming into the digestive system and traps the larger particles. As there is no distinct division between the rumen and the reticulum, together they are often referred to as reticulo-rumen.

10.4.3.3 Omasum

The omasum is much smaller than both the rumen and reticulum. Functionally, it grinds the digesta coming from the rumen or reticulum to reduce the particle size and to absorb excess moisture. As fermentation requires large amounts of fluid, it is important to recapture water to avoid dehydration. From the omasum, digesta proceeds into the abomasum.

10.4.3.4 Abomasum

The abomasum is the true stomach in case of ruminants. It has a role similar to stomach in monogastric (pig, dog, etc.) including the production of acids to help in the digestion process of partially digested feed (digesta). Protein that is insoluble in the rumen fluid, a small percentage of starch and any fats in the diet are passed from the rumen into the abomasum relatively intact. As large numbers of microbes are also flushed from the rumen, the abomasum is specialized to break down the microbes. The abomasum wall produces enzymes and hydrochloric acids which hydrolyzes proteins of both feed and microbial origin to smaller units. These microbes are an important source of nutrients for the ruminant. Because ruminants eat such large amounts of plant material, there is almost a continuous flow of feed through the abomasum.

10.4.3.5 Small Intestine

The small intestine is an elongated tube running from the abomasum to the large intestine. It is the main site of absorption of nutrients that have bypassed the rumen. The small intestine is approximately 26 metre long in adult sheep. Bile and pancreatic juice drain into the small intestine to aid in digestion of feed components. The small intestine has three regions, the duodenum, the jejunum and the ileum, and each region has specific role in the digestion.

10.4.3.6 Large Intestine

The large intestine comprises of caecum, colon (ascending colon, transverse colon and sigmoid colon), rectum and anus. The caecum is a blind pouch that opens into the digestive tract. In ruminants, approximately 10–15% of the animal's energy requirement is supplied through microbes in the caecum.

10.5 Microorganisms Involved in Enteric Methane Production

Rumen harbours a consortium of anaerobic microorganisms which are extremely diverse, and the microbial population comprises of bacteria, fungi, protozoa, archaea, bacteriophages, etc. which are in symbiotic relationship with each other. These anaerobic microorganisms degrade the nutritional components of the feedstuffs like carbohydrates, proteins and lipids and convert them into microbial cells, volatile fatty acids and fermentative gases. Majority of the rumen microorganisms are still uncultured even today; however, in recent times the extensive use of molecular biology techniques has helped researchers to unearth several rumen microorganisms which were not known earlier, for example, in bacteria alone there are at least between 300 and 400 phylotypes (Edwards et al. 2004; Larue et al. 2005; Yu et al. 2006). Additionally, protozoa, fungi, methanogenic archaea and bacteriophages also add to the diversity and functioning of the rumen microbial ecosystem. All the rumen microorganisms are highly specific and perform metabolic functions which are important for the nutrition, growth and health of the host animal. The rumen is an anaerobic and methanogenic environment where CO_2 and H_2 produced from the fermentation of feeds act as the main electron acceptor and donor, respectively, within the system (Morgavi et al. 2010).

The organic matter content of the feed material is degraded by concerted effort of different groups of anaerobic microorganism in the rumen. Structural carbohydrates, proteins and other organic polymers of feedstuffs ingested by sheep are broken down in the rumen to their monomer components by primary anaerobic fermenters (McAllister et al. 1996). These simple monomers are further acted upon by both the primary and secondary fermenters to volatile fatty acids and fermentable gases (CO_2 and H_2). When it comes to the methanogens, these groups of microbes are at the bottom of this trophic chain and use the end products of fermentation as substrates. The synthesis of CH_4 in the rumen aids to the efficiency of the system in that it avoids any increase in the partial pressure of H_2 to the levels that might inhibit the normal functioning of microbial enzymes involved in electron transfer reactions, particularly NADH dehydrogenase, resulting in NADH accumulation, and ultimately reduces rumen fermentation. The capturing of the H_2 produced by one microbial species by another is normally referred as interspecies H_2 transfer (Wolin et al. 1997) and is a process that in many cases involves a syntrophic relationship between two microbes.

10.5.1 Rumen Methanogens

Methanogens present in the rumen belong to the domain archaea, and most of them belong to methanogen clades with dominance of *Methanobrevibacter* species. The *Methanobrevibacter* clade comprises of nearly two third of rumen archaea while the remaining one third is reported to be composed of roughly equal parts by phylotypes belonging to *Methanomicrobium* and the rumen cluster C (Janssen and Kirs

2008). Most of the methanogens present in the rumen are devoid of cytochromes, so they are less efficient in obtaining energy from the methanogenic process, and this is in contrast to the cytochrome containing order Methanosarcinales (Thauer et al. 2008) which are also present in the rumen environment. These organisms have lower threshold for partial pressure of H_2 and multiply quickly (organism becomes double in about an hours' time), and they develop better at the mesophilic temperature and near neutral pH of the rumen (Thauer et al. 2008).

The methanogens use three major substrates, namely, CO_2, compound containing a methyl group or acetate (Liu and Whitman 2008) for CH_4 production. However, in the rumen the predominant pathway is the hydrogenotrophic pathway using CO_2 as the carbon source and H_2 as the main electron donor (Hungate 1967). Biochemical studies of culturable methanogens have shown that *Methanobrevibacter ruminantium, Methanobacterium formicicum* and *Methanomicrobium mobile* utilize H_2/CO_2 and formate to produce CH_4.

Other pathways for CH_4 production also exist in the rumen, and formate is also reported to be one of the important electron donors used by many rumen hydrogenotrophic methanogens and may account for up to 18% of the CH_4 produced in the rumen (Hungate et al. 1970). Other substrates like methylamines and methanol produced in the rumen can also be used by methylotrophic methanogens of the order Methanosarcinales and *Methanosphaera* sp. from the order Methanobacteriales (Liu and Whitman 2008) for CH_4 production. Methanogen like *Methanosarcina mazei* synthesizes CH_4 from acetate, methanol and methylamines, while *Methanosarcina barkeri* utilizes H_2, CO_2, acetate, methanol and methylamines for CH_4 synthesis (Jarvis et al. 2000). Though the contribution of these substrates to methanogenesis has not been measured, it is likely to be small as the methanogens able to perform this conversion are not predominant members of the rumen methanogenic population (Janssen and Kirs 2008). In addition to the above substrates, CH_4 is also produced from acetate via the aceticlastic pathway, and this pathway appears to be limited only to members of the order Methanosarcinales (Liu and Whitman 2008). But studies have shown that this is not a very important pathway for CH_4 production in the rumen (Oppermann et al. 1961; Stewart et al. 1997). Studies have shown that methanogens are closely associated with the liquid as well as with the solid phases of rumen and rumen epithelium (Pei et al. 2010). In most of the methanogens, methyl-coenzyme M reductase (MCR) is most common and is essential in the final step of CH_4 production. MCR catalyzes the conversion of methyl-2-sulfanylethanesulfonate (methyl-SCoM) and N-7-mercaptoheptanoylthreonine phosphate (CoB7SH) to CH_4 and the mixed disulphide CoBS-SCoM (Wongnate and Ragsdale 2015).

10.6 Different Metabolic Pathways Involved in Enteric Methane Production

The presence of methanogens in the rumen is unique, and they produce CH_4 from the substrates which are available in the anaerobic environment, namely, H_2, CO_2, formate, acetate and methanol (Rea et al. 2007; Hook et al. 2010). The fermentation of carbohydrates results in the formation of H_2, CO_2, formate and acetate, while methanol comes from the fermentation of pectin. Till date, the pathways of methanogenesis from the above precursors are yet to be demonstrated in the rumen. Moreover, it is very difficult to culture the rumen methanogens; therefore less information are available pertaining to their metabolism and physiology. But with the advent of genome sequencing technology, it has become easier to understand the pathway of CH_4 production in the rumen.

Reports are available for *Methanobrevibacter ruminantium* and *Methanobrevibacter* sp. *AbM4*, methanogenic archaea, where whole genome sequence study has shown two complete methanogenic pathways for reduction of CO_2 and oxidation of formate to CH_4 in the two species of methanogenic archea (Leahy et al. 2010; 2013). Detailed study of *Methanobrevibacter* sp. *AbM4* isolated from the abomasal contents of a sheep has shown that it is a strict anaerobe and its hydrogenotrophic metabolism is characterized by its ability to produce CH_4 from H_2, CO_2 and formate (Leahy et al. 2013). Different pathways used by various genus and species of methanogens and their precursors found in the rumen will help to explain the differences in the utilization of substrate for enteric CH_4 production in ruminants. Some of the common pathways reported by different workers are briefly described below.

10.6.1 Pathway of CO_2 Reduction in the Rumen

Although the methanogens are very assorted, they can only utilize a limited number of substrates, and the most common three types of substrates required by the methanogens are CO_2, methyl group containing compounds and acetate (Hook et al. 2010). However, the most commonly available organic substances found in the rumen like carbohydrates and short- or long-chain fatty acids and alcohols are not used as such as substrates for methanogenesis by the methanogens. These organic compounds initially must be converted to utilizable substrates by other anaerobic bacteria or eukaryotes for the use of methanogens for CH_4 synthesis process.

The most common substrates required for methanogenesis are H_2 and CO_2. Anaerobic fermentation activity in the rumen involves an oxidation process, which generates reduced cofactors (NADH, NADPH and FADH), which are then reoxidized to NAD+, NADP and FAD+ by dehydrogenation reactions, releasing H_2 in the rumen. As an electron acceptor process, methanogenesis removes H_2 gas from the rumen. Therefore, methanogenesis is highly essential for attaining a high-performing rumen ecosystem for proper functioning of the rumen. Accumulation of excess H_2 in the rumen may inhibit several enzyme systems; mainly the activity of dehydrogenase enzyme may be severely affected resulting in the impairment of normal rumen fermentation process (Pereira et al. 2015).

The combination of H_2 and CO_2 is the most common substrate of the methanogens for methanogenesis, and the detailed pathway for the formation of CH_4 has been described by Liu and Whitman (2008). In this pathway, CO_2 is reduced successively to CH_4 by H_2 as the primary electron donor through formyl, methenyl, methylene and methyl intermediates. The reduction of the carbon moiety involves several steps catalyzed by a number of unique cofactors and enzymes. The details are depicted schematically in Fig. 10.1.

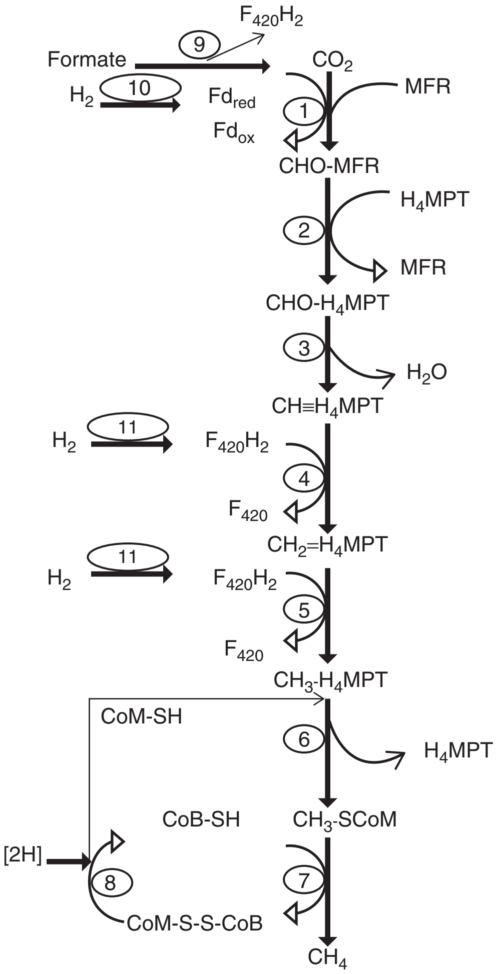

Fig. 10.1 Methanogenesis from H_2/CO_2 or formate in the rumen (Adapted from Liu and Whitman 2008)

Enzymes: *1*. formyl-MFR dehydrogenase (Fmd); *2*. formyl-MFR:H$_4$MPT formyl-transferase (Ftr); *3*. methenyl-H$_4$MPT cyclohydrolase (Mch); *4*. methylene-H$_4$MPT dehydrogenase (Hmd); *5*. methylene-H$_4$MPT reductase (Mer); *6*. methyl-H$_4$MPT:HS-CoM methyltransferase (Mtr); *7*. methyl-CoM reductase (Mcr); *8*. heterodisulfide reductase (Hdr); *9*. formate dehydrogenase (Fdh); *10*. energy-conserving hydrogenase (Ech); *11*. F$_{420}$-reducing hydrogenases

Abbreviations: *Fd*^{red} reduced form of ferredoxin, *Fd*^{ox} oxidized form of ferredoxin, *F*^{420}*H*^{2} reduced form coenzyme F$_{420,}$*MFR* methanofuran, *H*^{4}*MPT* tetrahydromethanopterin, *CoM-SH* coenzyme M, *CoB-SH* coenzyme B, *CoM-S-S-CoB* heterodisulfide of CoM and CoB, *CoA-SH* coenzyme A

10.6.2 Pathway of Formate Oxidation

This is also one of the pathways involved in methanogenesis in the rumen of sheep and other ruminants. Formate also acts as a substrate for CH_4 production, and it accounts for about 15–20% of the total CH_4 production in the rumen (Hungate et al. 1970; Asanuma et al. 1999a; 1999b). The utilization of formate begins with oxidation to CO_2, which subsequently enters CO_2 reduction pathway, and the steps involved in the process are described schematically in Fig. 10.1.

Formate dehydrogenase (Fdh) catalyzes the conversion of formate to CO_2+H_2, and Fdh is a molybdenum-containing enzyme with molybdopterin as cofactor, flavin adenine dinucleotide, zinc, iron, inorganic sulphur and two distinct subunits (FdhA, FdhB) in an αβ configuration. Detailed molecular studies by researchers have revealed that the genes encoding the two subunits from *Methanobacterium formicium* overlap by one base pair. In the entire genomic sequence, the content of adenine phosphate + thymine (A+T) is 59 mol %, while in the fdhA gene sequence the A+T content is 71 mol % (Shuber et al. 1986). In the process of gene expression, the fdhA and fdhB genes are co-transcribed, and the starting site lies in 4.3 kb upstream of the fdhA gene (Patel and Ferry 1988). In another development the genes for the dehydrogenase from *Methanococcus maripaludis* have attracted the attention of researchers worldwide. The fdh genome of *M. maripaludis* contains two important gene clusters (fdh1, fdh2), one of which (fdh1) have been reported to play an important role in the transfer process of formate to CO_2+H_2 (Lupa et al. 2008) and can encode two subunits and a putative formate transporter while the other (fdh2) encodes only two subunits (Wood et al. 2003).

10.7 Factors Influencing Enteric Methane Production in Sheep

There are several factors known to influence enteric CH_4 production, and some of the important factors pertaining to sheep are animal factors, type of feed offered to sheep, grazing pasture, probiotic feeding, supplementation of feed additives and CH_4 inhibitors, plant secondary metabolites, rearing of sheep under different feeding system, types of plants consumed by sheep, etc.which are discussed briefly in this section.

10.7.1 Animal Factors

Enteric CH_4 production in animals also depends on the animal species. Animal factors like dry matter intake, rumen volume and adaptivity of different breeds are some of the factors in sheep which can influence enteric CH_4 production. For example, some sheep breeds are more adapted to thrive in diverse conditions. Smaller breeds of sheep which are sturdier and generally found in mountainous and hilly terrains are more efficient in utilizing low-quality native pastures than the large size breeds of sheep which are found in the plains or lowlands. These may be due to physiological and behavioural differences among the different breeds of sheep (Fraser et al. 2015). The large sheep breeds and crossbred animals theoretically partition relatively more nutrients towards growth and productive purposes. As the dry matter intake of the animal increases, the enteric CH_4 production also increases, and the DM intake to a large extent depends on the body size of the sheep. Therefore larger sheep may be expected to eat more and in the process may produce more CH_4.

On the other hand, some breed of sheep may produce lower enteric CH_4 per kg of DM intake (g CH_4/kg DM intake). These differences may be due to fermentation of less amount of organic matter in the rumen; a shift in volatile fatty acid production towards alternative H_2 utilizing (propionate or reductive acetogenesis) pathways; and an increase in the relative yield of microbial cells produced by fermentation (Nolan 1998), which may potentially be affected by host-derived differences in rumen morphology and function. The mean retention time and flow of digesta in the rumen is also one of the important factor reported to influence enteric CH_4 production in sheep. Pinares-Patino et al. (2003) reported that up to 40% of the observed variation in CH_4 production in sheep could be attributed to differences in mean rumen outflow.

10.7.2 Type of Feed Offered

The type of feed consumed by the sheep will determine the rumen fermentation, the type of volatile fatty acids formed and the amount of CH_4 production in the rumen. Diets with a high proportion of concentrates in general will promote a high propionate type of ruminal fermentation and are conducive for reduced enteric CH_4 production (O'Mara 2004). The proportion of concentrate to forage content of the ration influences the rumen fermentation and hence the acetate: propionate ratio. Therefore, CH_4 production would be less when high concentrate-based diets are fed to sheep (Moss et al. 2000). Very high level of concentrate feeding to sheep may not be wise, as higher level of feeding may result in acidosis which has very severe clinical impact on the livestock health and on the economics of sheep rearing.

The concentrates contain less structural carbohydrates relative to forages; thus, when concentrate portion of the diet is increased in the diet of sheep, there is a concomitant increase in the proportion of propionate and a decrease in acetate. Thus a decrease in enteric CH_4 production would be expected. The reduction of ruminal pH with an increase in concentrate intake has deleterious effect on both the protozoa and cellulolytic bacteria which results in lower H_2 production in the rumen (Castillo-González et al. 2014). Thus lower H_2 available to the methanogens hinders higher CH_4 production in the rumen.

10.7.3 Grazing and Enteric Methane

Sheep is a grazing animal and the forages grazed by the animals impact enteric CH_4 production. CH_4 emissions from sheep on grazing pasture are not that easy to predict because it is difficult to determine the exact feed intake; the nutritional value of the pasture may vary both among and within the season. Generally the nutrient content of forages will depend on the stage of maturity. As the pasture becomes matured, the nutrient content of the forages decreases, and the concentration of structural carbohydrates increases, thus lowering the nutritive value of pasture. So when sheep graze on poor-quality pastures, acetic type of fermentation will predominate in the rumen, resulting in an increase CH_4 production. CH_4 production from relatively nutrient-rich pasture will be lower than poor-quality pasture (Clark et al. 2011). When the non-fibre carbohydrate content of forages is higher, lower CH_4 production has been reported in animals. There is also evidence that using clovers and grasses with high water-soluble carbohydrates in animal diets can directly reduce CH_4 emissions (Lovett et al. 2004).

However, the grazing sheep have the ability to assimilate nutrient-rich plant material albeit grazing on poor-quality pasture. The structure of the mouth enables them to select the tender, succulent, readily visible, sweet-smelling and sweet-tasting plant parts over those that are coarse, dry, obscure and obnoxious smelling and tasting (Arnold 1981). Therefore, pasture quality may have only minor influence on the enteric CH_4 production in sheep.

10.7.4 Probiotic Feeding

Microbial feed additives (probiotics) like *Saccharomyces cerevisiae* have been used extensively in the diet of sheep and other ruminant species as an alternative to antibiotics for enhancing growth performance of food animals (Soren et al. 2013). Probiotics, as the definition indicates, are live organisms which when administered to animals confer some beneficial effect to the host in terms of growth, reduction in the incidence of diarrhoea, etc. The use of probiotic for lowering enteric CH_4 production in different species of livestock has also been carried out, but the results pertaining to abatement of enteric CH_4 are conflicting. Several ruminal microorganisms have been tried to be used as probiotic for the abatement of enteric CH_4. The population of acetogens which are established in the rumen early in the life of sheep can be one of the approaches in this direction. The acetogen population in the rumen of Indian breed of sheep has been already established (Malik et al. 2015). These acetogen populations are able to utilize H_2 for acetate production in lambs. As the lambs develop into adult rams, the population of methanogens outnumbers the acetogens. The methanogens are populous and more efficient than the acetogens in the rumen environment. This is due to the fact that methanogens require lower concentration of H_2 to reduce CO_2 into CH_4 than that of acetogens which probably need a higher concentration of H_2 in the medium to reduce CO_2 into acetate.

The use of acetogens as probiotics has been attempted by several researchers either with or without the addition of methanogen inhibitors (Lopez et al. 1999), but the results so far are not conclusive. Live yeast, the most commonly used probiotic in sheep production (Soren et al. 2013), has not been extensively tested for their effect on CH_4 production (Chaucheyras-Durand et al. 2008). The inconsistency on the effect of yeast supplementation on the CH_4 production from several studies has been shown by meta-analysis (Sauvant 2005), where its supplementation showed inconsistent effect on CH_4 production. However, yeasts are capable to show great functional and metabolic diversity, and some strains have been reported to decrease CH_4 production in vitro (Newbold and Rode 2006). These results have not been confirmed in animal studies.

10.7.5 Feed Additives and Methane Inhibitors

The CH_4 production in livestock increases when they are maintained on poor-quality roughages with no supplementation (Leng 1991). Under these circumstances numerous mitigation strategies have been constantly tried by animal scientists to reduce CH_4 production from ruminants by different dietary manipulation or by means of supplementation of different additives. Dietary manipulation like increasing concentrate portion of the diet (Yan et al. 2000; Lovett et al. 2005; Beauchemin and McGinn 2005), supplementation of oil (Fievez et al. 2003; Machmüller et al. 2000), dicarboxylic acid (malic and fumaric acid) and feeding of quality forages has been reported to reduce CH_4 to a considerable extent.

Supplementation of fat and oil in the diet of sheep has been reported to influence rumen fermentation, inhibit protozoal population and reduce enteric CH_4 production. Any manipulation involving fat or oil supplementation in ruminants must be attempted with utmost care as higher level of fat can inhibit rumen microbes and cause a reduction in the fibre digestibility. The effect is also demonstrated by meta-analysis of sizable number of data on the effect of dietary fat supplementation on rumen fermentation, digestibility and enteric CH_4 in sheep and dairy cattle (Patra 2014b). The analysis showed that with each percentage increase in the supplemental dietary fat, enteric CH_4 emission decreased by 4.30% in sheep. In the same study CH_4 suppression was followed by a reduction of both DM and NDF digestibility with increased fat supplementation. Several studies have attempted to modify rumen fermentation for lower CH_4 production in sheep by supplementing oils like coconut oil, sunflower oil and soybean oil (Machmüller et al. 2003; Mao et al. 2010; Bhatt et al. 2011) in the diet of sheep. Coconut oil supplementations in ruminant studies have been found to be very effective in lowering enteric CH_4 which is mostly due to medium-chain fatty acids (C8 to C16) in the oil.

The supplementation of nitrate in sheep diet has been proclaimed to modify rumen fermentation for lower enteric CH_4 production (van Zijderveld et al. 2010; Pal et al. 2015). Nitrate acts as H+ sink alternative to methanogenesis that can provide an energetic benefit in the rumen on adding nitrate to the diet. In the rumen, NO_3 is reduced to nitrite and then ammonia, a process which is actually more energetically favourable than the formation of CH_4 (Ungerfeld and Kohn 2006). The ammonia generated in the process provided nitrogen to the animal and can be beneficial in diets low in crude protein. Thus stoichiometrically, supplementing nitrate to animals should be able to decrease CH_4 by 25.8 g per 100 g NO_3 (van Zijderveld et al. 2010), a value authors often compare results against, to check efficiency of CH_4 reduction by means of complete NO_3 conversion to ammonia. When sulphate is supplemented in ruminant's diet, similar type of phenomenon occurs. Sulphate can act as an electron acceptor, and it can reduce CH_4 by competing for electrons which is a more favourable reaction than methanogenesis (Ungerfeld and Kohn 2006). Toxicity can be a concern with either of these compounds in the diet; NO_3 at high levels may cause methaemoglobinaemia (van Zijderveld et al. 2010), and SO_4^{-2} may cause polioencephalomalacia (Sarturi et al. 2013), respectively.

Many chemical feed additives like ionophores (monensin, lasolasid), antibiotics and CH_4 inhibitors (chloroform, bromochloromethane, 2-bromoethanesulfonate, p-aminobenzoic acid) and defaunating agents (calcium peroxide, copper sulphate, dioctylsodium sulfosuccinate and detergents) have been tried in ruminant nutrition to improve rumen fermentation by reducing CH_4 vis-à-vis enhancing the efficiency of ruminant production. Bromochloromethane is a potent chemical known to inhibit rumen methanogens directly; thus, enteric CH_4 production has been reported to decrease by up to 50% in vivo (Hristov et al. 2013). This compound has a structural analogue to methyl-coenzyme M, which acts as an inhibitor to the enzyme methyl-coenzyme M reductase, which catalyzes the final reaction in the formation of CH_4 (Romero-Perez et al. 2014).

However, most of these additives presently are discontinued for the use in ruminant diet due to toxicity-related problems and microbial adaptation in the rumen to these chemicals. Because of these problems, animal nutritionists and rumen microbiologists are compelled to explore some natural alternatives to these chemical feed additives for eco-friendly animal productions.

10.7.6 Plant Secondary Metabolites

Plant secondary metabolites (PSM) were earlier considered as anti-nutritive factors in animal nutrition because of their antibacterial properties and adverse effect on nutrient utilization (Soren et al. 2015). These PSMs found in plants are not mainly involved in the primary biochemical processes like plant growth, development and reproduction; instead, they produce a line of defence which guarantees survival of the plant structures and reproductive elements by protecting against insect predation. Currently numerous studies have attempted to exploit these PSMs as natural feed additives to improve the rumen fermentation efficiency (enhancing protein metabolism, decreasing CH_4 production), reducing nutritional stress such as bloat and improving animal health and productivity (McIntosh et al. 2003; Patra et al. 2006; Benchaar et al. 2007). Recent studies have shown that plant secondary metabolites like tannins, saponins and essential oils at lower concentration could be used to manipulate rumen fermentation favourably by reducing enteric CH_4 production vis-à-vis improve sheep production.

10.7.6.1 Tannins

Plants containing tannins exhibit their antimethanogenic effect mostly due to the presence of condensed tannins (CTs), which are polymers of flavonoid and form complexes with soluble proteins and make them insoluble in rumen but release them in the small intestine under the acidic conditions, reducing bloat and increasing amino acid absorption. There are two modes of action by which tannins affect the methanogenesis process in the rumen: a direct effect on ruminal methanogens (Tavendale et al. 2005) and an indirect effect on H_2 production due to reduction in feed/fibre degradation (Tiemann et al. 2008). The feeding of legume birdsfoot trefoil (*Lotus corniculatus*) containing high concentration of condensed tannins to lambs is reported to lower enteric CH_4 production by 12–15% (Beauchemin et al. 2008; Doran-Browne et al. 2015), mediated through a direct toxic effect on methanogens. Similar type of CH_4-lowering effect (12% per kilogram of intake) was also reported by Carulla et al. (2005) by feeding the extract of *Acacia mearnsii* (61.5% CT) to sheep, and the same study also revealed no adverse effect on the digestibility of fibre.

10.7.6.2 Saponins

Saponins are natural detergents found in many plants and possess detergent or surfactant properties because they contain both water-soluble and fat-soluble components. They consist of a fat-soluble nucleus, having either a steroid or triterpenoid structure, with one or more side chains of water-soluble carbohydrates. A number of studies have reported that supplementation of saponins or plants rich in saponins decreased CH_4 production in the rumen by suppressing or eliminating protozoa in the rumen. A decrease in protozoa numbers has been reported in the rumen of sheep infused with saponins or fed on saponin-containing plants. This is caused by alteration in the cell membrane permeability causing death of protozoa population in the rumen (Klita et al. 1996). When there is a decrease in the number of ruminal ciliate protozoa, it will enhance the flow of microbial protein from the rumen; therefore, the efficiency of feed utilization will increase and enteric CH_4 will decrease. The CH_4-lowering effect of saponins varies considerably and depends on the dose and source of saponins. While feeding saponins at lower doses may not decrease CH_4 production, higher doses may adversely affect the animal health and production (Klita et al. 1996; Wang et al. 2000). Therefore when CH_4 mitigation approaches by means of saponins supplementations are attempted; both feed intake and digestibility should be given due consideration as much of the reduction in in vitro CH_4 has been accompanied by reduction in NDF digestibility (Hess et al. 2003). Common plant material and their extract rich in saponins are *Yucca schidigera*, *Quillaja saponaria*, *Acacia concinna* pods (contains triterpinod saponins), *Knautia arvensis* leaves, *Sapindus mukorossi* fruit pulps (contains triterpinod saponins), *Sapindus saponaria* fruits, *Sesbania sesban* leaves and *Trigonella foenum-graecum* seeds which have been reported to inhibit CH_4 production (Rira et al. 2015).

10.7.6.3 Essential Oils

Essential oils (EOs) are steam-volatile or organic solvent extracts of plants (Gershenzon and Croteau 1991). The most important active compounds present in EOs are broadly included in two chemical groups: terpenoids (monoterpenoids and sesquiterpenoids) and phenylpropanoids. They are mostly obtained from herbs and spices and also present to some extent in many plants for their protective role against microbes (bacterial, protozoa or fungal) or insect attack. Structurally they are mainly cyclic hydrocarbons and are alcohol, aldehyde or ester derivatives. Most of the research work pertaining to the use of essential oils for lowering enteric CH_4 production have been carried out mostly through in vitro experiments (Calsamiglia et al. 2008; Bodas et al. 2008; Benchaar et al. 2009; Soren et al. 2010; Soren et al. 2011), and most of the studies have shown that the CH_4-lowering effects of EOs are dose dependent. Garlic oil has been extensively studied for CH_4-suppressing effect under in vitro experimental conditions. García-González et al. (2008) conducted a series of studies and reported that addition of garlic oil reduced in vitro CH_4 production and shifted the ruminal fermentation towards more propionate production. The dose-dependent response of garlic oil supplementation on CH_4 suppression was also reported by many researchers, wherein garlic oil supplementation reduced CH_4 production by up to 74% when included at 100, 250 (Chaves et al. 2008) and 300 mg/L ruminal fluid (Busquet et al. 2005). In vitro studies with different spice straws, viz. coriander (*Coriandrum sativum*) and dill (*Anethum sowa*) at 20%, ajowin (*Trachyspermum ammi*) and fennel (*Foeniculum vulgare*) at 10% and fenugreek (*Trigonella foenumgraecum*) at 5% level containing different essential oils, with sewan grass (*Lasiurus sindicus*), showed positive rumen fermentation attributes and lowered CH_4 production (Soren et al. 2010; Soren et al. 2011).

10.7.7 Rearing of Sheep Under Different Feeding System

Sheep in general are grazing animals, but due to intensification of the production system, they are also reared under semi-intensive and intensive type of feeding system in different parts of the world. Enteric CH_4 production depends on the feed consumed, substrate degraded and type of end products formed in the rumen of sheep. Rumen fermentation which will form more of propionate will lower enteric CH_4 because propionate formation process consumes H_2, whereas the acetate and butyrate formation process releases H_2. Thus any feeding system which will favour shifting of rumen fermentation from acetate to propionate will lower H_2 release and CH_4 production (Basarab et al. 2013), and these associations have been demonstrated in many of the studies in sheep.

Sheep raised on intensive feeding regime will produce less CH_4 than their counterpart reared on extensive system or on pasture because the more fibrous the feed available to the animal, the greater the CH_4 emissions. Grains such as corn, barley and soya bean and oil cakes (soybean meal, groundnut meal, etc.) are much easier for ruminants to digest, and the amount of CH_4 produced by sheep fed a grain-based diet is less (Knapp et al. 2014) than that of sheep fed grass-based diets. In general oil cakes or oilseed meals are less methanogenic in comparison to cereal grains and agro-industrial by-products. The presence of secondary plant metabolites in many of the feed ingredients is also responsible partly for lower CH_4 production as many of the methanogenic microorganism are inhibited and propionic acid is the major volatile fatty acid formed when such feed are fed to the ruminants (Szumacher-Strabel and Cieslak 2012).

Sheep raised on extensive type of feeding management are exposed to pastures containing grasses and forages at different stages of maturity, and this may affect the enteric CH_4 production. Feeding on forage-based diet will result in acetate type of fermentation (methanogenic) and will increase CH_4 production compared to propionic-type fermentation which, on the other hand, is stimulated by concentrate (Rowlinson et al. 2008; Kingston-Smith et al. 2010) feeding and by allowing the sheep to graze on high-quality grazing pastures. Research has shown that increased quality and digestibility of forages result in reduced CH_4 production. Grazing systems which are managed properly and allowed for rotational grazing will have tendency to reduce forage maturity, thereby, improving forage digestibility as well as lower enteric CH_4 production.

Semi-intensive type of feeding management is practiced in many parts of the world where sheep are allowed to graze for about 8–10 h in a day, and concentrates are supplemented after grazing hours. Under this system of feeding management, the enteric CH_4 will be lower than extensive system as supplemental concentrate will aid in better synchronization of energy and protein with optimum fermentation (Soren et al. 2015).

10.7.8 Type of Plant Consumed by Sheep

The composition of diet and their intake are the main factors which affects CH_4 production in any ruminant species. Intake of forages rich in structural carbohydrates will produce more CH_4 than mixed diets containing higher levels of nonstructural carbohydrates (Sauvant and Giger-Reverdin 2009). Forages are the main source of nutrients in sheep's diet in most part of the world. The chemical composition of feed resources for livestock is not same and may vary in both chemical and structural composition as well as in its digestibility, in different regions of the world. And the same is also true for grazing pastures on which the sheep depends for the intake of dry matter and nutrients for maintenance and production. Tropical grasses generally use C4 metabolic pathways for photo respiration while most of temperate grasses use C3 metabolic pathways for carbon fixation. It has been reported that C4 metabolic pathway often leads to a higher rate and degree of deposition of lignin in plant tissues, a factor which can alter voluntary intake and digestion (Wilson 1994) and CH_4 production. The presence of secondary plant metabolites such as tannins, saponins and essential oils in many of the forages (legumes, tree leaves, shrubs, etc.) can alter rumen fermentation pattern and lower CH_4 production in sheep (Jouany and Morgavi 2007).

10.8 Conclusions

Sheep is basically a grazing ruminant, and microorganisms present in the rumen are responsible for anaerobic fermentation of the substrate into volatile fatty acids and fermentative gases. The VFAs are the main source of energy for sheep. The presence of large consortia of microorganisms in the rumen is unique, and each organism is in symbiotic relationship with each other. The end product of fermentation like CO_2 and H_2 is used by the methanogens for CH_4 synthesis in the rumen. Different pathways for CH_4 synthesis exist in the rumen, and different microorganisms are involved in the process. Only few methanogens have been thoroughly explored and majority of them have not been studied so far. But with the advent of advance molecular biology techniques like next generation sequencing, it has become easier to study the unknown microorganisms involved in the methanogenesis process. Enteric CH_4 production from ruminant livestock like sheep is a worldwide problem related to global warming. Blueprint for enteric CH_4 mitigation strategies in sheep can be effectively devised only when sound knowledge of the course involved in methanogenesis process along with the microorganisms involved and the factors responsible for the process are properly known.

10.9 Future Prospect

The microbial diversity in the rumen of grazing sheep changes with the quality of the forages available in the pasture, and the enteric CH_4 production also to a larger extent depends on this factor. In the present livestock production system, the requirement of mutton from sheep is also increasing to meet the protein requirement of humans. So in the process, sheep husbandry is undergoing tremendous changes with changes in the feeding system, and sheep in many countries are reared in intensive type of feeding system for early finisher weight gain. In the process, the fermentation pattern is also changing with a change in microbial population. Therefore, a thorough knowledge of the processes along with microorganisms involved in the methanogenesis in sheep will help to formulate CH_4 mitigation strategies for lowering the enteric CH_4 production.

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Alteration in Rumen Functions and Diet Digestibility During Heat Stress in Sheep

11

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Abstract

The rumen is an anaerobic vat that provides a conducive environment to the microflora for fermenting the nutrients. The three main functions of rumen include fermentation of structural carbohydrates, recycling of urea and detoxification of toxic components in forages. Fermentation process produces three main volatile fatty acids (VFAs) such as acetate, butyrate and propionate. The balance between the concentrations of VFAs is necessary to maintain normal ruminal functions. The alterations in various factors like pH, rate of salivation,

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feed type, temperature, etc. also influence the rumen functions like rumen motility and digestibility of nutrients. High ruminal temperature affects the digestibility of dry matter (DM) and neutral detergent fibre (NDF) positively, whereas it negatively influences the digestibility of organic matter (OM). Altered digestibility in animals subjected to heat stress is attributed to changes in bacterial activity and ruminal and intestinal absorption of nutrients since the fermentation process is mainly performed by the ruminal commensals. In heat-stressed animals, the synthesis of microbial protein is also reduced due to reduced availability of energy supply to the microbes. Heat stress also has a role in development of ruminal acidosis. Disruption of feeding patterns by changes in the weather has been implicated as a cause of acidosis. Further, heat stress also was found to increase enteric methane (CH_4) production. The reduced gut motility, rumination, ruminal contractions and passage rate of digesta during high ambient temperature are the major factors which influence CH_4 production. Heat stress was found to influence the microbial population in rumen. During heat stress, *Clostridium coccoides* and *Streptococcus* spp. population increased, whereas *Fibrobacter* population decreased in the rumen. Though the rumen microbial spectrum has numerous bacteria, fungi, protozoa and archaea species, the characterization and culturing of a wide number of species has not been attempted yet. Future research efforts are needed to establish a reference set of rumen microbial genome sequences as understanding the interrelationship between rumen microbes is very vital for developing enteric CH_4 mitigation strategies.

Keywords
Acetate • Heat stress • Methane • Microbes • Propionate • Rumen fermentation • VFAs

Contents

11.1 Introduction

It is predicted that there will be a 2.3–4.8 °C increase in environmental temperature by 2100 due to climate change (IPCC 2007). A reduction in animal productivity by 25% is also estimated in tropical and subtropical countries due to global warming (Seguin 2008). The livestock system in the entire world is vulnerable to climate change more specifically in Third World countries where the economy is still much dependent on agriculture and allied activities. Ruminant farming, both large and small, has been the backbone for poor farmers in Third World countries. The evolutionary process has favoured the ruminants as the most successful herbivores among mammals represented by 200 species among which there are 75 million wild and 3.5 billion domesticated animals across the globe (Hackman and Spain 2010). Ruminants possess a forestomach known as rumen which harbours microflora and fauna that partially digest the feed before entering the abomasum, the true stomach. Ruminants cannot. The flora and fauna of rumenoreticulum produce the enzymes needed to degrade the complex plant polysaccharides, assisting the host animal since they lack enzymes for above-mentioned function (Henderson et al. 2015). The end product of microbial fermentation is volatile fatty acids (VFAs) that act as a predominant nutrient source for the host animal. This ability of ruminants to convert plant-derived compounds into human edible products like milk and meat has exerted positive selection pressure during evolution.

Climate change is expected to exert profound impacts on poor livestock keepers involved in sheep farming and on the corresponding ecosystem of goods and services which they depend on. Knowledge of various dimensions of climate change impacts on the animals is essential to mitigate the effect of global warming on livestock systems to sustain animal production. With these backgrounds, the present chapter is targeted to capture, arrange and synthesize information pertaining to alterations in the functions of rumen due to thermal stress in sheep. The chapter presents information with respect to impact of heat stress on rumen microbial dynamics, digestibility, microbial protein synthesis, ruminal acidosis, etc.

11.2 Significance of Rumen Functions in Sheep

The foregut of ruminants performs three most important functions which make them survive in a variety of habitats on earth. Firstly, they ferment structural carbohydrates such as cellulose and hemicellulose. Ruminants evolved a special digestive system in which foregut fermentation of plant fibre results in formation of end products and other nutrients responsible for animal growth (Clauss et al. 2010). The rumen harbours a complex microbial system comprising of bacteria, protozoa, fungi and archaea and phages that ferment the diet ingested by ruminants. The digestive system in sheep is characterized by physiological and structural adaptations that enable them to utilize recalcitrant carbohydrates like cellulose, hemicellulose, etc. (Van Soest 1994). The rumen content is a watery and strictly anaerobic vat (redox potential, approximately – 400 mV) with a constant temperature held at about 38–40 °C and a pH between 5.5 and 7.0, all of which are essential for effective microbial activity. In the rumen, bacteria (10^{10}/ml), protozoa (10^6/ml) and fungi (10^3/ml) at high density digest plant material. The predominant end products of rumen fermentation are short-chain fatty acids (SCFAs), ammonia (NH_3), methane and carbon dioxide. The microbial protein that is synthesized during the anabolic process of microbes is an important source of protein for ruminant animal.

Secondly, recycling of urea, which is produced by the salivary glands of sheep. This urea is hydrolysed to NH_3 and CO_2. The former is essential for microbial protein synthesis. In sheep, the microbial fermentation of feed particles and microbial-derived protein contributes to 70% of ME and 90% of amino acids reaching the small intestine, respectively (Nocek and Russell 1988; Bergman 1990).

Thirdly, the ability of detoxification of forages by rumen microbial population. This can be explained by an example, *Leucaena*, an arboreal protein-rich legume used as forage throughout tropical and subtropical areas (Allison et al. 1990). It contains mimosine, an amino acid, that is toxic to animals when it is at levels of up to 5% because of its conversion by microbes to 3-hydroxy-4-[1H]-pyridone (3,4-DHP), a goitrogen (Hegarty et al. 1976). In spite of this, ruminants can tolerate mimosine owing to quick adaptability of rumen microbes to detoxify mimosine. Interestingly, the scientists have found geographical variations in the ability of ruminants to tolerate *Leucaena* that was attributed to ruminal microbes that can break down the toxic 3,4-DHP (Jones 1981). This was confirmed by the transfer of ruminal fluid from Hawaii and Indonesia to Australian goats (Jones and Lowry 1984; Jones and Megarrity 1986). A ruminal bacterium, *Synergistes jonesii*, was reported to degrade 3,4-DHP, and the same has been used to inoculate in ruminants of those regions where *Leucaena* was not previously used (Allison et al. 1992; Andrew et al. 2000).

11.3 Rumen Fermentation and Diet Digestibility in Rumen of Sheep

The rumen provides favourable condition for microflora and fauna to rapidly break down complex polysaccharides of plant origin, with subsequent fermentation of the released simple sugars to produce short-chain fatty acids (SCFAs) like acetic, propionic and butyric acids. The SCFAs are generated primarily from fibre feeds containing cellulose and hemicellulose and grains rich in starch, with a lower proportion of SCFAs being produced from dietary proteins, pentoses of nucleic acids and glycerol of glycerophospholipids. In the rumen, about 30–50% of the holocellulose is digested by the microbes. Sixty percent or more of the starch are degraded, and most sugars are digested 100% within the rumen. In general, the total amount of SCFA concentration in the rumen is between 60 and 150 $\mathrm{mmol \cdot L^{-1}}$ (Bergman 1990), but this varies considerably with dietary intake. The digestibility of various components of the ruminant diet is described below:

11.3.1 Non-fibrous Carbohydrates

Dietary non-fibrous carbohydrates (NFCs) comprise of carbohydrates that include sugar, starch, pectic substances and fructans. Around 30–45% of the dietary intake on dry matter (DM) basis is contributed by the above-mentioned NFCs (Hall et al. 2010). This fraction of NFC acts a readily available source of energy for effective microbial growth (Ariza et al. 2001). But the other side of the coin is inclusion of NFC as additional source of energy can adversely affect the performance of ruminants as NFCs may negatively affect the protein-energy balance in the diet, creating metabolic constraints that may lead to a decrease in nitrogen retention by the animal (Costa et al. 2011; Detmann et al. 2014). A fraction of nonstructural carbohydrates (NSCs) comprise organic acids, simple to oligosaccharides, starches, and other carbohydrate reserves; and the total NSC that includes pectin is referred as non-fibrous carbohydrates (NFCs) (Mertens 1992).

11.3.2 Mono-, Di- and Oligosaccharides

Sucrose phosphorylase digests the 1, 2 glycosidic linkage formed from α-ᴅ-glucose and β-ᴅ-fructose subunits (Stan-Glasek et al. 2010). The enzyme α-glucosidase digests maltose formed from two units of α-(1–4) glucose. Oligosaccharides, the 2- to 20-unit chains of monosaccharides, range between 0.3 and 6% in different plants representing larger diversity of biomolecules. Oligosaccharides are utilized by the polysaccharide hydrolases group of enzymes, which hydrolyse the glycosidic bond between two or more carbohydrates (Courtois 2009). The monosaccharides ferment at a faster rate within the rumen and yield VFA. The rate of hydrolysis of sucrose, lactose, glucose and monosaccharides varied from 1200 to 1404% h^{-1}, 248 to 204% h^{-1}, 422 to 738% h^{-1} and 300 to 700% h^{-1}, respectively (Wejsberg et al. 1998). Ruminal bacteria that ferment sucrose include *Streptococcus bovis*, *Selenomonas ruminantium*, *Lachnospira multiparus*, *Lactobacillus ruminis*, *Eubacterium cellulosolvens*, *Clostridium longisporum* and some strains of *Eubacterium ruminantium*, *Butyrivibrio fibrisolvens*, *Ruminococcus albus*, *Ruminococcus flavefaciens*, *Megasphaera elsdenii*, *Prevotella* spp., *Pseudobutyrivibrio ruminis* strain A and *Succinivibrio dextrinosolvens* (Martin and Russel 1987; Stewart et al. 1997; Stan-Glasek et al. 2010). *Ruminobacter amylophilus* utilizes alpha-linked glucose molecules (maltose, maltodextrins and starch) (Anderson 1995), and *Actinomyces ruminicola* hydrolyses xylan and starch and ferments several kinds of mono-, di- and oligosaccharides (An et al. 2006).

11.3.3 Pectic Substances

Pectic substances are a group of galacturonan polymers with neutral sugar substitutions largely galactose and arabinose (Jung 1997). Hall et al. (1998) reported that degradation of pectin occurs at a rate of 13% h^{-1} (Hall et al. 1998) and the variation in utilization is from 79.4 to 95.9% (Marounek and Duškovă 1999). Pectin lyase has the potent pectinolytic activity (Wojciechowicz et al. 1982), which aids in fermenting pectin, predominantly to acetate (Czerkawski and Breckenridge 1969; Marounek and Duskova 1999). The bacteria that can utilize pectin include *Butyrivibrio fibrisolvens*, *Fibrobacter succinogenes*, *Prevotella* ssp., *S. bovis* and *Lachnospira multiparus* (Czerkawski and Breckenridge 1969; Gradel and Dehority 1972; Baldwin and Allison 1983). Among them, *Prevotella* ssp. was found to be the dominant genus in the rumen microbiome of sheep, comprising more than 30% of the total bacterial community (Lopes et al. 2015).

11.3.4 Starch

Starch is a polymer of amylose and amylopectin. Amylose, α-*1,4*- linked polymer of glucose, is degraded by α-amylases into glucose and maltose and by β-amylases that remove maltose units. Amylopectin is also made up of glucose units, but is highly branched with alpha-1,6 linkages. It is degraded to maltose by β-amylases, glucanohydrolases and isoamylase. Starch is not only digested by ruminal microbial enzymes but also by enzymes in the small intestine of the ruminants. In sheep, the capacity for digestion of raw starch in the small intestine is about 100–200 g/d (Orskov 1986) and depends on the supply of pancreatic amylase (Huntington 1997). Relatively high-starch diets cause increased propionate to acetate ratio due to the domination of propionate-producing bacteria (Ørskov 1986; France and Dijkstra 2005). The rate of ruminal starch fermentation further depends on structure, source, processing, diet composition, quantity of feed intake per unit time and degree of adaptation of ruminal microbiota to the diet (Piva and Masoero 1996; Huntington 1997; Eastridge 2006). The high propionic acid content in the rumen sometimes exceeds the hepatic capacity to metabolize the same which may result in abnormal synthetic pathways of branched-chain fatty acids in adipose tissue (Orskov 1986). The bacteria *Ruminobacter amylophilus*, *Streptococcus bovis*, *Prevotella ruminicola*, *Succinimonas amylolytica* and many strains of *Butyrivibrio fibrisolvens*, *Selenomonas ruminantium*, *Eubacterium ruminantium*, *Butyrivibrio fibrisolvens* and *Clostridium* ssp., all of the entodiniomorph protozoa and the chytrid fungi are amylolytic.

11.3.5 Structural Carbohydrates

Structural carbohydrates comprising holocelluloses (cellulose + hemicelluloses) and lignin are less digestible than non-fibrous carbohydrates; their levels are inversely correlated with the concentration of diet. The hemicelluloses and lignin further embed the cellulose fibres (Marchessault and Sundararajan 1993; Van Soest 1994). This fraction affects the rate of fermentation in addition to delaying the passage of feed out of the rumen and encourages growth of acetate-producing bacterial species, which favours a higher acetic to propionic acid ratio (Boadi et al. 2004; Hegarty and Gerdes 1998). The reduced fibre digestion is attributed to decreased rumen pH and the availability of surface area for colonization (Sutton et al. 1987; Chesson and Forsberg 1997). All the rumen fungi, i.e. *Neocallimastix* (Vavra and Joyon 1966), *Piromyces*, *Caecomyces* (Gold et al. 1988), *Orpinomyces* (Barr et al. 1989) and *Anaeromyces* (Breton et al. 1990), show a preference for the thick-walled sclerenchyma and vascular tissues (Akin et al. 1983; Ho and Bauchop 1991) and are capable of digesting various fibrous materials. In addition, the bacteria, *Ruminococcus albus* (Suen et al. 2011), *Ruminococcus flavefaciens* and *Fibrobacter succinogenes*, also ferment the structural carbohydrates.

11.3.6 Cellulose

Cellulose is chemically made of homogenous polymers of β-1,4-D-glucose linked through β-1,4-glycosidic bonds, which makes up to 35–50% of plant dry weight (Lynd et al. 1999). Cellulose of fodder origin is digested up to 70, 17 and 13% in the rumen, caecum and colon of sheep, respectively (Gray 1946). Endoglucanases, i.e. 1,4-β-D-glucan-4-glucanohydrolases, exoglucanases (cellulodextrinases, cellobiohydrolases) and β-glucosidases are the three types of enzyme activities in cellulose systems (Henrissat 1994). Endoglucanase action yields odd-length oligosaccharide fragments by attacking at random, on the internal amorphous sites of cellulose. Exoglucanase group of enzymes systematically cut cellulose at reducing and non-reducing ends, and glucose is the ultimate product of action of β-glucosidase on soluble cellulodextrins and cellobiose (Lynd et al. 2002). Carbohydrate-binding molecules (CBM) bring cellulase catalytic domain opposite to cellulose, which specially enhances the efficiency of exoglucanases (Teeri et al. 1998). The major cellulolytic bacteria in the rumen are *Fibrobacter succinogenes*, *Ruminococcus albus* and *R. flavefaciens*. They depolymerize the cellulose by a process of hydrolysis and efficiently utilize the resulting cellodextrins (Weimer 1996; Koike and Kobayashi 2001). The rate of digestion varies from 5 to 10% h^{-1}; the primary limitation in efficient digestion is the lignin content of the feed (Weimer 1996; Chesson 1993).

11.3.7 Hemicelluloses

It is structurally made of xylans with a backbone of β-1,4-linked xylose residues and attachment of side chains (e.g. acetic acid, ferulic acid, coumaric acid, arabinose, glucuronic acid, 4-O-methylglucuronic acid) to the xylose residues (Chesson et al. 1983; McNeil et al. 1984). The hemicellulose-degrading bacteria are *Fibrobacter succinogenes*, *Ruminococcus albus*, *R. flavefaciens* and some strains of *Butyrivibrio fibrisolvens* and *Bacteroides ruminicola* (Hespell 1988), *Eubacterium xylanophilum* and *Eubacterium uniformis* (Kamra 2005).

11.3.8 Lignin

Lignin is the most structurally complex carbohydrate possessing a high molecular weight and the most recalcitrant, consisting of various biologically stable linkages (Perez et al. 2002). The occurrence of strong bonds between cell wall polysaccharides and lignin reduces the accessibility for microbial hydrolases (Chesson 1993). Anaerobic fungus could solubilize up to 16% of the lignin from fibre (Orpin 1975). *Neocallimastix frontalis*, *N. patriciarum*, *Caecomyces communis*, *Ruminomyces elegans* and *Piromyces* (Kamra 2005) are capable of degrading the lignocellulosic bonds in the sheep's rumen.

11.4 Ruminal Digestion of Protein

There is a partial degradation of proteins by the action of proteolytic enzymes of microorganisms resulting in production of peptides and amino acids, which are later subjected to the action of peptidases and deaminase of the microbes, producing NH_3, VFA and CO_2 (Annison and Lewis 1981; Balcells and Castrillo 2002). Ruminal microorganisms utilize NH_3 along with some simple peptides and amino acids as nutrients for their own growth. When these microorganisms pass into the abomasum and small intestine, cellular proteins are digested by the intestinal enzymes and are absorbed. Considerably, 40% or more of the bacteria will have proteolytic activity.

However, there are a few species (*Streptococcus bovis*, *Peptostreptococcus* species and *Prevotella ruminicola*) that have a more intense proteolytic activity than the others (Valente et al. 2016).

Urolytics (*Enterococcus faecium*) are able to hydrolyse urea and release NH_3 in the rumen (Khattab and Ebeid 2014). Similarly, lipolytic bacteria (*Anaerovibrio lipolytica*) hydrolyse triglycerides into glycerol and fatty acids, and the enzymes produced had higher activities at neutral to alkaline pH.

11.5 "Synchrony" Hypothesis

Nutritional synchrony means the phenomenon of provisioning dietary protein and energy (ruminally fermented carbohydrates) to the rumen in such a manner that they are available simultaneously in ratios needed by the ruminal microorganisms (Hall and Weimer 2007). This practice of provisioning will allow more efficient utilization of nutrients, thus enhancing production of microbial products, increasing nutrient supply to the animal and potentially improving animal production performance (Sinclair et al. 1993; Hall and Huntington 2008). Synchronization of readily degradable carbohydrates with rapidly degraded proteins results in higher microbial protein yield (Charbonneau et al. 2006) and affects the degradation rate of the dietary components (Niwinska and Andrzejewski 2011).

11.6 Gases Produced During Fermentation

The disposal of hydrogen (H_2) generated as a result of fermentation is essential to the optimum functioning of the ruminant digestive system (Hungate 1966). Methanogens use H_2 derived from fermentation process as their energy source and combine it with CO_2 to form CH_4, which is belched out by the animal. Apart from H_2, other end products of fermentation like formate- and methyl-containing compounds are important substrates for methanogenesis (Liu and Whitman 2008). Enhanced efficiency of microbial protein synthesis is opined as the important target in reducing the emissions of N, while synchronization of carbohydrate and protein supply in the rumen has been suggested as one of the possible solutions to achieve this aim (Kaswari et al. 2007; Reynolds and Kristensen 2008; Yang et al. 2010). Reduction of CO_2 to CH_4 is essential to maintain efficient ruminal fermentation atmosphere as otherwise it may lead to accumulation of reducing equivalents (McAllister et al. 2015). The CH_4 produced by rumen ecosystem is estimated to be about 15% of total atmospheric CH_4 emissions. There is a loss of 5–12% of gross energy of diet as a result of methane production (Reid et al. 1980; Moss et al. 2000). The proper selection of carbohydrates in the ration with respect to structural and non-fibrous carbohydrate content can reduce the formation of CO_2, H_2 and formate which are the major precursors of CH_4 production in the rumen (Mitsumori and Sun 2008). Nitrate and sulfate supplementation to the diet is considered as an effective means for mitigating enteric CH_4 emissions from sheep (Zijderveld et al. 2010).

11.7 Significance of Microbial Digestion in Rumen: Microbial Diversity in Rumen of Sheep

The ability of ruminants to utilize such a wide range of feeds is due to highly diversified rumen microbial ecosystem consisting of bacteria (10^{10}–10^{11} cells/ml, representing more than 50 genera), ciliate protozoa (10^4–10^6/ml, from 25 genera), anaerobic fungi (10^3–10^5 zoospores/ml, representing five genera) and bacteriophages (10^8–10^9/ml) (Hobson 1989). These numbers might even be underestimated as majority of them are non-culturable. Following the development of techniques for cultivating strictly anaerobic organisms, a variety of bacteria were isolated and characterized from the rumen (Bryant 1959). The development of cultivation-independent techniques like 16S ribosomal RNA gene sequencing and metagenomic studies constantly emphasizes that the majority of sequences is derived from organisms that are phylogenetically distinct from currently cultivated species (Kim et al. 2011; Fouts et al. 2012). In recent years, there have been few attempts to systematically culture other organisms; however, recent studies in Japan (Koike et al. 2010; Nyonyo et al. 2013) and New Zealand (Kenters et al. 2011) have successfully increased the number of taxa of rumen bacteria that have cultured representatives. There is global project called "Hungate 1000" project aiming at production of a reference set of rumen microbial genome sequences of available cultivated rumen bacteria and methanogenic archaea, along with representative cultures of rumen anaerobic fungi and ciliate protozoa. The Livestock Research Group of the Global Research Alliance has identified it as a priority project. This work is also supported by the US Department of Energy Joint Genome Institute (JGI) through their Community Sequencing Programme (CSP). Currently, the public has access to genome sequence information of a small number of rumen bacteria and methanogenic archaea, and there is little information available on the rumen anaerobic fungi or ciliate protozoa. This reference genome information will help the international efforts to develop CH_4 mitigation and rumen adaptation technologies as well as to initiate genome-enabled research that is targeted at understanding rumen function, feed conversion efficiency, methanogenesis and plant cell wall degradation in order to find a balance between food production and greenhouse gas (GHG) emissions.

Despite there is a broad range of variation in ruminants with respect to feeding strategies and diets, an interesting fact is that similar rumen bacteria were abundant around the world. The little observed variation in bacterial compositions in animals from different regions is attributed to differences in diet, climate and farming practices (Henderson et al. 2015). The 30 most abundant bacterial groups were found in over 90% of samples and together comprised 89.4% of all sequence data and were similar to those described in an earlier meta-analysis of rumen microbial communities (Kim et al. 2011). The researchers have found seven most abundant bacterial groups which comprise about 67% of all bacterial sequence data detected in all samples and hence are considered as the "dominant" rumen bacteria. These include *Prevotella*, *Butyrivibrio* and *Ruminococcus* and unclassified *Lachnospiraceae*, *Ruminococcaceae*, *Bacteroidales* and *Clostridiales*. These bacterial populations are present in a large population of ruminants leading to the opinion of existence of "core bacterial microbiome" at the genus level or higher (Weimer 2015) though these bacterial groups were not equally abundant in all animal species, with the exception of *Butyrivibrio* (Paillard et al. 2007) which are not adequately represented by characterized cultures (Creevey et al. 2014) and whose functions are not well deciphered. Inspection of the most abundant and prevalent bacterial operational taxonomic units (OTUs) showed that only 14% fell within a named species and 70% were not even within a formally recognized genus. When the analysis included as-yet-unnamed cultured isolates, the dominant OTUs were better (35%) but still poorly represented by cultures that belonged to potentially the same species (Henderson et al. 2015).

The studies showed that almost all the archaea were identified as methanogens known to be residents of the rumen and are remarkably similar in all the regions of the world (Janssen and Kirs 2008). The 74% all archaea include members of the *Methanobrevibacter gottschalkii* and *Methanobrevibacter ruminantium* clades that were reported in almost all samples analysed. Together with a *Methanosphaera* sp. and two *Methanomassiliicoccaceae*-affiliated groups, the five dominant methanogen groups comprised 89.2% of the archaeal communities, showing that rumen archaea are much less diverse than rumen bacteria (Henderson et al. 2015) which indicates the narrow range of their substrate. *Methanomicrobium* has previously been reported as abundant in ruminants in Asia but comprises >5% of the archaeal community of some Australian, Brazilian, Chinese, North American and South African cattle, as well as South African sheep, showing them to be widely distributed, but not universally prevalent (Janssen and Kirs 2008). In contrast to bacteria, the rumen archaea are comparatively well represented by cultures, with 58% of the most abundant and prevalent OTUs falling within a named species and all but 22% within named genera (Henderson et al. 2015). The lesser diversity among methanogenic archaea is a point of importance since it will help in designing efficient methane mitigation strategies like vaccination against certain dominant methanogens.

Though rumen protozoa were detected in domestic animals as early as the nineteenth century by Gruby and Delafond (1843), it was only post 1920 that the researchers paid significant attention towards the identification and characterization of the protozoa in rumen (Kamra 2005). Almost all protozoal sequence data (> 99.9%) were assigned to 12 genus-equivalent protozoal groups. Scientists across the globe reported that there is strong host individuality of rumen protozoal community structure (Weimer 2015). The genera *Entodinium* and *Epidinium* have been found to occur in over 90% of samples and represent 54.7% of protozoal sequence data (Henderson et al. 2015) with many of the genera reported in more than 70% of the samples, indicating a wide prevalence. Genera such as *Enoploplastron* and *Ophryoscolex* had a wider host distribution and are considered to be mainly present in sheep and cattle, respectively (Williams and Coleman 1992).

The rumen has a large number of fungi constituting around 10% of the microbial mass (though numbers vary widely on the basis of animals and diet), yet they remained unrecognized until about 35 years ago (Orpin 1975, 1977a, b, c; Yokoyama and Johnson 1988). Orpin identified three species of anaerobic fungi, *Neocallimastix frontalis*, *Sphaeromonas* (now named *Caecomyces*) *communis* and *Piromonas* (now named *Piromyces*) *communis*, in the rumen of sheep and described a two-stage life cycle: a free-floating, motile zoospore stage and a nonmotile, vegetative mycelial structure (thallus) carrying a sporangium (Orpin 1975). These obligate anaerobic fungi have an important role in fibre degradation as evidenced by the presence of different enzymes involved in fibre degradation (Paul et al. 2003).

Bacteriophages are the viruses inhabiting bacteria and are reported to be present in the rumen with specificity of each phage for its host bacterium present in the rumen. By their ability to lyse the bacteria, phages help in bacterial mass turnover in the rumen (Klieve et al. 1996), and the bacterial protein is easily made available to the animals as a source of amino acids. The specificity of the bacteriophages for lysis of a particular rumen bacterium may be exploited for removal of unwanted bacteria from the rumen ecosystem especially methanogens (Klieve et al. 1999; Bach et al. 2002). The phage population in an animal at a given time is more individual specific for that animal, as it was observed that the animals kept on a similar diet penned together in the same shed may have diverse population of these phages. The diurnal variation and feeding time also cause changes in the number of phage particles as it was reported that there is a drop in numbers immediately on feeding followed by a gradual increase up to 8–10 h post feeding and then decline to reach the base level (Swain et al. 1996).

11.8 Factors Influencing Rumen Functions

The feed ingredients consumed by ruminants are all initially subjected to the fermentation that results in the degradation of complex carbohydrates and complete proteins to short-term intermediates such as sugars and amino acids, respectively. This efficiency of ruminants is attributed to highly diversified rumen microbial ecosystem. The rumen microbes can live at acidities between pH 5.5 and 7.0, in the absence of oxygen, at a temperature of 39–40 °C, in the presence of moderate concentration of fermentation end products, and at the expense of the ingesta provided by the ruminant (Hungate 1966). The products of this initial degradation are ultimately metabolized to microbial mass and CO_2, CH_4, NH_3 and VFAs (primarily acetate, propionate and butyrate and to a lesser degree branched-chain VFA and occasionally lactate). The host animal absorbs VFA mostly through the rumen wall and digests proteins, lipids and carbohydrate constituents of microbes and feed residues entering the small intestine to supply its maintenance needs and for the production of meat and milk. Ruminants derive about 70% of their ME from microbial fermentation of feed particles, and microbial protein accounts for as much as 90% of the amino acids reaching the small intestine (Nocek and Russell 1988; Bergman 1990). The various factors that affect rumen function are:

11.8.1 pH

An important factor, which may alter the rumen function, is pH value. Lower pH value can be harmful to rumen microbes, especially the fauna (Franzolin et al. 2010). The pH in the rumen is influenced by multiple factors, including metabolic activities of rumen microorganisms, water flux through the rumen wall, absorption of VFA, flow of saliva and its buffering activity, pH of the feed and water turnover of the lower digestive tract. The optimal pH should be 6–7 for cellulolysis, proteolysis and deamination (Lewis and Emery 1962; Mould et al. 1983). At pH < 6, ruminal cellulolysis is totally inhibited (Mould et al. 1983), due to the decreased cellulolytic bacteria (Kim et al. 2016), and the total dry matter digestibility decreases with decreasing pH (Tilley and Terry 1964).

11.8.2 Diet Type

Rumen pH fluctuates throughout the day depending on the type of diet, time of feeding of concentrates and the supplementation of fibre sources such as hay. Feeding of concentrates at higher amounts leads to decreased rumen pH; similarly, feeding forage alleviates the subacute ruminal acidosis caused by low pH (Kim et al. 2016).

11.8.3 Physical Form of the Diet

The physical form of the diet, e.g. a reduction in the feed particle size or the processing of grain, decreases pH of the rumen (Krause et al. 2002). This response causes less saliva production and more rapid breakdown of carbohydrates in the rumen. The amount of rumen fermentable carbohydrate present in the rumen or the digestibility of starch in the rumen can be negatively correlated to rumen pH (Yang and Beauchemin 2001; Krause et al. 2002).

11.8.4 Feeding Patterns

It was observed that variation due to biphasic feeding patterns induced by twice-daily feeding at or post milking may produce a substantial but relatively short-lived depression of ruminal pH.

11.8.5 Types of Feeds

Feeds like silages that are high in preformed acids will also reduce rumen pH (Lean 1987). The nature of diet determines pH, but is typically found between 5.5 and 7.0 when ruminants are predominantly fed a forage diet (Aschenbach et al. 2014). Highly fermentable diets are rapidly converted to volatile fatty acid (VFA) in the rumen, thereby reducing the pH (Pourazad et al. 2015). Rumen pH starts to decline immediately after feeding the silage or predominantly on feeding the concentrates. Supplementation of thiamine, riboflavin, niacin and vitamin B_6 in the diet alters the rumen's microbial synthesis of the respective B vitamins (Castagnino et al. 2016).

11.8.6 Saliva

It is believed that saliva is an extremely important source of fluid to rumen. The saliva production in sheep is about 15 L/day (Kay 1960). Buffering capacity of the rumen is normally influenced by factors altering the amount or quality of saliva production, the concentration of ruminal acids and CO_2 and the rate of absorption or passage of digesta through the rumen. The parotid, buccal and pharyngeal salivary glands produce most of the HCO_3^- and HPO_4^{-2} at a rate of 125 and 25 meq/L, respectively (Lean 1987). Rumen's buffering capacity will be lowest for energy feeds, intermediate for low-protein feeds (15–35% crude protein) and grass forages and highest for protein-rich feeds (>35% crude protein) and legume forages (Jasaitis et al. 1987). Below pH 5.5, lactate-fermenting bacteria are unable to grow, owing to lower salivary flow rates and hence low concentration of bicarbonates, allowing lactic acid build up in the rumen, further depressing pH.

11.8.7 Buffering Capacity

The rumen liquor is usually well buffered, due to the presence of bicarbonates (primary buffers) and phosphates (secondary buffers) of saliva (Puggaard et al. 2011; Røjen and Kristensen 2012; Storm et al. 2014). For instance, sheep and cow produce at least 15 L/day (Kay 1960) and 180 L/day saliva, respectively. The physiological buffering capacity of the rumen allows the rumen pH to be maintained between 6 and 7 on most diets. However, the reduced saliva production due to feeding lower forage source may result in reduced fibre digestion and less microbial protein flow to the small intestine (Hills et al. 2015). The amount of decrease in pH post increase in fermentation rate depends on the buffering capacity of the rumen (Counotte et al. 1981).

11.8.8 Chewing Activity

Chewing activity indicates the quality of fibre in the diet and, therefore, is also an indication of rumen health. Chewing activity can be considered as a non-invasive measure of rumen function in a dairy herd (Lesch and Swayer 1981).

11.8.9 Chemical Properties of the Diet

The feed quality is determined by chemical properties such as percentage DM, digestibility, energy, nonstructural carbohydrate (NSC) content, crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF). For effective rumen fermentation, the minimum recommended concentration of total dietary NDF for cows was set at 25% of dietary DM with the condition that 19% of dietary DM must be NDF from forage, along with the maximum dietary NFC of 44% and minimum dietary ADF of 17% (NRC 2001). Further, the high-concentrate diets given to high-yielding animals must contain sufficient physically effective fibre that can stimulate rumination, saliva production and rumen buffering to prevent ruminal dysfermentation and subacute ruminal acidosis (SARA). The β-glucosidase and cellulase production in the rumen may be affected by presence or absence of simple sugars. Some inducers of cellulase production include sophorose, cellobiose, α-cellobiose-1,5-lactone and oxidized products of cellulose hydrolysis (Lynd et al. 2002).

11.8.10 Forage Characteristics

It was found that lush and leafy pastures with high leaf to stem ration can cause ruminal acidosis (Westwood and Lean 2001). Usage of nitrogenous fertilizers for pastures increases the N concentrations and microbial protein load in the small intestine. Stage of the plant used for feeding determines its NDF content, for example, ryegrass grazed at the two-leaf stage will have a lower NDF and higher crude protein than at the three-leaf stage. Ad libitum grazing alters the rumen function by decreasing pH and increasing volatile fatty acids in the rumen as cows prefer the best-quality pasture with lower NDF and higher crude protein percentages.

11.8.11 Feed and Forage Processing

It has been observed that the chop length of forages used for silage or haymaking will also influence rumen function. The silage and hay with short chop length reduce chewing and rumination time and, therefore, saliva production (Sudweeks et al. 1975; Grant et al. 1990; de Boever et al. 1993). Particle size is negatively correlated with chewing activity per kg DM, while it is positively correlated with ruminal pH (Allen 1997; Mertens 1997). The particle size and processing also apply to the concentrates since it was found that starchy cereal grains, particularly wheat and barley, can be rapidly rumen fermentable, produce lactic acid and increase the risk of acidosis (Nikkhah 2012). However, the dry matter intake (DMI) will be limited by rumen fill or chewing time, or both, on feeding longer-particle-length compared to the short-particle-length feeds (Kammes and Allen 2012). Further, the particle size and particle specific gravity also affect the passage rate of the digesta from rumen. Though most particles of 5 cm may pass through the reticulo-omasal orifice, generally those leaving rumen are smaller than 1 mm (Welch 1986).

11.8.12 Antinutritional Factors

Higher degree of lignification and presence of phenylpropanoid units, coumaric and ferulic acids or their complexes with hemicellulose and cellulose reduce the ruminal digestion (Burritt et al. 1984). The forages grown at higher environmental temperatures usually have decreased ruminal digestibility due to the presence of high amount of dead material, antinutritional factors and low N content (Van Soest and Robertson 1985 and Minson 1985). Plants containing secondary metabolites and condensed tannins and saponins have been shown to potentially manipulate rumen fermentation by enhancing the feed utilization efficiency and inhibiting rumen CH_4 production (Kreuzer et al. 2009; Wang et al. 2009; Mao et al. 2010).

11.8.13 Passage Rate

Along with decreased degradability, passage rate also affects the microbial efficiency and N use efficiency (Sniffen and Robinson 1987; Dewhurst et al. 2003). Increased amounts of small particle entrapment in the rumen's floating raft of digesta might affect the passage rate of digesta into the intestines (Wilson and Kennedy 1996). The other factors affecting the passage rate include the environmental temperature and feed intake (Miaron and Christopherson 1992). Cold environments tend to increase the ruminal outflow, and rumen outflow rates tend to be higher at high levels of feed intake (Kennedy and Milligan 1978; Allen 1997).

Intake of forages can not only be limited by distension, it may also be limited by the osmolality and concentration of SCFA in the digesta. The other factors that can limit forage intake include abdominal temperature and uptake of propionic acid by the liver and hormones such as insulin, glucagons, gastrin and cholecystokinin (Forbes and Barrio 1992).

11.8.14 Temperature and Osmotic Pressure

The rumen with temperature around 38–42 °C has a suitable environment for the development of a large number of anaerobic microorganisms (Pourazad et al. 2015). The environmental temperature has a significant influence on the animal's voluntary feed intake and metabolism (Miaron and Christopherson 1992). The dry matter digestibility decreases during winter (Christopherson 1976) and appears to be associated with increased gut motility, passage rate and circulating thyroid hormones. Further, the thyroid hormones are associated with appetite, food intake and digestive functions (Young 1981). The osmotic pressure of rumen contents ranges between 260 and 340 moles with an average value of about 280 moles. Rumination process is inhibited, and absorption of VFA decreased at values greater than 350 moles (Russell 2002).

11.9 Effect of Heat Stress on Diet Digestibility in Rumen

There is a widespread agreement that ambient temperatures have a significant influence on farm animal's feed intake, metabolism and heat balance (Fuquay 1981; Johnson 1980; Ronchi et al. 2001). Heat stress has long been known to adversely affect rumen health (Mishra et al. 1970) due to a variety of reasons (Bernabucci et al. 1999, 2009; Kadzere et al. 2002). Stress and the consequent release of stress-related neuroendocrine hormones adversely affect various aspects of ruminant health, including feed intake, rumination and other dynamic characteristics of the digestion processes (Freestone and Lyte 2010; Beede and Collier 1986).

Varying reports exist with respect to the effect of heat stress on digestibility. Some authors reported an increase in digestibility due to heat stress (Nonaka et al. 2008; Weniger and Stein 1992), and some reported negative or no correlation between heat stress and digestibility (Mathers et al. 1989; Silanikove 1985). Reports published by several authors indicated that there was a positive relationship between ambient temperature and diet digestibility in sheep (Graham et al. 1959). Several authors established that there is an influence of environmental temperature on digestibility in sheep and cattle and that there is a physiological basis for the response (Christopherson 1976; Westra and Christopherson 1976; Kennedy et al. 1976; Kennedy and Milligan 1978; Warren et al. 1974; Colditz and Kellaway 1972; Nicholson et al. 1980). However, Bhattacharya and Uwayjan (1975) and Christopherson (1985) concluded that the effect of high ambient temperature on digestibility was uncertain, lower or higher digestibility being associated more with the changes in feed intake.

The high ruminal temperature did not affect DM and NDF digestibility, whereas it tended to decrease OM digestibility as compared with the normal ruminal temperature (66.6 vs. 67.4%) (King et al. 2011). The effect of environment on digestion cannot be attributed to the effects of temperature of the drinking water since Cunningham et al. (1964) did not observe a change in digestibility with changes in water temperature.

Studies conducted on sheep subjected to heat stress have reported an improved fibre digestibility (Lippke 1975; Bhattacharya and Hussain 1993). In contrary, negative or no relationships between high ambient temperatures and diet digestibility have been reported in small ruminants by Silanikove (1985, 1992). In another study conducted by Bernabucci et al. (1999), ewes chronically exposed to heat showed lower digestibility and had lower pH, reduced cellulolytic and amylolytic bacteria concentrations, slower passage rate of digesta and osmolarity of rumen content, suggesting a possible impairment of bacterial activity and high dilution of rumen fluid. Further, Bernabucci et al. (2009) reported that diet digestibility in ewes chronically exposed to heat stress conditions is not related to changes in DMI or rate of passage of digesta into the gastrointestinal tract. They indicated that dilution of rumen content due to higher water intake, reduction in rumen bacterial activity, decline in rumen motility and reduction of salivation may be responsible for digestibility changes when animals are chronically exposed to extreme THI.

It has been observed that other than alteration of bacterial activity, the different responses in digestibility when ewes were exposed to extreme THI might be related to the changes in ruminal and intestinal absorption of nutrients that can occur in animals chronically exposed to high ambient temperatures (Christopherson 1985; McGuire et al. 1989). The lower absorption of nutrients might be due to redistribution of cardiac output from the digestive system to peripheral tissues and the respiration system to increase heat loss as an acclimatization response to hot environments (Christopherson 1985). During heat stress, in order to maintain body temperature, more blood flows to the extremities; hence, the blood flow to rumen epithelium is reduced, thereby altering the acid-base balance. Heat stress also induces a reduction in the amount of salivary HCO_3^- content being passed into the rumen, which may impair rumen function (Kadzere et al. 2002).

11.9.1 Heat Stress and Microbial Protein Synthesis in Sheep

It is a well-established fact that proteins synthesized by bacteria form the major source of protein for ruminant animal. Microbial protein is digested in the small intestine and absorbed as amino acids that constitute more than 70% of the daily requirement (Lu 1989). One way the animals respond to changes in their environment is by altering their behaviour. This includes changes in feeding behaviour, particularly feed intake. Disturbances in digestion can also occur, which eventually will cause reduced efficiency in utilization of nutrients and energy for physical maintenance (Freestone and Lyte 2010). In an attempt to dissipate body heat, dairy cows react to heat stress by reducing feed intake and rumination time, increasing respiration rate, standing time and water intake, excessive salivation, drooling and panting. This leads to less favourable rumen environment and function, lower rumen pH and lower VFA and microbial protein production and nutrient digestibility. Generally, heat stress decreases protein levels in milk which is attributed to the lowered microbial protein synthesis in the rumen and lowered feed intake (Staples and Thatcher 2011). The heat-stressed goats had lower ($P < 0.05$) microbial protein synthesis (Hamzaoui et al. 2013) since higher temperatures will diminish the carbon and energy supply through the microbial fermentation (Tajima et al. 2007). Moreover, maintenance requirements increase as the cows attempt to maintain the body temperature in thermal stress.

11.9.2 Heat Stress and Rumen VFA Levels in Sheep

The molar proportions of acetic acid/propionic acid/butyric acid are 70:20:10 in hay-fed sheep (Gray and Pilgrim 1951) and 55:35:15 in grain-fed sheep (Annison and Lewis 1959; Kiddle et al. 1951). Highly fermentable diets increase the production (Sutton et al. 1986) and concentration (Penner et al. 2009) of SCFA in the rumen. A starch diet increases propionic acid and decreases the acetic acid concentration. When animals graze on fresh grass or when fed starch-rich diets, exceptionally high values of propionic acid can be reached, e.g. 200 $\text{mmol}\cdot\text{l}^{-1}$.

Significant reductions in the levels of short-chain fatty acids, the key energy sources of ruminant animals, were found during heat stress (Freestone and Lyte 2010). Tajima et al. (2007) found that the environmental parameters such as temperature and humidity have a notable effect on the bacterial composition of the rumen which may lead to substantial decrease in SCFA concentration related to reduced DMI and coupled with elevated energy expenditures, contributing to the impaired animal growth performance. The ratio of acetate to propionate is decreased during heat stress, and more specifically, the molar concentration of acetate decreased (Nonaka et al. 2008). Uyeno et al. (2010) attributed it to changes in fermentation patterns owing to variations in composition of bacteria. The effects of ruminal temperature on in vitro fermentation characteristics were investigated, and it was found that high ruminal temperature decreased total VFA concentration as compared with the normal ruminal temperature; however, ruminal temperature did not affect molar proportion of VFA (Salles et al. 2010; King et al. 2011).

Tajima et al. (2007) reported that there was a tendency for decreasing ruminal pH values with the increase of the environmental temperatures. Total concentration of SCFA in the rumen was reduced when the animals were kept at 33 °C. Among SCFAs, the proportion of propionic acid was stable throughout the temperature shifts, while acetic and butyric acids demonstrated the reverse tendencies, with the former decreasing and the latter increasing with the rising environmental temperatures. Hence, the ratio of acetic acid to propionic acid was found to decrease with the increasing temperature. The changes in the microbiota composition in response to heat stress at 33 °C are accompanied by a significant decrease in SCFA concentrations in the rumen.

Another school of thought believes the contrary that heat-stressed cows consume less feed and consequently ruminate less and this results in decreased buffering agent, i.e. saliva entering the rumen. In addition, because of the redistribution of blood flow to the periphery and subsequent reduction in blood flow to the gastrointestinal tract, end products of digestion, i.e. VFAs, are absorbed less efficiently, and thus the total rumen VFA content increases (Bernabucci et al. 2010). Figure 11.1 describes the various impacts of heat stress on diet digestibility, rumen functions and microbial population in rumen of sheep.

11.9.3 Heat Stress and Rumen Acidosis in Sheep

The role of heat stress in development of ruminal acidosis was established by Elam (1976), "The highest incidence of acidosis and similar problems is observed in feedlots during the warmer seasons, and this is especially high during the summer months". The acidosis is due to disruption of feeding patterns by changes in the weather (Owens et al. 1998), and feedlot deaths "related to digestive causes" have been reported to peak during the summer months (Miles et al. 1998). Ruminants

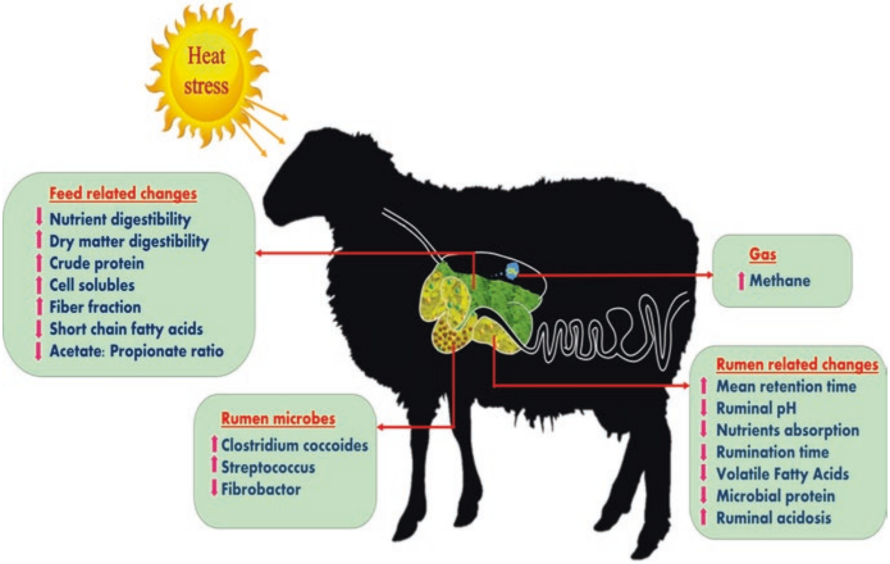

Fig. 11.1 Impact of heat stress on diet digestibility, rumen functions and microbes

reduce their feed intake during hot weather, thereby reducing the passage rate through the digestive tract, the net result being elevation of rumen acid production per unit of feed and decrease in rumen pH (Sanchez et al. 1994).

Furthermore, increased respiration rates also contribute to rumen acidosis because panting causes enhanced CO_2 loss from the animal body. In order to be an effective blood pH buffering system, the body needs to maintain a 20:1 HCO_3^- to CO_2 ratio. Because of the hyperventilation-induced decrease in blood CO_2, the kidney secretes HCO_3^- to maintain this ratio. This ultimately leads to reduction of the amount of HCO_3^- in saliva to buffer and maintain a healthy rumen pH. In addition, drool of saliva associated with panting reduces the quantity of saliva available for the rumen. The reductions in saliva HCO_3^- content and the decreased amount of saliva entering the rumen predispose the cow under heat stress to subclinical and acute rumen acidosis (Kadzere et al. 2002).

Changes in cow's feeding behaviour probably also contribute to rumen acidosis. Cows in thermo-neutral conditions typically consume 12–15 times per day, but decrease feeding frequency to 3–5 times per day during heat stress. The decreased frequency is accompanied by larger meals and thus more acid production post-eating. Moreover, cows will typically overeat the day following a heat wave, and this gluttonous behaviour is well known to cause rumen acidosis (Bernabucci et al. 2010).

11.9.4 Heat Stress and Methane Production in Sheep

Methane is the second most significant anthropogenic GHGs after CO_2, and its concentration in the atmosphere is elevating (Yusuf et al. 2012). It is produced in the rumen by methanogenic archaea referred to as methanogens which comprise of a phylogenetically diverse group of microorganisms that constitute about 10^{10} cells/g rumen contents (Joblin 2005).

Methane production from enteric fermentation is a function of the rate of organic matter (OM) degradation, the types of VFAs produced, the efficiency of microbial biosynthesis (Monteny et al. 2001) and the types of bacterial population (Kittelmann et al. 2014). The methane production of the diet is correlated with DMI, forage portion of the diet and many other factors (Nkrumah et al. 2006; Benchaar et al. 2001). Daily CH_4 emissions are positively correlated with the activity of the cows and negatively correlated to the indoor air temperature (Ngwabie et al. 2011). The factors that influence the methane production by ruminants are gut motility, rumination, ruminal contractions and passage rate of digesta during high ambient temperature. Methane emission from sheep is positively correlated with mean retention time (MRT) of digesta, which is known to be influenced by the hormone triiodothyronine (Barnett et al. 2015).

Yadav et al. (2016) found that the CH_4 emission per kg DMI and per kg organic matter intake (OMI) decreased significantly ($p < 0.05$) at 30 °C and 35 °C exposure; however, it increased at 40 °C exposures. Respiration quotient was significantly ($p < 0.05$) lower at 40 °C exposure as compared to 25 °C, 30 °C and 35 °C. Yadav et al. (2016) established that CH_4 emission decreased progressively with the increase in temperature up to 35 °C and then increased to initial levels. Barnett et al. (2015) reported a positive correlation of methane production with ambient temperature and a negative correlation with triiodothyronine (T3).

11.9.5 Heat Stress and Rumen Microbial Diversity in Sheep

Rumen foregut microbial community structure varies according to morphological, physiological and even behavioural characteristics that have evolved along with the varied feeding strategies in the different ruminant lineages allowing ruminant species to exploit a wide range of feed types (Hofmann 1989). In addition to feed composition effects, these host adaptations might also play a role in regulating rumen microbial community structure (Russel and Rychlik 2001). Microbial communities could clearly be discriminated by both host and diet, with bacteria being the main drivers behind the observed differences indicating their more diverse metabolic capabilities compared with the less versatile archaea and protozoa (Henderson et al. 2015).

It is believed that enteric microbiota respond to the endocrine changes in the host body and evidences are accumulating about this concept. The phenomenon of ability of microbes to recognize and respond to changes in the environment of their host is termed microbial endocrinology. Tajima et al. (2007) have reported that the changing housing temperatures altered rumen microflora in Holstein heifers. Profiling the bacterial species composition of rumen fluid using 16sRNA gene cloning revealed that elevations in environmental temperature and humidity (2 weeks in a climactic chamber maintained at 33 °C and 80% humidity v. 20 °C and 60% humidity) resulted in consistent changes in microbial diversity, reduced weight gain and an overall lowering of rumen pH (Freestone and Lyte 2010).

Later work from Uyeno et al. (2010) identified the temperature-responsive rumen species in the heat-stressed heifers as members of the *Clostridium coccoides-Eubacterium* family of bacteria and the genus *Streptococcus*, both of which increased in numbers, and the genus *Fibrobacter*, whose population sizes decreased (Freestone and Lyte 2010). It was also found that following the exposure to catecholamine stress hormones, members of the *Streptococcus* genus produce a potent growth stimulator that has cross species activity (Freestone et al. (unpublished data)). Although the rumen bacterial composition was altered in response to the rising temperatures and humidity, the diversity indices such as Shannon index and the OTU numbers were very stable in all the clone libraries. This suggests that the altered physiological parameters of animals in response to heat stresses are not selecting for a specific groups of bacteria thus diminishing the diversity indices in the rumen (Tajima et al. 2007).

11.10 Conclusion

Sufficient evidence exists to validate that heat stress can alter the rumen functions both by affecting biotic and abiotic components of rumen ecosystem. While there is some equanimity on the relative importance of possible different factors in altering rumen functions, there is widespread agreement that heat stress can compromise the production in animals by altering rumen microbiota. Though there is paucity of information regarding microbial endocrinology aspects of rumen microbes and time-dependent effects of heat stress on various aspects of rumen ecosystem, there is a strong belief among the scientist community that selection of animals that exhibit minimal changes in the rumen environment with respect to heat stress will be a new paradigm towards climate-resilient animal production.

11.11 Future Perspectives

There is still a lot of scope for research in various aspects of alterations in rumen function due to heat stress like changes in the microbial environment with temperature, changes in interspecific interactions among various residents of rumen ecosystem and changes in quality of protein due to heat stress and more importantly how the host endocrine response will affect the rumen microbiota. A more multidimensional approach to the study of rumen ecosystem with respect to heat stress is the need of the hour.

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Methane Estimation Methodologies in Sheep

12

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Abstract

Methane arising from the enteric fermentation in ruminants is one of the major greenhouse gases (GHGs) and a key component as far as agricultural emission is concerned. Relative high global warming potential and biological energy loss from animal system makes methane (CH_4) much more important than any other GHG. Researchers worldwide have attempted many approaches with variable success for enteric methane mitigation and the search for advanced sustainable approach is still on. However, attempting mitigation without knowing the precise emission from a country is not going to serve any purpose. Most of the countries, especially developing nations, are still lacking a valid database for enteric methane emission. In order to arrive at a national methane emission figure, a country should have proper methodologies for estimating the methane emission from different ruminant species fed on various dietary combinations as per local and seasonal availability. As sheep are being maintained by small and marginal farmers, therefore, the loss of biological energy in the form of CH_4 under the resource-

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deficit scenario of farmers make this species as equally important as cattle and buffaloes. This chapter describes various methodologies which can be employed for the direct or indirect estimation of CH_4 emission from sheep. Each methodology has been discussed in the chapter at length along with their advantages and limitations. Though the adoption of a methodology for the estimation of CH_4 depends on many factors, in vivo techniques such as GreenFeed, sulfur hexafluoride tracer technique and respiration chambers are instrumental in order to estimate the precise emission and could be useful in determining the national CH_4 emission when a large number of experiments are conducted involving large animals and locally available seasonal feedstuffs with repeated measurements.

Keywords
Methane • Estimation methodologies • Sheep • Livestock • In vivo techniques • Indirect methods

Contents

12.1 Introduction

Methane (CH_4) is generated as a by-product resultant of microbial digestive process (fermentation) in the animal's digestive system and later on eructated by the animal to surrounding atmosphere. The extent of methanogenesis primarily depends on the nature of dietary ingredients (Malik et al. 2015). Fermentation of fibrous feed in the rumen leads to comparatively more enteric CH_4 emission than the fermentation of soluble carbohydrates in the forestomach. In addition, the factors like animal species, breed, productivity level, pH of rumen fluid, acetate: propionate ratio and methanogenic archaea also influence the intensity of ruminal methanogenesis. Globally, livestock contribute about 95–105 million tons (including enteric fermentation and excrement) of CH_4 per year. The contribution from enteric fermentation as compared to excrement CH_4 emission is quite large and constitute about 90–95% of total CH_4 emission from livestock sector. Enteric CH_4 contributes 17% and 3.3% of the global CH_4 and greenhouse gases (GHGs) emissions, respectively (Knapp et al. 2014). The enteric CH_4 emission due to expanding demand for dairy products is projected to significantly increase in the near future. Regional estimates by various agencies suggested a huge disparity in enteric CH_4 emission across the globe, and countries like Latin America, Africa, China and India hold first, second, third and fourth position in enteric CH_4 emission, respectively (Malik et al. 2016). Thus, it is obvious from the above discussion that enteric CH_4 emission from the livestock is large and contributes significantly to the global warming. The shorter lifespan of CH_4 (12 years) in the atmosphere and high global warming potential (25 times more than CO_2) are few criterions which make this more favorable for environmentalist than any other GHG to attempt stabilizing global warming through CH_4 amelioration.

In spite of removal of unwanted fatal products (H_2 and CO_2) arising from fermentation, ruminal methanogenesis due to high calorific value (55.65 MJ/kg) deprives host animals (Malik et al. 2013) from a sizable fraction of energy (6–12% of the intake) and that is why animal nutritionists are forced to minimize the emission from enteric fermentation. Worldwide, the researchers have come up with several CH_4 mitigation strategies to ameliorate the emission to a meaningful extent. Unfortunately, the country- and region-specific precise estimates for enteric CH_4 emission is not known especially for the developing countries, and therefore, attempting reduction using specific mitigation approaches will not end up with anything. For example, there is a huge disparity between the enteric CH_4 emission estimates from the Indian livestock, and this ranged from 7 to 18 million tons per year. One of the major cause for such inaccurate estimate for enteric CH_4 emission is lack of the suitable and validated methodologies. The emission is usually workedout using different equations developed elsewhere that hardly depicts the similarity in prevailing feed resources, dietary regimes and productivity level among the countries. The first attempt in targeting the amelioration should be accurate measurement of emission to decide the extent of reduction and thereafter choosing of approach which could achieve the desirable reduction. In this chapter, various approaches employed for enteric CH_4 emission from sheep along with their merit and demerits are discussed at large so that the researchers and other stakeholders can easily decide the accurate, economic and repeatable technique for measuring the emission. An effective measurement technique is required to evaluate mitigation technology, preparation of country-specific inventory and assessment of carbon footprint of yielding products from livestock.

12.2 Various Methodologies for Measuring CH_4 Emission

Worldwide spreading of livestock make them a significant source of CH4 emission. The livestock fulfill their feed requirements in different ways from pasture grazing to stall fed. Therefore, measuring the CH_4 emission covering all prevailing feeding practices using conventional measuring technique is extremely difficult. The very first question in our mind is why we need to measure the CH_4 emission. The measurement is absolutely necessary to

1. explore the trend and identify the contribution of sheep in relation to other livestock species in a given country or region.
2. devise effective ways to mitigate the emission.
3. confirm the effectiveness of strategies which are used for intended purpose of reduction (PGgRC 2015).

Methodologies employed for quantifying the CH_4 emission from sheep are described in subsequent sections. The merits and demerits of each methodology is compiled in Table 12.1 for easy comparison and for ascertaining the effectiveness of the quantifying method.

12.2.1 Respiration Chamber

Respiration chambers have been used since a long time for the purpose of studying anabolic and catabolic pathways related to energy utilization (Johnson et al. 2003). There are two types of chambers: closed circuit and open circuit chambers. These respiration chambers, apart from feeding, watering, fecal and urine collection, also have the provision for collection of exhaled gases from all possible sources including enteric fermentation. Chamber is fitted with air inlet at the front and an outlet at the back along with internal ventilation fans for efficient mixing of incoming air and expired gases, and air from the space is removed through air pump. The chamber is also equipped with sensors for measuring climatic parameters such as relative humidity, temperature and pressure. The outlet gas is analyzed through continuous sampling. The CH_4 emissions can be determined by measuring the total airflow and calculating the difference between inlet and expired air (Munoz et al. 2012). Methane and carbon dioxide are analyzed by infrared analyzer, while oxygen concentration is determined by paramagnetic analyzer (Pinares-Patino et al. 2007; Chagunda and Yan 2011). In addition to measurement of gas concentration, respiration chambers also allow the nutritional evaluation of test diet and even can explore the minor effect of diets and supplements on CH_4 emission (Storm et al. 2012). Figures 12.1 and 12.2 describe the open circuit chamber in cattle and sheep respectively.

Due to high accuracy, repeatability and less animal-to-animal variations, respiration chambers are generally referred as “gold standard” for enteric CH_4 measurement (Williams et al. 2013). The animals are required to be acclimatized to the chamber conditions before measuring the gas concentration. The major disadvantage associated with respiration chambers is their high cost of construction and subsequent maintenance charges. This method confines the animals to a limited area and restricts their movement which affects the intake and natural behaviors and therefore the CH_4 production (Ellis et al. 2007). The technique requires great technical expertise to generate accurate CH_4 emission data. Another major issue with respiration chamber is that the measurement of CH_4 emission in pasture-grazing sheep is not possible, and the data generated cannot extrapolate as such in grazing animals. Due to the confinement of animals in chamber for a short period, the data generated provides a snapshot of the emissions (PGgRC 2015).

Table 12.1 Summary of the methods employed for measuring methane emission in sheep

Method	Description	Advantages	Limitations
Respiration chamber	Chambers are used for quantifying the CH_4 emission via collecting exhaled gas sample from all sources such as mouth, nostrils and rectum and analyzing the concentration	This technique is highly accurate, repeatable and less variable. Even relatively small changes in CH_4 emission can be detected with respiration chamber	The major limitation of using respiration chambers for quantifying the emission is very high cost of construction and subsequent maintenance. Results cannot be extrapolated to loose housing animals or pasture-grazing animals. Small numbers of animals can be used for quantifying the emission. Impose restrictions on eating and other natural behaviors which influence CH_4 emission from that in normal environment. Conducting studies in pasture-grazing animals is not feasible
Ventilated hood system	It is a simplification of the respiration chamber where gaseous exchange only from the head is measured rather than from whole body	The cost of ventilated hood is relatively less as compared to whole animal chamber. Animal-to-animal variation is relatively small as compared to other techniques	Prior to use of ventilated hood system for collecting exhaled gas sample, an extensive training is required for accustoming the animal to the hood
Sulfur hexafluoride tracer technique	SF_6 permeation tubes placed into the reticulorumen serve the basis of daily CH_4 emission by determining the CH_4:SF_6 ratio through analysis of both CH_4 and SF_6 in collected gas sample	SF_6 technique is able to measure the CH_4 emission from sheep in the natural environment. Widely used in many countries in both grazing as well as stall-fed sheep and can be used in large herd for measuring the emission	The variability in daily and animal-to-animal emission is large and requires highly technical expertise to minimize the variation. Labor extensive, large variation in permeation rate of SF6 affects the CH_4 emission calculation

(continued)

Table 12.1 (continued)

Method	Description	Advantages	Limitations
CO_2 technique	In this technique, CO_2 is used as a tracer gas to determine the CH_4:CO_2 ratio which indicates the efficiency of microbial fermentation	Measuring the CO_2 and CH_4 ratio through different analyzers is easier than the SF_6 technique. The equipment (Gasmet) used for measuring the concentration of gases is portable and can easily be used	Diurnal variations is large and therefore repeated measurements at different time periods should be done to consider the diurnal and postprandial variations. Therefore, adequate number of measurements in different times of the days should be considered to account for diurnal and postprandial variation in CH_4 and CO_2 emissions in animals. The volume of CO_2 produced can vary with size, physical activities and productivity level of the sheep
In vitro gas production technique	In vitro technique employs different devices/equipment for setting up the incubations, but all these equipments ferment the feed in controlled simulated conditions. The technique is used for screening the large number of samples in short for their likely inclusion as methane suppressing agent in animal's diet	The time required for first-hand information of the CH_4 production from given feed ingredients/ration is very less; many feedstuffs can be screened simultaneously. This method is inexpensive and widely used all over the world	Animals are not employed in this technique., hence, animal-to-animal variation in CH4 emission cannot be explored. In vitro evaluation of feed for CH_4 production only simulates the ruminal fermentation without considering the emissions and digestibility by the whole animal as well as long-term adaptation of the ruminal microbes
Polythene tunnel	Air sample entering and leaving the tunnel are analyzed for CH_4. This could be an effective alternate for respiration chambers for measuring CH_4 emission from grazing sheep	Large portable tunnel may fully cover a small area where sheep are grazing and thus quantify the emission. Due to portableness, this system can be used in number of pastures	Considerably less (15–20%) CH_4 emission is reported under tunnel as compared to respiration chamber. Different feeds/ treatments cannot be investigated as the sheep graze the pasture available under the tunnel only

(continued)

Table 12.1 (continued)

Method	Description	Advantages	Limitations
GreenFeed	GreenFeed can measure CH_4 and CO_2 emission from both pasture-grazing and stall-fed animals. Measures and records CH_4 emissions from individual animal through repeated measurement for 3–6 min. As soon as animal start picking pellet feed from a specialized manger, a fan draws air from around its head and nose into an air-handling system which is later on analyzed for CH_4 and CO_2	It is an external tracer release system. It offers the liberty to the investigator for controlling the timing of feed availability and measuring CH_4 emissions at different time periods	A specialized ear tag with radio frequency identification is required to track the animal. It measures CH_4 emissions when the animals have their head in the feeder, and therefore, whole-day emissions should be examined thoroughly. Measures CH_4 emitted from animal's mouth and nose and does not account the CH_4 from rear of the animal
Laser detector	Methane emission is measured through a hand-held portable laser detector. This detector is pointed at the livestock to record the CH_4 output. The peaks representing the respiratory cycle are analyzed for CH_4 output	Large number of animals can be screened for CH_4 output without interfering with their normal activities. LMD is portable, noninvasive, stress-reducing technique that predicts CH_4 emission from individual animal in its natural environment	Does not account CH_4 emission from the rectum. Climatic factors may affect the accuracy and precision of emission
Portable accumulation chamber	These chambers are made up of clear polycarbonate. Methane concentration is measured by recording the change in concentration over time using a gas detector	Though this technique is not as sensitive as respiration chambers, it still gives at par estimate. The technique is good for the genetic screening of animals for selecting low-CH_4 output animals	Low repeatability of short-term CH_4 measurement than respiration chambers and therefore more measures are required for capturing the variation within a day

(continued)

Table 12.1 (continued)

Method	Description	Advantages	Limitations
Infrared thermography	IR thermography involves the measurement of surface temperature of body surface. IR camera converts emitted radiation into electrical signal and then thermal pattern	The technique does not interfere with natural activities of the animal, and emission is determined based on the thermal images. This technique seems promising, however, a robust validation with other in vivo techniques is warranted	For taking IR, the skin should be free from debris which is comparatively difficult in case of sheep. Technique demands the recording of temperature from at least 20 body locations which will take about 6.5 h. Measurements should be taken in the absence of direct sunlight
Micrometrological methods	Involve the measurement of fluxes and concentration of CH_4 in atmosphere of larger area containing animals and relating these to the emissions. Measuring points and theories differ between various methods	These methods cause least interference with animals' natural behaviors and potential tool for estimating carbon footprint of an area	Micrometrological methods cannot measure the emission from individual as well as indoor-housed animals. These methods are hardly employed for testing mitigation strategies. Measurements depend on metrological and landscape conditions
Intraruminal device	Device contains an intraruminal capsule fitted with sensors for measuring CH_4 emission through analysis of received signals on a wireless sensor network platform	Device also measures the temperature and pH of the rumen. It can apply to any species with diverse feeding practices	Device lifespan is an important point as a new device has to be used for measurement every time. Real-time validation is required for the comparison with other techniques
Proxy measures	Composition of biological samples (milk and feces) is used for quantifying the CH_4 emission	There is no disturbance to the animal's natural behavior as no equipment is fitted. Studies suggest significant correlation with SF6 and respiration calorimetry	Only limited studies have been conducted and the results remain inconclusive. Further research is warranted to establish the significance of these proxy methods for predicting CH_4 emission

(continued)

Table 12.1 (continued)

Method	Description	Advantages	Limitations
Prediction models	Existing data from the experiments is used for the prediction of CH_4 emission. The intake of dry matter, metabolizable energy, neutral detergent fiber, acid detergent fiber, etc., are taken into consideration while developing prediction models for CH_4 emissions	National or global emissions are estimated by prediction models. These models are easy to apply; however, the accuracy depends on the experimental data used for model development	Model developed from the data derived from respiration chamber cannot be applied directly to pasture-grazing animal. Needs a continuous update by using data from different feeding systems

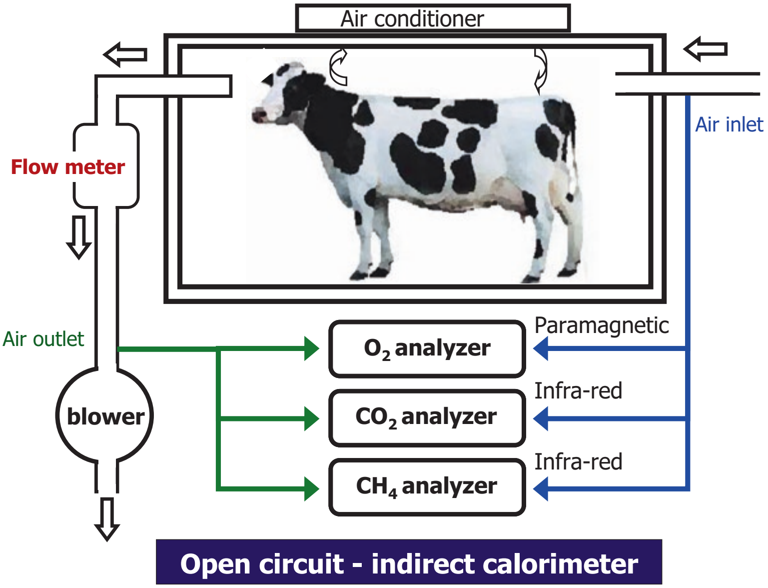

Fig. 12.1 A schematic view of the open circuit chamber

Fig. 12.2 Open circuit respiration chamber for sheep

12.2.2 Portable Accumulation Chambers

Portable accumulation chambers (PAC) may be useful especially when screening large number of animals for selecting low-CH_4-emitting sheep. PAC provides the facility of screening large number of animals for a short period of time. One such PAC is being developed by Pastoral Greenhouse Gas Consortium (PGgRC), New Zealand, where sheep walking into the chamber will be held inside for about 25–30 min during which CH_4 concentration is analyzed. PAC is made up of transparent polycarbonate box. Increasing concentration of CH_4 in polycarbonate box when the sheep is in box provide the estimate for CH_4 emission. The change in CH_4 concentration in the chamber's atmosphere is measured over time using gas detector. This technique showed at par results with respiratory chamber measurements (Goopy et al. 2009, 2011, 2016), and the repeatability of the results has been demonstrated in the field. Dorich et al. (2015) compared the enteric CH_4 emission in 16 Holstein cows using portable automated open-circuit gas quantification system and sulfur hexafluoride (SF6) tracer technique. The portable automated open-circuit gas quantification system, due to low coefficients of variation (ranging from 14.1% to 22.4%) and moderate relationship (coefficient of determination = 0.42) between CH_4 emissions and dry matter intake (DMI), proved a reliable method of CH_4 measurement as compared to SF6 which resulted in large coefficients of variation (ranging from 16.0% to 111%) for CH_4 emissions and a poor relationship (coefficient of determination = 0.17) between CH_4 emissions and DMI (Dorich et al. 2015). Short-term measurement usually lead to a lower repeatability in CH_4 emission, hence, long term measurement is required for the validation in order to minimze the variation in recommended emission level. Robinson et al. (2015) recommended a long-term comparison of PAC and respiratory chambers data to prove the usefulness of PAC CH_4

measurements. Like respiration chambers, PAC also has the provision for recording temperature, pressure, feed intake and feed quality. However, PAC is not as accurate as respiration chambers, and they also provide the snap shot of the emission in an artificial environment.

12.2.3 Ventilated Hood System

Ventilated hood system is a simplified version of respiration chamber which measures the gas exchange from the head rather than the whole body. In this technique, the head of the animal is accommodated in a hood, and air samples are drawn and analyzed for CH_4 concentrations in both incoming and outlet air. The accuracy of gas analysis and comfort of animal in hood are determined by the flow rate of exhaust air. The hood also has the provision of measuring temperature, pressure, humidity, etc. Ventilated head hoods of different size and designs have been used in different studies on enteric CH_4 measurements (Suzuki et al. 2008; Place et al. 2011; Takahashi et al. 1999). The ventilated hood system can be equipped with additional monitor and acquisition system for monitoring the behavior of the animal. Boadi et al. (2002) compared ventilated hood system with the SF6 technique and reported similar daily CH_4 production in both the methods. However, the animal-to-animal variation was more in SF_6 than the head hood system. In a study of Troy et al. (2013), higher CH_4 emission was reported in ventilated hood system as compared to respiration chamber. The expenditure of head box system is exclusively less as compared to the whole respiration chamber animal (Young et al. 1975; Kelly et al. 1994) and requires less space than the other one. The relocation of head hood from one place to another is easy and can be mounted on a cart. Similar to the respiration chamber, CH_4 measurement by the hood system also demands the extensive training for the investigators and animals to get themselves accustomed to the system. Figure 12.3 describes the ventilated hood system for CH_4 measurement.

12.2.4 Polythene Tunnel Systems

Polythene tunnels are just like respiration chambers, but these are easy to transport and operate and can be placed on pasture where animals are grazing. These tunnels overcome the limitation of respiration chambers where measurement of enteric CH_4 emission in pasture-grazing sheep is difficult. Polytunnels are used for measuring the emission in grazing animals without much disturbance to their natural behavior. In polythene tunnel system, the air is drawn through a large tunnel and CH_4 concentration is measured in air sample entering and leaving the tunnel with the help of gas chromatography. It is generally used for measuring the emission during the grazing of fresh forages of interest in natural conditions. Air is drawn through the internal space at $1m^3$ (Lockyer and Jarvis 1995), and sample can be drawn continuously at exhaust port (Lockyer 1997). The micropumps pass the exhausted air to a dedicated gas chromatograph (Murray et al. 2001), and the data from sensor is sent to a data

Fig. 12.3 Ventilated hood system for measuring in vivo methane emission

logger which captures flow rate, humidity and temperature within the tunnel. The polythene tunnel is an automated system where measurements can be performed with high repeatability. The portability of tunnels, in addition to reusing a number of times, makes it favorable for measuring emissions from pasture-grazing sheep. Lockyer and Jarvis (1995) and Lockyer (1997) noted average CH_4 production as 13–14 and 74.5 g/day for sheep and calves, respectively. However, the emissions decreased with advancing grazing time, which could be due to the diminishing forage mass in the pasture under the tunnel. The CH_4 production in sheep measured in respiration was greater than in the tunnel (Murray et al. 1999). Other researchers also observed less CH_4 emission in polytunnel method than in the respiration chamber (Lockyer and Champioun 2001).

The major concern with polytunnel system is that different dietary treatments cannot be studied at same time as animals in the tunnel are grazing only on the pasture under the tunnel (Bhatta and Enishi 2007). The major challenge of the tunnel is frequent calibration for obtaining the good recovery. The factors such as temperature, humidity, grazing pattern and changing animal behavior can cause the fluctuations in measurement.

12.2.5 Sulfur Hexafluoride Tracer Technique

Sulfur hexafluoride (SF6) tracer technique of Zimmerman (1993) and Johnson et al. (1994) for enteric CH_4 measurement is widely used across the countries and animal species. Unlike the techniques discussed above, SF_6 estimates the CH_4 emission in natural environment. This technique works on the idea that CH_4 emission can be measured if the emission of a tracer gas from the rumen is known. SF6, due to its inertness, nontoxic nature, stability, low atmospheric concentration and absence of natural emission sources, is being used as reference gas for quantifying the emission of enteric CH_4. Permeation tube serves as the source of SF_6 in the reticulo-rumen (Lassey et al. 2001). An acclimation period of 7–14 days is required to accustom the sheep to halter, canister and diet under investigation. The permeation tubes are placed into the rumen with the help of balling gun. The breath sample from individual animal is collected in prevacuumed canister tied over the neck and fitted with halter comprising air filter, capillary tube and connectors. The sample in canister is diluted with nitrogen to ensure the easy drawing of gas sample to analyze on gas chromatograph for CH_4 and SF_6. The enteric CH_4 measurement is based on the CH4: SF_6 ratio after making an adjustment for the background concentration of each gas. Figure 12.4 describes the SF_6 methodology of CH_4 estimation in sheep during grazing and stall-fed condition.

Pinares-Patińo and Clark (2008) recommended the use of SF_6 method in grazing animals involving large herds. The tracer technique is widely used in India, New Zealand, USA and many other countries for measuring CH_4 emission in grazing and stall-fed animals. Unlike the respiration chamber, the SF_6 method can be employed in large numbers of animals for concurrent CH_4 measurement in less time and cost. Furthermore, the SF6 method imposes little effect on animal behaviors under typical animal management conditions (Johnson et al. 1994).

SF6 tracer technique enables researchers to measure CH_4 emmisions in ruminants in their natural settings, but there are certain limitations associated with this technique. It is more labor intensive and demands technical skills for error-free CH_4

Fig. 12.4 Enteric CH_4 measurement in pasture-grazing and stall-fed sheep at National Institute of Animal Nutrition and Physiology, Bangalore, India

measurement. The inconsistent release rate from permeation tubes, background-level determination, inconsistency between CH_4 measurements are the factors which lead to faulty measurements. Johnson et al. (1994) observed similar CH_4 emission when SF6 technique and respiration chambers were used for the measurement in grazing cattle (7.3% versus 7.2% of gross energy intake). However, McGinn et al. (2006) observed slightly lower emissions (5–10%) with SF_6 method than the respiration chambers in both sheep and cattle and opined that this variation could be due to the CH_4 loss via rectum. On the other hand, Munoz et al. (2012) noted higher CH_4 emissions for the SF_6 technique than the respiration chamber (RC) method.

12.2.6 CO_2 Technique

By using CO_2 as internal marker, Garnsworthy et al. (2012) developed a novel technique for the estimation of CH_4 emission through collecting eructated air samples during milking. This technique basically determines the CH_4:CO_2 ratio and thereby the efficiency of microbial fermentation which is a deciding factor for CH_4 emissions. In the technique, the carbon from fat, carbohydrates or protein which is not metabolized to CO_2 is estimated as CH_4 emission (Madsen et al. 2010). Measurements of CH_4 and CO_2 are generally done with analyzers. Portable equipment called GasMet based on infrared technology is used for the estimation (Teye et al. 2009). Limited studies showed CH_4:CO_2 ratio in between 0.34 and 0.39 in different breeds of cattle (Lassen et al. 2012), and factors such as diurnal variations in the CH_4:CO_2 ratio is a result of the differences in digestive and metabolic activities and rumen fermentation pattern. The diurnal variation could be minimized through adequate measurements at different points of time in a day. The factor influences the energy requirement also has an impact on CO_2 production, which could be determined from the size and activity of the animal (Storm et al. 2012). The expected day-to-day variation could be minimized by applying the technique to large number of animals from many experiments. The technique is still new and warrants further investigation to establish the significance with minimum error in measurement.

12.2.7 GreenFeed

GreenFeed is a newer technique developed by Zimmerman and Zimmerman (2012) for the measurement of enteric CH_4 emission in ruminants. This technique is suitable for measuring the emission from animals in their natural rearing conditions such as pasture grazing and stall feeding. Unlike SF6 technique, GreenFeed does not collect the gas sample for a complete feeding cycle of 24 h. The device in GreenFeed records short-term (3–5 min) CH_4 emissions from individual animal with repeated measures during 24 h. The animal is attracted to a kind of trough which has bait of pellet concentrate and where sensors record short time CH_4 emission using breath sample. The GreenFeed has multiple components such as feeding

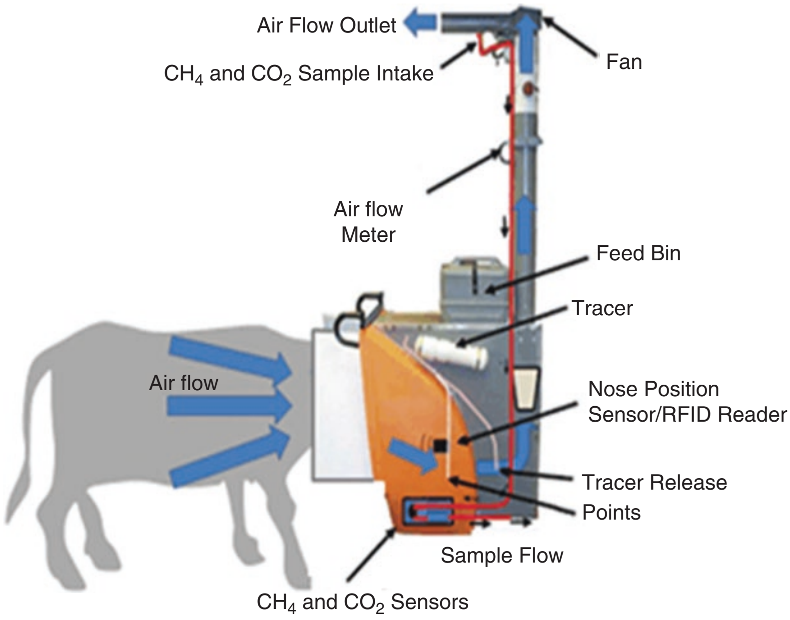

Fig. 12.5 Different components of automated head chamber system (Huhtanen et al. 2015)

station, animal identification system, airflow manifold inlet, sensors for gas measurement, data collection and storage system, remote communication, monitoring system, etc. Different components of automated head chamber system (AHCS) are shown in Fig. 12.5 (Huhtanen et al. 2015) where air flow monitoring, gas sample collection, sensor based analysis and animal identification is being taken care of.

The assumption of using GreenFeed is that the CH_4 emission from animal can be worked out through repeated short-time measurement of emission many times within a day for many days. A specially designed feeding station is used for capturing the emission, and these units can be used in stall fed, free stall barns, robotic milking systems, feedlots and pastures. The unit identifies the individual animal through a specialized ear tag with radio frequency identification and once the animal is identified, the feeding station then drops feed into the trough. As soon as animal start eating, a fan draws air into air-handling system from in and around the head and nose of the animal. The GreenFeed is designed to measure gas fluxes of CH_4, CO_2 and, optionally, oxygen, hydrogen, and hydrogen sulfide from individual animals. Figure 12.6 describes the GreenFeed unit for CH_4 measurement from livestock.

The CH_4 emission is calculated using the same principle as in respiration chamber by considering volumetric air flow rate adjusted to standard temperature and pressure and corrected for capture rate (Huhtanen et al. 2015).

Comparison of GreenFeed with other techniques (respiration chambers) revealed similar CH_4 emission but lower than the values obtained in SF6 technique (Hammond

Fig. 12.6 Methane measurement in GreenFeed unit

et al. 2015), which is probably due to the higher variability for SF_6 measurements when background gases are combined with poor barn ventilation. Arbre et al. (2016) demonstrated that achieving the repeatability estimates of 0.70 took 45 days, while similar estimate can be achieved in 4 days in SF6 technique. Even further prolonging of measurement to 45 days improved the repeatability estimate (0.90) in GreenFeed. An added disadvantage with this technique is that it only measures CH_4 emissions when animals have their head in the feeder and eating.

12.2.8 Laser Methane Detector

Laser methane detector (LMD) could be a quick and reliable method for measuring CH_4 emission from sheep in a stress-free natural environment (Chagunda et al. 2009). One such detector is developed by Tokyo Gas Co. for measuring CH_4 emissions in sewage systems, mines and demolition sites. The device is handheld and portable which record the emission just by pointing it on the animal, using infrared absorption spectroscopy, and the wavelength harmonic detection module determines CH_4 concentration. The data obtained in the form of peaks representing respiratory cycle is stored in a memory card (Ricci et al. 2014). Like many other techniques, laser CH_4 detector also does not account the emission from rectum and meteorological factors such as wind speed, wind direction, temperature, humidity and atmospheric pressure which may influence the precision of measurements (Chagunda 2013).

12.2.9 Infrared (IR) Thermography

This technique relies on the principle that the animal's body surface temperature is related to the feed efficiency which in turn affects the degree of CH_4 emission from the animal. Montanholi et al. (2008) demonstrated that CH_4 emission from ruminants can be estimated using a portable infrared camera without touching the animal. The camera is to be calibrated at room temperature and relative humidity before use. The camera first converts skin surface naturally emitted radiation (wavelength 8–12 mm) into an electrical signal which is later processed into a thermal pattern. The camera is capable to detect temperature differentials as minimum as 0.1 °C. If images are taken from 20 different locations and 20 min taken for each image, it will take about 7 h for generating data from one animal. The accuracy of readings depends on the cleanliness of body surface from debris (Poikalainen et al. 2012) and the intensity of sunlight. The image should be taken in the absence of direct sunlight for the precise readings. The postprandial period, i.e., around 100 min after a meal, is recommended best time to assess the CH_4 production via infrared thermography.

Due to the noninvasive process and relatively cheaper price, this technique is more convenient than any other conventional method of measuring heat and CH_4 production. However, the factors such as direct sunlight, wind, etc., affect the thermal images and so the emission estimate. In addition, the technique is labor intensive and time consuming if the herd size is increased.

12.2.10 Intraruminal Gas Measurement Device

The intraruminal gas measurement device was developed by the Commonwealth Scientific and Research Organization in Australia to estimate enteric CH_4 emission from ruminants. The device can be used as an alternative to SF_6 tracer technique and respiration chambers. The device is impermeable to liquid and is placed into the stomach of the animal. The animals swallow the device as a bolus with tubular body. The bolus is permeable to gases and has gas sensors that can detect CH_4 in rumen. A controller is attached to the gas sensor so that it can periodically process and give out data regarding the amount of CH_4 in the rumen (Wright et al. 2013). The device is advantageous as it can be applied to a wide variety of ruminants (e.g., cattle, sheep, giraffe) and does not impede the animal in its natural environment.

12.2.11 Facemask

Facemask also uses the same principle as in chamber and hood for quantifying the CH_4 emission from livestock (Liang et al. 1989). This technique is relatively simple and nonexpensive. It can be used in stall-fed as well as pasture-grazing animals for measuring CH_4 emission; however, the estimation is usually lower than the other techniques (Liang et al. 1989). The animal is to be accustomed to the facemask

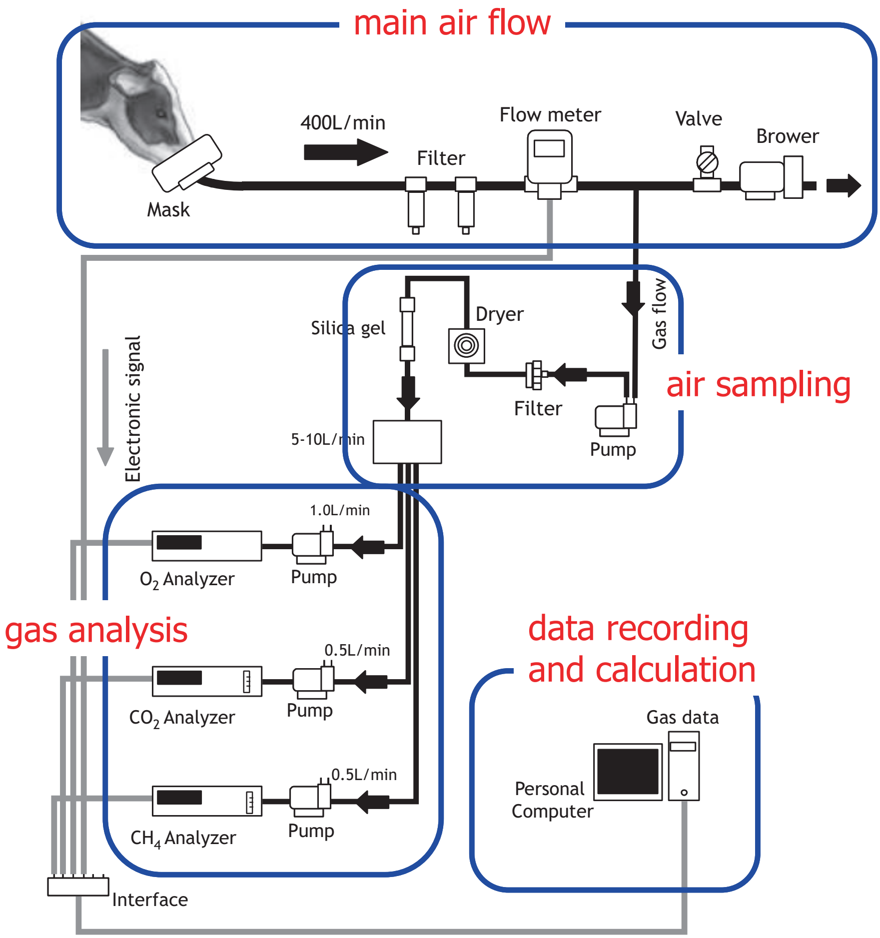

Fig. 12.7 Schematic presentation of facemask technique (Courtesy T Nishida)

which otherwise affects the eating and drinking ability. The short-term CH_4 measurements in this technique may lead to erroneous results (Johnson and Johnson 1995). A schematic presentation of facemask technique is furnished in Fig. 12.7.

12.2.12 In Vitro Gas Production Test

This technique is employed in laboratory where conditions akin to the rumen are simulated in an artificial environment and gas production is recorded, which is subsequently analyzed on gas chromatograph for CH_4. This technique is a powerful tool for generating real-time data in short duration for a large number of samples for their CH_4 reduction abilities (Lee et al. 2003). The basic principle of the in vitro technique is to ferment feed under controlled laboratory conditions employing rumen microbial inoculums. Feedstuffs, subjected to different treatments, are incubated at 39 °C with a mixture of rumen fluid, buffer and minerals for a certain time period, typically 24, 48, 72, 96 or 144 h (Storm et al. 2012). The amount of total gas produced during incubation is measured, and its composition is analyzed to obtain data on the in vitro production of CH_4. In this technique, the in vitro degradation of the feedstuffs can also be checked to verify whether the reduction in CH_4 is happening at the cost of total feed degradation. For the in vitro measurement of CH_4 production, a number of systems viz. syringes, RUSITEC, closed vessel batch fermentation, automated system, etc., have been employed for the purpose. Depending on the system, it is possible to conduct upto several hundred parallel incubations with sufficient replicates in the experiments which are difficult to manage in vivo. Compared to in vivo experiments, in vitro is much easier, for animal-to-animal variation can be avoided by using the same ruminal inoculum for all treatments. Bhatta et al. (2006, 2008) found in vitro gas production technique at par with SF6 technique and the respiration chamber technique. A major disadvantage of in vitro is that it only simulates the ruminal fermentation of feed and not emissions and digestibility by the entire animal. Furthermore, under normal conditions, it does not include long-term adaptation of the ruminal microorganisms to the tested feedstuffs. Other factors, such as bicarbonate concentrations in media and headspace gas composition, also affect the gas production (Patra and Yu. 2013). Therefore, in vitro results should be interpreted with utmost care in quantifying the CH_4.

12.2.13 Micrometeorological Methods

Micrometeorological variables have been developed (Lassey 2007; Harper et al. 2011) for measuring CH_4 emission from the animals/farms. Micrometeorological methods are based on the measurement of fluxes and concentrations of gases in the free atmosphere and relating these for calculating the gas emissions from animals. External tracer ratio technique (Harper et al. 2011) can be used for measuring CH_4 emission from open paddock. The measurement depends on the exchange rate of air which itself is affected by the temperature gradient, temperature humidity index, and the air velocity and, therefore, may provide the misleading information on the emission. Another micrometeorological method is open path spectrometer (Bjorneberg et al. 2009) where the radiation from an incandescent silicon carbide source is collimated and passed into an interferometer. There are so many other methods for measuring the CH_4 emission, but the accuracy of emission measurement by these methods depend on certain wind velocity, wind direction, landscaping (topography), and location of animals in the paddock. The micrometeorological methods are expensive and require sensitive instruments to analyze CH_4 concentration (Hill et al. 2016). These methods cannot be employed for the measurement of emissions from individual animals and indoor-housed animals. Furthermore, the testing of mitigation options in micrometeorological techniques is very difficult (McGinn et al. 2011).

12.2.14 Proxy Methods/Models

Many biological markers based on milk and feces composition have been developed for predicting the CH_4 emission from a large number of animals with minimal inputs. These biological markers have a close relationship with CH_4 emissions (Dehareng et al. 2012). Concentrations of certain fatty acids in milk have correlation with CH_4 emission, and it has been validated in many studies (Dijkstra et al. 2011). However, Williams et al. (2014) observed a weak correlation between CH_4 production and the concentrations of specific fatty acids in milk fat. Archaeol, a membrane lipid in methanogens, has been found to be a potential molecular proxy in ruminants (Gill et al. 2011). However, selective retention of archaea in the rumen and degradation of the archaeol during gut transit restricts the use of archaeol to the full extent as proxy marker as weak-to-moderate correlation was reported between archaeol concentration and CH_4 emission in many studies (Gill et al. 2011; McCartney et al. 2013). These methods could be useful to predict the CH4 emission in future in order to identify low-CH_4-emitting animals, but further research is warrant to improve the predictability using these proxy methods.

Every country needs an accurate inventory for CH_4 emission from livestock in order to identify the hot spots and relative emission from the different livestock species; however, estimating the emission at country level through conducting trials is not possible, and hence, there is a need for such methods which could provide accurate data on country-level emission without conducting experiments. One of the potential alternate for this is to use prediction models developed on the basis of existing data from numerous experiments considering different animal characteristics (weight, age, breed), feed characteristics (nutrient and energy content), feed intake (dry matter or nutrients), physiological stage of the animal, etc. Such models often use data derived from in vivo experiments conducted in different species where emission is quantified using respiration chambers or sulfur hexafluoride tracer technique.

The prediction models can be classified into empirical models and mechanistic models. Various reports suggest that the mechanistic models are superior to empirical models as far as accuracy of the emission measurement is concerned. The empirical model of Moe and Tyrrell predicts the emission from cattle, and the model relates intake of carbohydrate fractions to CH_4 production. MOLLY model is a dynamic mechanistic model of nutrient utilization in cattle, and CH_4 emission is predicted by considering hydrogen balance. As excess hydrogen produced during fermentation is partitioned between microbial growth, biohydrogenation and propionate production, it is assumed that the remaining hydrogen should be used in rumen methanogenesis (Kebreab et al. 2004). COWPOLL is another model which considers stoichiometry of the fermentation within the rumen and representation of the ruminal microbes into three main categories, i.e., amylolytic, cellulolytic and protozoa (Kebreab et al. 2008).

Indian Council of Agricultural Research (ICAR), New Delhi, has implemented a project for developing a database for quantifying the state- and district-wise enteric CH_4 emission from various livestock species in the country. The model used for predicting the emission considers livestock population, different categories of livestock, physiological stage, feeding practices, seasonal variability and CH_4 production potential of feed resources and feeding regimes (Bhatta et al. 2015, 2016). These models allow us to predict CH_4 production from different livestock without employing extensive and costly equipments and conducting experiments.

12.3 Conclusions

Many methods have been employed to measure CH_4 emission for different purposes such as nutritional evaluation of unexplored feed resources, likely possibilities for including new items in the diet, screening of animals for genetic selection, etc. None of the methods is suitable in all conditions for reliable measurement of CH_4 emissions; however, the best choice of method depends on the purpose of each experiment. The respiration chamber method is a good and precise method for assessing the daily CH_4 emission from limited number of animals. SF6 method can be employed to obtain real-time data when a large number of animals and dietary treatments has to be screened; however, the technical expertise and extensive labor are few points which should be considered. The latest GreenFeed method of measuring CH_4 emission appears sound under the circumstances when large a number of animals have to be screened in a short time with repeated measurements and may be useful in conducting numerous experiments in order to identify hotspots and subsequent extrapolation of the emission on a larger scale.

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Enteric Methane Emission and Reduction Strategies in Sheep

13

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Abstract

Climate change is associated with the anthropogenic emissions of greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) is widely evident throughout the world. CH_4 is considered one of the major GHGs, 20 times more potent than CO_2, contributing to 15–20% of total global GHG emission. Sheep and goat produce enteric CH_4 through the microbial degradation of feed. Globally, livestock sector produces approximately 80 Tg CH_4 per year through enteric fermentation. Of the total CH_4 production, 11 Tg is from Indian subcontinent, which corresponds to 14% of total global CH_4 production. Indian goat and sheep breeds produce 10.1 and 11.6 g/head/d CH_4 respectively. In the era of changing climate, it is very essential to have strategies that can reduce the CH_4 emission and improve the animal production. Among the various CH_4 mitigation strategies, dietary or nutritional interventions are most suitable and adoptable with no detrimental impacts on animal health. Other CH_4 mitigation strategies like biotechnological intervention and feed additives may fail due to the diversity in rumen micro fauna. A global vision of production systems should be taken into consideration while implementing the strategies to reduce the impact of CH_4 on global warming. All GHG emissions from the animal up to the farm scale as well as grassland use must be considered, and this is very essential to find a global solution.

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Contents

13.1 Introduction

Climate change associated with the anthropogenic emissions of greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) is widely evident throughout the world. The GHG layer in the atmosphere is more or less transparent to incoming short-wave radiation, but it is opaque to the outgoing long-wave radiation and reflects back to the earth surface, resulting in abnormal warming of the earth surface called greenhouse effect (IPCC 2001). CH_4 is one of the major GHGs contributing to around 15–20% of total global GHG emission, and its global warming potential (GWP) is 20 times more than CO_2. Sheep and goat produce enteric methane through the microbial degradation of feed. Bacteria, protozoa and fungi (primary digestive microorganisms) together hydrolyze starch, proteins and plant cell wall polymers into simple amino acids and sugars. Further, these amino acids and sugars are fermented to volatile fatty acids (VFA; acetate, propionate and butyrate), hydrogen (H_2) and CO_2. Hydrogen, the gas responsible for CH_4 production, is produced by microorganisms which produce acetic acid during the fermentation. Butyrate is the other VFA responsible for CH_4 production, whereas production of propionate consumes H_2, making H_2 unavailable for CH_4 production, which causes dietary energy loss. Table 13.1 describes the enteric CH_4 emission in sheep and goat.

Globally, livestock sector produces approximately 80 Tg CH_4 per year through enteric fermentation (Cynoweth 1996). Of the total CH_4 production, 11 Tg is from Indian subcontinent, which corresponds to 14% of total global CH_4 production. CH_4 is responsible for 18% of the global atmosphere warming (Fig. 13.1). According to Singh (1997), Indian goat and sheep breeds produce 10.1 and 11.6 g/head/d CH_4 respectively. Globally, 700 g/kg of CH_4 is released into the atmosphere through anthropogenic activities, of which agriculture sector accounts for about two-third, with enteric methane fermentation contributing one-third of CH_4 from agriculture

Table 13.1 Estimates of methane emissions from sheep and goat

Animal type and region ($\times 10^{-6}$)	World Pop.	CH_4 Prod. (kg/hd/year)	Total CH_4 Prod.[b]
Sheep			
Developed countries[a]	400	8	3.2
Goats	476	5	2.4

Adapted from Crutzen et al. (1986)

[a] Includes Brazil and Argentina

[b] Total estimate for emissions from domestic animals has an uncertainty factor of ±15%

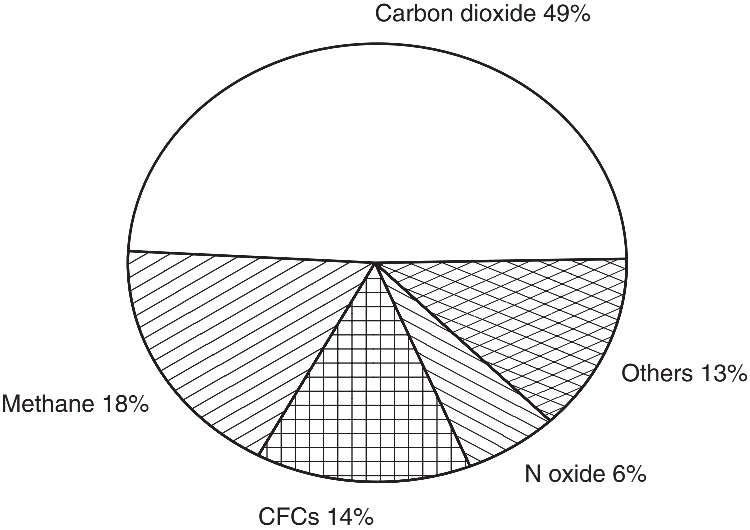

Fig. 13.1 Relative contribution (%) of greenhouse gases to atmospheric warming (Source: World Resources Institute)

sector (Moss et al. 2000). According to the reports of 1996, world population of the sheep and goat are estimated to be around 1057 million and 677 million respectively (Morand-Fehr and Boyazoglu 1999) and annually one sheep releases 9 kg CH_4 (Mbanzamihigo et al. 2002). Further, sheep and goat together emit 200 g/kg of CH_4 through enteric methane fermentation. In addition to the GHG emission and global warming issues, release of CH_4 through enteric CH_4 fermentation indirectly causes loss of dietary energy (20–150 kJ/MJ) (Johnson and Johnson 1995). This chapter is an attempt to discuss in detail the various enteric CH_4 reduction strategies in sheep. Efforts have been made to address the role of sheep in contributing to global warming and the various options that are available within the rumen to target for reducing the enteric CH_4 emission in sheep. In addition, emphasis has been given for identifying different strategies and these strategies are explained in detail with appropriate examples which might help sheep industries in reducing CH_4 emission and for optimizing their productivity by preventing the dietary energy loss.

13.2 Consequences of Global Warming

Figure 13.2 depicts the trend in atmospheric CH_4 accumulation. Even with the current global warming rate of 0.8 °C, deleterious impacts are already evident on both global economy and ecology. Arctic Ocean ice masses are already shrunken to half from 1970s level (Stroeve et al. 2007). Simultaneously, volume of ice is also decreasing with thinning of ice sheets (Kwok et al. 2009). An increase in the temperature by 4 °C or more can change the earth system and its natural resources and ecological services. Increase in the frequency of extreme events, rise in sea level and loss of biodiversity are some of the other consequences of global warming. Thermal expansion of ocean and glacier melt water influx are the two largest contributors to the rise in sea level (Rahmstorf et al. 2007). Global sea level is rising very rapidly and has risen by about 20 cm. Scientists also projected a rise of 50–150 cm by the end of 2100 (Rahmstorf et al. 2007). In addition to this, IPCC projected an increase in the frequency of weather events like drought, heat waves, intensified rainfall events, floods and hurricanes (IPCC 2007). Loss of species and genetic diversity is also expected with 2 °C rise in temperature. Adaptive and regenerative capacity of the nature will be destabilized with 20–30% loss of genetic diversity as per IPCC prediction. Further, Mangroves and coral reefs will face detrimental impacts. In addition, the climate change impacts will also be evident on all natural resources such as drinking water and animal genetic resources.

Any perturbations in the normal functioning of the climate system can lead to huge ecological calamities like unexpected cessations of ocean currents, sudden shifts in the monsoonal circulation and destabilization of large glacier masses (Lenton et al. 2008). Even 1.9 °C increase in the temperature can lead to the entire Greenland ice sheet melting and it can further contribute to 7 m rise in sea level (IPCC 2007).

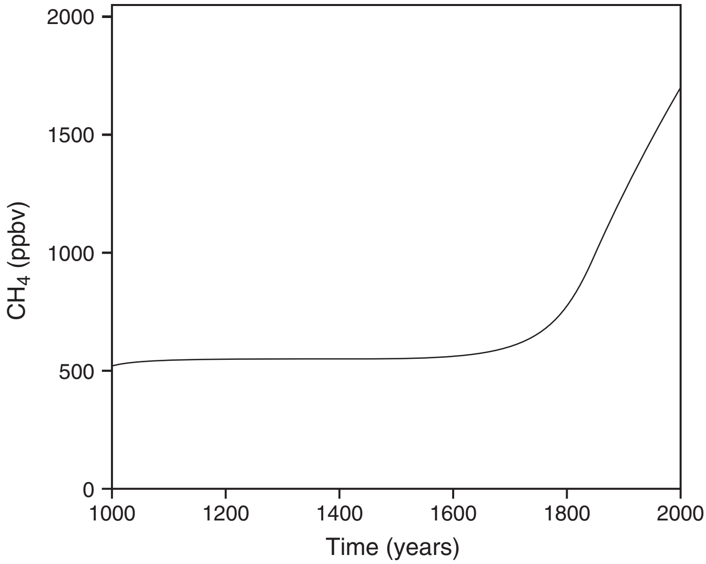

Fig. 13.2 Trends in atmospheric methane accumulation (Khalil and Rasmussen 1986)

13.3 Effect of Climate Change on Livestock

Climate change can have severe impacts on livestock which can be categorized into direct and indirect effects. By far the production losses are primarily incurred through indirect impact. The compromised quantity as well as the quality of feed during summer season might affect the livestock production systems. Climate change can have significant effect on the trade of finished lambs both by altering the lambing time of ewes and by affecting the forage growth pattern during spring season (Rowlinson 2008). Table 13.2 describes the impact of climate change on livestock and its production system.

Table 13.2 Impacts of climate change on livestock and livestock systems

Factor	Impacts
Feeds	*Land use and system change*
	As climate changes and becomes more variable, species niches also change. May modify animal diets and compromise the ability of stallholders to manage feed deficits
	Changes in the primary productivity of crops, forages and rangeland
	Effects depend significantly on location, system and species. But in C4 species, temperature increase up to 30–35 °C may increase productivity of crops, fodders and pastures
	For food-feed crops, harvest indexes will change and so will the quantity of stover and availability of metabolizable energy for dry season feeding
	In the semi-arid rangelands where contractions in the growing season are likely, rangeland productivity will decrease
	Quality of plant material
	Increased temperatures increase lignifications of plant tissues and thus reduce the digestibility and the rates of degradation of plant species. The resultant reduction in livestock production may have an impact on food security and incomes of smallholders
	Interactions between primary productivity and quality of grasslands will demand modifications in grazing systems management to attain production objectives
Biodiversity	In places, warming accelerates the loss of genetic and cultural diversity in agriculture already occurring as a result of globalization, in crops and domestic animals.
	A 2.5 °C increase in global temperature above pre-industrial levels will see major losses; 20–30% of all plant and animal species assessed could be at high risk of extinction (IPCC 2007)
	Ecosystems and species show a wide range of vulnerabilities to climate change
Livestock	Major impacts on vector-borne diseases: expansion of vector populations into cooler areas or into more temperate zones.
	Increases the heat-related mortality and morbidity in livestock

Thornton et al. (2009, 2008)

13.3.1 Direct Effects

Direct effects of climate change on livestock production are caused by alterations in the climatic variables such as temperature, humidity, precipitation and wind speed. Different animals (ruminants and non-ruminants) respond to variations in the ambient temperature differently based on their range of comfort zone. Ruminant animals are blessed with wide range of comfort zone and higher level of temperature tolerance, so narrow fluctuations in the ambient temperature do not have any significant effects in their performance. As per IPCC projections, areas that are currently wet will become wetter and dry regions will become drier in future. So the areas with low temperature and high precipitation will become more suitable for the sheep production because of the higher rate of their survival. At the same time, production performance of dairy cows and buffaloes in the tropical dry regions can be hampered due to increase in ambient temperature. To counter the detrimental effects of elevated ambient temperature, animals should be provided with adequate amount of water and shade. However, unlike the ruminants, non-ruminants possess a very narrow range of comfort zone. This is one of the main reasons for keeping pig and poultry under an intensive system of rearing so that the farmers can effectively manage these animals. During winter season, these houses may serve as source of cold protection to the animals. However, existing housing systems may not be sufficient to counter the detrimental effects of heat stress. Air conditioning/cooler systems should be established in order to cool the animals during summer. In addition, there were issues associated with the transport of live animals during summer season when the environmental temperature is at the peak. Although experts feel that the direct effects of climate change on the animal are likely to be small, still they feel efforts are needed to breed for thermo-tolerance by effectively utilizing the indigenous germplasm (Rowlinson 2008).

13.3.2 Indirect Effects

13.3.2.1 Nutrition and Feeding

Climate change is widely believed to have multiple impacts on the pasture and grazing systems available for the animals (Hopkins and Del Prado 2007); these include:

- The change in CO_2 concentration drastically affecting the herbage growth
- The composition of pastures as well as the ration of grasses and legumes availability are altered
- The alteration in the concentration of water-soluble carbohydrates and N might alter the herbage quality and total dry matter (DM) yields
- The drought condition during summer season might again affect the DM yields
- Increased N leaching as a result of greater intensity of rainfall

It is very unlikely that climate change would bring in any changes in the composition of feed that is offered to sheep. The least cost ration formulation tool offers huge scope for changing the ingredients without altering the specifications of the nutrients that are needed for a particular species. Practices do exists pertaining to including imported ingredients and high quality by-products in the ration formulation. The forage component is a major component of diet in ruminants, and this differs with the rearing system, with the forage making up the entire diet in extensive system of rearing as compared to intensive system where concentrate supplementation forms an equal part of the diet along with forages. Climate change is expected to have negative impact on the source of forages that are available to feed ruminant species, and it was projected that both quality and quantity of forages were found to be compromised. This may play a role in impacting the available forage resources and a lot of changes are expected on the forage species which are yet to be explored. The dry matter production is compromised particularly in the winter season. Therefore, the expected increase in temperature is believed to have benefits for early seasonal growth in mixed pasture. Further, the increased rainfall in certain areas can increase the soil moisture deficits, which may again affect the dry matter yield, and this warrants additional irrigation to restore the appropriate growth of pasture. The altered climate may affect the stage of maturity of crop before harvesting, and this can affect both the quality and the quantity of existing species. Again, improving the microclimate might help to reverse this condition. However, in hilly areas which are characterized by low temperature, climate change is expected to increase the pasture production and this might have a positive impact on animal production.

In a few regions, climate change may lead to shifting in the forage species by increasing the hectare of grown crop, which might help to meet the requirement in other regions during scarcity period. However, in arid and semi-arid regions in certain instances the palatable species might be replaced by non-palatable species, resulting in lower edible biomass for the animals.

13.4 Methane Mitigation in Sheep

Enteric CH_4 mitigation from sheep could have double benefit of preventing the global warming as well as preventing the dietary energy loss. There are various approaches by which reduction in enteric CH_4 emission is targeted: inducing changes in metabolic pathways, altering the rumen microbial population and improving the diet digestibility potential.

During the digestion process in the anaerobic condition in rumen, hydrogen is released in the process of generation of energy in the form of ATP. Free hydrogen that is liberated during the process of digestion must therefore be removed; otherwise, it inhibits dehydrogenases and affects fermentation process. The type of diet and the type of rumen microbes decide the amount of hydrogen produced in the rumen. The type of VFAs that are produced in the rumen determines the quantum of free hydrogen remaining in the rumen. For example, production of propionate consumes hydrogen molecule, while production of acetate and butyrate releases hydrogen molecules. Therefore, targeting propionate to be the end product of digestion could serve as alternate hydrogen sink in the rumen. Further, the process of

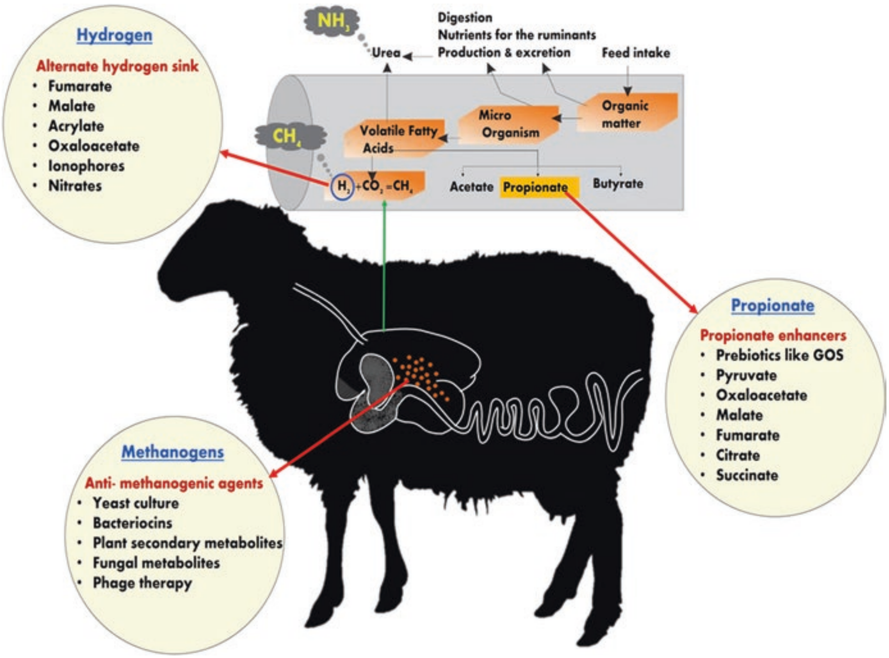

Fig. 13.3 Different mechanisms of enteric methane reduction in sheep

methanogenesis also utilizes hydrogen to form CH_4. The formation of CH_4 from hydrogen and CO_2 is brought about by methanogenic archaea. Figure 13.3 describes the different mechanisms by which enteric CH_4 can be reduced in sheep.

There are three pathways by which enteric CH_4 reduction could be achieved: (1) provision of hydrogen sink; (2) supplementing with anti-methanogenic agents and (3) supplementing with propionate enhancers. Care should be taken that reduction of hydrogen production should be achieved without affecting the fermentation process. Therefore, reducing methanogenic population should be targeted with concomitant stimulation of pathways that consume hydrogen to prevent the negative effects associated with increased partial pressure of this gas. Figure 13.4 describes the different CH_4 mitigation strategies in sheep.

13.4.1 Mitigation Through Feeding

13.4.1.1 Increased Proportion of Concentrates in the Diet of the Animal

Alteration of ruminal pH with intent to modify ruminal microbial population has been widely practised to reduce enteric CH_4 emission. One such attempt is to replace plant fibre with starch, thereby decreasing the ruminal pH to alter the microbial population. The protozoa and cellulolytic bacteria do not tolerate low pH, thereby

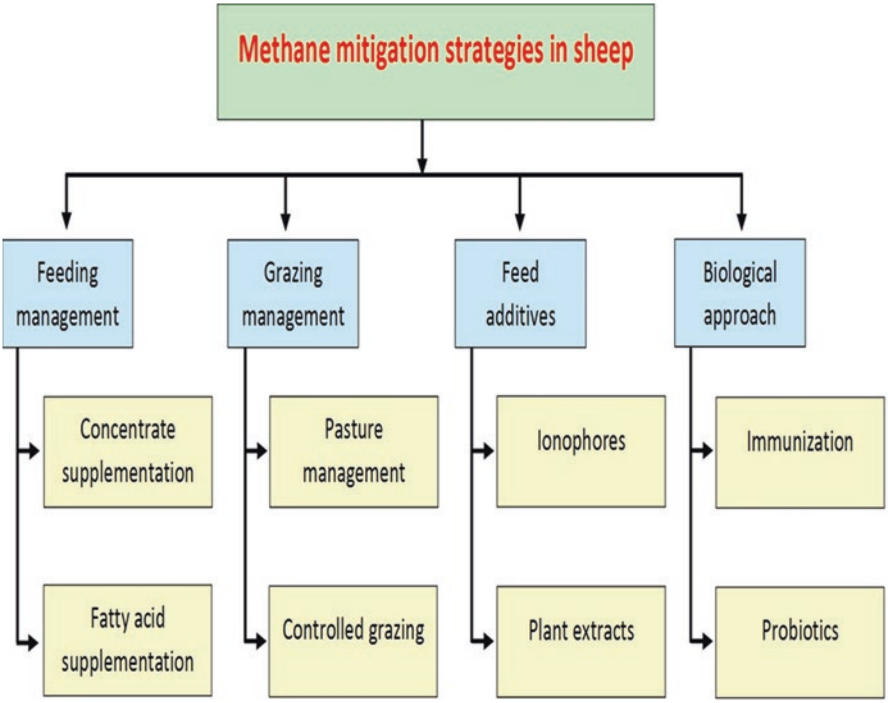

Fig. 13.4 Different methane mitigation strategies in sheep

leading to lower production of H_2. With the exception of buffalo, a strong positive correlation has been established in different animal species between ruminal pH and mocrobial population (Morvan et al. 1996). This particular exemption in buffalo could be attributed to the presence of non-H_2-producing cellulolytic bacteria *F. succinogenes*. Generally a curvilinear relationship has been established between the levels of concentrate in the diet. The concentrate supplementation brings about CH_4 reduction by altering the VFA production (Bhatta et al. 2005). It has been established that increased concentrate supplementation leads to more propionate production, thereby reducing the enteric CH_4 emission as propionate acts as alternate H_2 sink (Sauvant and Giger-Reverdin 2007). Further, the level of dietary starch is also correlated with CH_4 production during concentrate supplementation. Generally the diet containing starch content of 40% and above decreases CH_4 production by over 56% (Martin et al. 2007). However, the level of concentrate should be balanced as over-supplementation leads to acidosis in the rumen. This drawback of acidosis could be reversed through dietary fat supplementation to depress ruminal methanogenesis without reducing the ruminal pH. Generally, medium-chained fatty acids were found to be more effective in altering the methanogen population as compared to long-chain fatty acids (Machmuller et al. 2003). Poly unsaturated fatty acids (PUFA) can also depress CH_4 production by eliciting toxic effect to the cellulolytic bacteria and protozoa (Nagaraja et al. 1997; Doreau and Ferlay 1995). This toxic effect of PUFA could be attributed to its action on the cell membrane of gram-positive bacteria. Further, it has been established that linolenic acid has toxic effect on the bacteria. All these changes in the microbial population shift the ruminal fermentation towards propionate production, thereby leading to more utilization of H_2. The limitation of fat supplementation is that the microbial population may tend to adapt to fat supplementation in a long run. This warrants future research efforts in exploring fatty-acid-supplementation-oriented enteric CH_4 reduction without allowing microbes to adapt for such supplementation (Grainger et al. 2008).

13.4.2 Grazing Management Practices

13.4.2.1 Pasture Management

Improved pasture management is often considered as a reliable option for reducing enteric CH_4 emission. Quality pasture can reduce emission either through improving the animal productivity or by reducing the proportion of energy lost. There is evidence showing reduced CH_4 emission per unit of quality pasture consumed in temperate region as compared to tropical region (Molano and Clark 2008). However, there are also reports suggesting no impact of pasture quality on CH_4 reduction potent. These results suggest that well-managed pastures do not invariably lead to CH_4 reduction but it could curb lifetime CH_4 emission or emission per kilogram of product. Increased stocking densities as a result of improved pastures could increase emission rate per hectare. In a study conducted on an Australian sheep farm, Alcock and Hegarty (2006) reported a very low level of CH_4 reduction on body weight basis. The reason for the less reduction of CH_4 in their study could be attributed to the high productivity of sheep on individual basis in their farm. However, Lovett et al. (2006a, b) reported the influence of soil types, with higher milk yield and lower GHG emission per kilogram of milk produced when dairy cows grazed in the drier soils.

13.4.2.2 Controlled Grazing

Implementing controlled grazing system is considered as one of the best ways to improve the sheep productivity. This approach could yield higher proportion of quality forage as compared to conventional grazing practices. The latest developments pertaining to new fencing and watering technologies offer huge scopes for the farmers and entrepreneurs to develop their grazing systems. The uninterrupted use of grazing land by sheep throughout the grazing season can be achieved through management practices of continuous stocking. Such system most often fails to maximize the productive potential of the land, leading to forage wastage, less pasture productivity and lower weight gain per unit of land. Rather, controlled grazing is considered to be a better management strategy to produce a more productive grazing system. In this grazing system the grazing land is subdivided into individual grazing units called paddocks, which are alternatively grazed and rested throughout the grazing system. Pasture productivity, stocking density and the desired residency period of the sheep are the factors which will determine the size and number of paddocks. Therefore the controlled grazing system is better placed than the conventional grazing system to maintain an effective balance between forage demand and supply. As a result, controlled grazing system has several advantages such as promoting higher forage yield, uniform level of forage quality and improved harvest efficiencies. These advantages make controlled grazing system more effective in producing more productive sheep with greater body weight gain per acre, thereby improving the economy of sheep farms while reducing the rate of CH_4 emission per kilogram body weight gain. Further, controlled grazing system has another notable advantage of acting as a natural sink for CO_2. The improved pasture quality in the controlled grazing can build up the carbon in the soil and plant biomass, leading to reduced CO_2 emission to the atmosphere. However, in semi-arid region where the growing of the vegetation takes place from July–September and withers off in October–November, this practice has no relevance. Similarly, when the majority of the sheep are reared under an extensive system of rearing and there is migration during acute summer, this option is not feasible.

13.4.3 Mitigation Through Feed Additives

13.4.3.1 Ionophores and Organic Acids

Monensin, the common ionophore antibiotics used to improve the animal production efficiency, is considered as one of the best feed additives which has the properties to reduce enteric CH_4 emission (Beauchemin et al. 2008). This reduction in CH_4 emission by monensin is brought about by shifting the fermentation pattern towards propionogenesis. Further, organic acids such as malate and fumarate are other feed additives that could help to reduce enteric CH_4 emission in sheep. Wallace et al. (2006) reported an exceptional CH_4 reduction percentage of around 75 on supplementing 10% encapsulated fumeric acid in sheep diet. Further, Martin et al. (1999) reported that malate content of fresh forages such as lucerne can lead to enteric CH_4 reduction by changing the rumen fermentation pattern. Similar results were also reported by Bhatta et al. (2008) in sheep.

13.4.3.2 Plant Extracts

The use of plant secondary metabolites such as tannins, saponins and essential oils to reduce enteric CH_4 emission is gaining importance in recent years as these metabolites are of natural origin as compared to chemical additives (Bhatta et al. 2002, 2006). The mechanism of CH_4 reduction using tannin supplementation is brought about by two pathways recently: direct anti-methanogenic effect and indirect pathway of less hydrogen production through reduced feed degradation. Bhatta et al. (2009a) observed direct reduction in methanogenesis by tannin supplementation by two ways: directly by reducing the number of archaea and indirectly by reducing the number of protozoa. The source containing both condensed and hydrolysable tannins is more effective in suppressing CH_4 emission as compared to those containing only hydrolysable tannins. This was further confirmed by feeding trials in goats kept in an open circuit respiration chamber. It was observed that at lower level of tannin (2.5%), CH_4 suppression was primarily due to the reduction in the number of archaea/protozoa, whereas at higher levels of tannin (5.0%), increased CH_4 suppression was due to the combined effect of reduced archaea coupled with reduction in digestibility of nutrients (Bhatta et al. 2009a, b). The inhibitory effect of saponins on CH_4 reduction could be attributed to its anti-protozoal effect (Newbold et al. 1987). However, further research efforts are needed to identify the exact dose of plant extract supplementation which could prevent rumen microbial adaptation to avoid the presence of residues of such additives in animal products and to nullify anti-nutritional side effects of such supplementation.

13.4.4 Mitigation Through Biotechnologies

13.4.4.1 Immunization and Biological Control

The latest biotechnological tools are currently being explored for finding solution through sheep-mediated climate change. However, substantial progress has not been made in this aspect primarily due to multiple factors influencing enteric CH_4 production. In a study carried out in Australian sheep, a vaccine against three methanogens was developed, through which a decrease in CH_4 production by 8% was reported. However, such a vaccine was found to be ineffective against other methanogens (Wright et al. 2004). Further, the diversified microbial population depending on the feeding conditions may also contribute for this vaccine failure. There are also reports which identified the role of bacteriocins for enteric CH_4 reduction. Nisin is one such bacteriocin which was predicted to have CH_4 reduction potential in animals by mimicking the role of ionophore monensin (Callaway et al. 1997). However, there are no published reports on the effects of nisin for enteric CH_4 reduction under in vivo condition. Bovicin HC5 is a type of bacteriocin produced from rumen bacteria and is used for reducing the CH_4 production up to 50% under in vitro condition preventing adaptation of methanogens.

13.4.4.2 Probiotics

Another interesting approach for reducing enteric CH_4 emission is achieved through probiotics supplementation. There are also efforts to deviate H_2 from methanogenesis to acetogenesis pathway since the final end product acetate of this pathway can act as additional source of energy for the animals. However, acetogens were found to be less efficient than methanogens in the competition for reducing equivalents in the rumen further, and several attempts to boost their activity were found to be unsuccessful. There are also attempts to isolate new H_2-utilizing species which may be considered as a better alternative than already tested acetogens (Klieve and Joblin 2007).

13.5 Can Genetic Improvement of Sheep Reduce Methane Emission?

Increasing the level of production in the sheep through the identification and enhanced modification of heritable traits could help to decrease the overall CH_4 emission. Improving the feed conversion efficiency could help to reduce enteric CH_4 emission by increasing the animal productivity and this is the typical example of how a heritable trait could be used to minimize CH_4 emission in sheep. There are also strategies combining improved genetics with good management practices to increase the reproductive efficiency. Increased lambing rates and weaning weights through such attempts could curb CH_4 emission per unit of product. This is because the increased reproductive efficiency reduces the size of the flock to produce the desired number of lambs as the consumer demand can be met through fewer but efficient sheep. More emphasis should be given to conduct research pertaining to genetic improvement in an attempt to increase the overall productivity of sheep and at the same time reduce the enteric CH_4 emission.

13.6 Is There Any Animal Variation in Methane Production?

There are ongoing debates around the world pertaining to decreasing emission through low-CH_4-producing animals. Very high variability for CH_4 production have been established within the animal and ranking of animals based on CH_4 production potential may differ with diet composition and physiological status of the animals or between two successive measurements of same diet and feed intake (Pinares-Patino et al. 2007a; Munger and Kreuzer 2008). These authors have established repeatability between 47 and 73% based on the type of diet used for the animals, and this repeatability could be attributed either to the animal differences in microbial ecosystems or to intrinsic animal characteristics suc as retention time in the rumen. This is because animals with low retention time might produce less CH_4 in the rumen (Pinares-Patino et al. 2007a, b). However, there are no much research reports available to assess the heritability of CH_4 production and to apply such trait for genetic selection. In a study, Hegarty et al. (2007) established that selection of animals based on feed conversion efficiency residual feed intake could reduce CH_4 production.

13.7 Conclusion

There are several strategies available for enteric CH_4 mitigation. Currently, feeding management strategies are widely used to reduce CH_4 emission in sheep. There are also promising advanced biotechnological strategies available in sheep but their applications in the field condition are limited because of the wide variation in the diet composition and wider diversity in rumen microbial population. Strategies pertaining to improving the production efficiency of sheep might yield better results in terms of reducing the enteric CH_4 emission in sheep.

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Measurement of Severity of Heat Stress in Sheep

14

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Abstract

Animals show optimum growth, health, and productivity within a range of environmental temperatures. Exposure of the sheep to higher temperature leads to heat stress, which negatively affects their well-being and productivity. In addition to ambient temperature (AT), other climatic factors like humidity (RH), wind speed (WS), and solar radiation (SR) also influence the degree of heat stress in sheep. Further, climate change caused a higher rate of temperature increase in the tropical region. Hence, there is an urgent necessity to develop a simple, reliable,

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and easy method to assess the degree of heat stress in sheep particularly during summer. In the mid-twentieth century, temperature-humidity index (THI) was introduced to evaluate the severity of summer stress and was extended to dairy animals as a tool to explain the welfare of the animals. Moreover, several THI equations were developed by various scientists based on prevailing AT and RH. However, the main drawback of the THI was that it did not account for other weather parameters like WS and SR, even though they also equally influenced the level of heat stress in animals. Research efforts pertain to establishing a suitable thermal index by incorporating all cardinal weather parameters. With this background, heat load index (HLI) was developed as an alternative to THI relating RH, WS, and black-globe temperature (accounts both AT and SR). The few other modern indices available to assess the severity of heat stress in sheep are black-globe temperature-humidity index (BGTHI), thermal comfort index (TCI), and global comprehension index (GCI). In addition to weather indices, some physiological indices are also used to assess heat stress in sheep. Physiological responses like rectal temperature and respiration rate are considered as good indicators of heat stress in sheep. Moreover, strong correlations between blood parameters like hemoglobin, packed cell volume, and endocrine parameters such as cortisol and thyroid hormones production are well established in sheep. Further, genomics and proteomics tools are providing advanced options to evaluate the adaptation processes of sheep. Some of the genes identified in sheep during heat stress are heat shock protein, heat shock factor-1, thyroid hormone receptor, and prolactin receptor genes. Besides, the identified thermo-tolerant genes could be used as an ideal marker for assessing the level of heat stress and may be further utilized for marker-assisted selection breeding programs to develop superior thermo-tolerant breeds.

Keywords
Climate change • Heat load index • Heat stress • Solar radiation • Temperature-humidity index • Thermo-tolerant genes • Wind speed

Contents

14.1 Introduction

Thermo-neutral zone is a narrow range of ambient environmental temperatures that are favorable for normal production and well-being. The upper critical temperature is the point at which heat stress begins to affect the animal adversely. There are a number of climatic factors like temperature, relative humidity (RH), wind speed (WS), and solar radiation (SR) that influence the degree of heat stress in animals. In order to characterize and quantify thermal comfort zones, several thermal comfort indices were developed for different species. Currently, the primary focus for livestock and poultry industry has been on developing new heat-stress indices for risk assessment associated with stress response and performance (Eigenberg et al. 2005; Baccari 2001). These efforts may provide suitable inputs and thus an empirical relationship can be developed termed as "biological response function." Such developed thermal indices might help in quantifying the biological responses of livestock to heat-stress challenges. Further, such indices might help to assess the magnitude of impact of heat stress on the productive functions of livestock. Thus, the heat-stress indices might serve as useful surrogates for establishing the complex interactions between the physical and biological components associated with the livestock response mechanisms to stressful environment (Hahn et al. 2003).

Stressful climatic conditions may serve as a limiting factor in the tropics as there are evidences of extended episodes of high temperature and humidity. The sheep is well adapted to overcome the consequences of elevated ambient temperatures (ATs) by modulating its various physiological responses. The higher heat tolerance of sheep could be attributed to their high insulating fleece that prevent free air movement apart from resisting the inward convection of heat due to solar radiation (Mount 1979). Sheep depend on both panting and sweating mechanisms for effectively dissipating the body heat when subjected to adverse environmental condition. The cover of wool limits the efficiency of sweating in the nonsheared sheep.

At increased ambient temperatures above 36 °C, the ears and legs serve as a major channel for heat dissipation. If the physiological mechanisms are not sufficient to dissipate excess body heat, the rectal temperature rises substantially, which is often accompanied by events of biological and behavioral changes (Marai et al. 2007). The thermal stress is well known to negatively affect the efficiency of the production, reproduction system, and health. Any attempt to alter the internal microclimate closer to the boundaries of the thermal neutral zone (TNZ) will surely aid in minimizing the impact of extreme environmental conditions. Hence, it turns out to be an important affair to evaluate the thermal environment more precisely so as to assess the stress profile of an animal subjected to specific period and locus. Further, in a similar focus certain indices are designed and proposed by a few researchers describing the comfort of the animals. These indices comprise various climatic variables to arrive at a unique value and hence on a conclusive remark of whether the animal is stressed or not. Based on the implications of different inputs these indices have their own applicability.

There are several indices used to calculate thermal comfort. Moreover, a single index cannot be figured as optimal and used widely, because there are different climatic, animal, and management factors that need to be taken into account (Gaughan et al. 2008). And some of the indices are specific to some species or breed and hence cannot be replicated as such until well tried, tested, and compared. Therefore, this chapter aims to compile information on different thermal indices that are used for assessing the severity of heat stress in sheep. Further, efforts have also been made to highlight both phenotypic and genotypic indicators for heat stress in sheep.

14.2 Significance of Temperature-Humidity Index

During the twentieth century, there was a necessity to evaluate the effect of heat stress on animal productivity by a simple, reliable, and easy method to quantify the level of heat stress. Consequently, the measurement involving ambient temperature and relative humidity (RH) was developed—temperature-humidity index (THI)—to reveal the degree of stress and to establish its influence on animal production (Bianca 1962; NRC 1971). In the middle of the twentieth century, THI came into existence for the human beings to evaluate the discomfort during summer using the index developed by Thom (1958). In continuation, it was extended to dairy animals, which has become a reliable tool in animal biometeorology (Johnson et al. 1961; Hahn et al. 2003). Further, many computational methods were developed to establish an accurate tool encompassing all the major environmental factors except for environmental temperature and relative humidity. The THI formulas varies according to the authors who defined them based on the weightage given to dry bulb temperature (Tdb), moisture content of air, solar radiation, wind speed etc. (Kelly and Bond 1971; NOAA 1976; LPHSI 1990; Finocchiaro et al. 2005; Mader et al. 2006). However, few used wet bulb temperature (Twb), which represents the equilibrium of temperature (Thom 1959; Bianca 1962; NRC 1971), or dew point temperature (Tdp), which represents the temperature at which RH is 100% (NRC 1971; Yousef 1985). Thermo-neutral zone and heat tolerance threshold level vary in sheep between 5 and 25 °C, depending upon the breeds and climatic regions (Curtis 1983). Finocchiaro et al. (2005) established that heat stress affects Mediterranean dairy sheep production at THI $\geq$ 23, whereas Sevi et al. (2001) reported that the heat stress affects Comisana dairy sheep when THI $\geq$ 27.

There are few THI indices solely based on dry bulb temperature (Tdb), wet bulb temperature (Twb), dew point temperature (Tdp), and relative humidity (RH). Table 14.1 describes the various thermal indices to quantify heat-stress response in sheep. In tropical regions, high ambient temperature was considered to be the limiting factor for sheep production (Shelton 2000). The high ambient temperature with an elevated relative humidity further augments the severity of heat stress (Marai et al. 2000; Marai et al. 2001; Marai et al. 2007). For THI index when measured in Fahrenheit (°F), the equation is as follows (LPHSI 1990): THI = db°F − {(0.55–0.55 RH) (db °F − 58)}, where db °F is the dry bulb temperature in °F and RH is the relative humidity (%)/100, for sheep. THI values below 82 indicate an absence of heat stress, values between 82 and 84 indicate moderate heat stress, values between 84 and 86 indicate severe heat stress, and values over 86 indicate extremely severe heat stress (LPHSI 1990). However, if the ambient temperature is expressed in °C, the equation of THI may be used as per Marai et al. (2001): THI = db °C − {(0.31 − 0.31 RH) (db °C − 14.4)}, where db °C is the dry bulb temperature (°C) and RH is the relative humidity (%)/100. The specified THI value of less than 22.2 is considered absence of heat stress, values between 22.2 and 23.3 are called as moderate heat stress, values between 23.3 and 25.6 are considered severe heat stress, and values 25.6 and below are considered extreme severe heat stress (Marai et al. 2001). Another equation was proposed to estimate the level of heat stress in dairy sheep in the Mediterranean region: THI = dbT °C − {(0.55 − 0.55 RH) × (dbT

Table 14.1 The commonly used thermal stress indices to quantify heat stress in sheep

Sheep THI	Sheep breed	References
THI = [0.4 × (Tdb °C + Twb °C)] × 1.8 + 32 + 15	Most animals, including sheep	Thom (1959)
THI = (0.35 × Tdb °C + 0.65 × Twb °C) × 1.8 + 32 and THI = (0.15 × Tdb °C + 0.85 × Twb °C) × 1.8 + 32	Most animals, including sheep	Bianca (1962)
THI = Tdb °C + (0.36 × Tdp °C) + 41.2	Most animals, including sheep	Kibler (1964) and Yousef (1985)
THI = AT − 0.55 × (1 − RH) × (AT − 58)	Sheep	Kelly and Bond (1971)
THI = (Tdb °C + Twb °C) × 0.72 + 40.6	Most animals, including sheep	
THI = (0.55 × Tdb °C + 0.2 × Tdp °C)*1.8 + 32 + 17.5	Most animals, including sheep	NRC (1971)
THI = 0.72 (W °C + D °C) + 40.6, The THI values of 70 or less = comfortable, 75–78 = stressful, and values above 78 = extreme distress and animals may not able to sustain the normal core body temperature	Sheep	McDowell et al. (1976)
BGTHI = BGT + (0.36 × DPT) + 41	Sheep	Buffington et al. (1981)
TCI = (0.6678 × *AT*) + (0.4969 × *PVP*) + (0.5444 × *BGT*) + (0.1038 × *WS*)	Sheep	Barbosa and Silva (1995)
THI =db °C − {(0.31−0.0031 × RH) (db °C −14.4)}	Indigenous sheep	Marai et al. (2001) and Rana et al. (2014)
THI = dry bulb (°C) −0.55 (1 – relative humidity) × (dry bulb − 14.4)	Omani and Australian Merino sheep	Srikandakumar et al. (2003)
THI = Tdb °C − [0.55 × (1 − RH)] × (Tdb °C − 14.4)	All Animals	Finocchiaro et al. (2005)
THI = 9/5 × ((T × 17.778)−(0.55−(0.55 × RH/100)) × (T−14.444))	Ossimi sheep	Abdel Khalek (2007)
THI =T − (0.31−0.0031 × RH T) × (T − 14.4), indicates the following: <22.2 = absence of heat stress; 22.2 to <23.3 = moderate heat stress; 23.3 to <25.6 = severe heat stress; and 25.6 and more = extreme severe heat stress	Most breeds of sheep in semi-arid tropical environment	Marai et al. (2007)
THI = td − (0.55−0.55RH) × (td − 58)	Assaf sheep	Leibovich et al. (2011)
THI = Td − {(0.31−0.31 × RH) (Td − 14.4)}	Najdi sheep	Al-Haidary et al. (2012)
Temperature and humidity index were calculated using the following equation: THI = [0.8 × ambient temperature (°C)] + [(% relative humidity/100) × (ambient temperature – 14.4)] + 46.4	Afshari lambs	Mahjoubi et al. (2014)

(continued)

Table 14.1 (continued)

Sheep THI	Sheep breed	References
THI = Ta + (0.36 × To) + 41.5	Most breeds of sheep	McManus et al. (2014)
THI = 0.81 db °C + RH (db °C − 14.4) + 46.4	Merino sheep	Wojtas et al. (2014) and Mader et al. (2006)
THI = Ta + 0.36Tdp + 41.5	Santa Ines sheep	Chagas et al. (2015)

THI – Temperature Humidity Index; Tdb – dry bulb temperature; Twb – wet bulb temperature; Tdp – dew point temperature; AT – air temperature; RH – air relative humidity; BGT – black-globe temperature; PVP – partial vapor pressure; WS - wind speed (ms^{-1}); °C – Degree Centigrade; °F – Degree Fahrenheit; DPT – dew point temperature

°C − 14.4)}, where dbT is the average dry bulb temperature in °C and RH is the relative humidity in percentage (Finocchiaro et al. 2005; Saab et al. 2011).

Thom (1959) developed another THI index based on the ambient temperature (Ta) and RH as follows: THI = 9/5 × [(T × 17.778) − (0.55 − (0.55 × RH/100) × (T − 14.444)]; a value of THI < 72 indicates thermo-neutral conditions during winter and a THI value between 76 and78.5 represents mild-to-moderate heat stress in summer season. The heat stress in sheep can also be estimated through another THI using the following formula: THI = (Dry Bulb Temperature °C) + (0.36 Dew Point Temperature °C) + 41.2). In this case, a THI exceeding 72 indicates mild stress, 80 indicates medium stress, and above 90 indicates severe heat stress (Pennington and Van Devender 2004). Hahn and Mader (1997) proposed another new THI to represent a certain level of heat-stress thresholds to provide a measure of the magnitude of daily heat load (intensity and duration) on dairy cows which can be applied in sheep (Papanastasiou et al. 2014) as follows: $\text{Daily}\, THI - hrs = \sum_{i=1}^{24} THI - \text{base}$, hrs = 1…24, where THI is the hourly temperature-humidity index and is based on certain heat-stress threshold. Further, based on the daily THI-hrs, Panagakis and Chronopoulou (2010) introduced a seasonal THI to evaluate the heat-stress burden in dairy sheep as follows: $\text{Seasonal THI} - \text{hrs} = \sum \text{Daily THI} - \text{Hrs}$. Panagakis and Chronopoulou (2010) found that heat stress in dairy sheep at noon by an increase in the daily THI-hrs culminates in higher respiration rate in the heat-stressed animals.

14.3 Limitations of Temperature-Humidity Index

The THI is currently being used in assessing the severity of heat stress both in human beings and in livestock. However, THI has two important drawbacks, of not taking into account the solar radiation (SR) and wind speed (WS). In the changing climate scenario, all the cardinal weather parameters are altered and these parameters influence the production performance of livestock. Hence to call THI as an appropriate quantification of stress response in sheep, all the cardinal weather parameters must be taken into account. This warrants the development of much more appropriate indices which can take into account all the cardinal weather parameters. Apart from temperature and humidity, solar radiation and wind speed are also equally important weather parameters which can influence significantly the stress response in animals. Hence, further research efforts are needed in this line.

14.4 Advanced Indices to Quantify Stress Response in Livestock

Research efforts pertaining to developing a weather index incorporating all four cardinal weather parameters are very scanty. However, the few available reports clearly suggest the advantage of these efforts over the THI. Various adjustments to the THI have been proposed to overcome the shortcomings related to the lack of inclusion of WS and SR in the equation. To overcome these drawbacks of traditional THI, Buffington et al. (1981) used black-globe temperature (BGT) instead of dry-bulb temperature in their equation. Applications of the black-globe temperature-humidity index (BGTHI) to dairy cows suggested that values of 70 or below had little impact, while values of 75 or higher markedly reduced feed intake. On the basis of the impact on panting score in feedlot cattle, THI equation was redefined by Mader and Davis (2002) and Eigenberg et al. (2005) as follows:

$$THI_{adj} = 4.51 + THI - 1.992\,WS + 0.0068\,SR$$

where

WS = Wind speed, m/s
SR = Solar radiation, W/m^2

Recently, Gaughan et al. (2008) developed a heat load index (HLI) based on the behavioral responses and changes in dry matter intake of feedlot cattle summer season (Gaughan et al. 2008). The HLI is based on RH (%), WS (m/s), and black-globe temperature (BGT, °C). In case the BGT cannot be measured, it can be computed directly from the air temperature and solar radiation. The HLI consists of two parts based on a black-globe temperature threshold of 25 °C:

$$HLI_{BGT<25} = 10.66 + 0.28\ RH + 1.3\ BGT - WS$$

$$HLI_{BGT>25} = 8.62 + 0.38\ RH + 1.55\ BGT - 0.5\ WS + \mathrm{e}^{(2.4 - WS)}$$

where

e is the base of the natural logarithm.

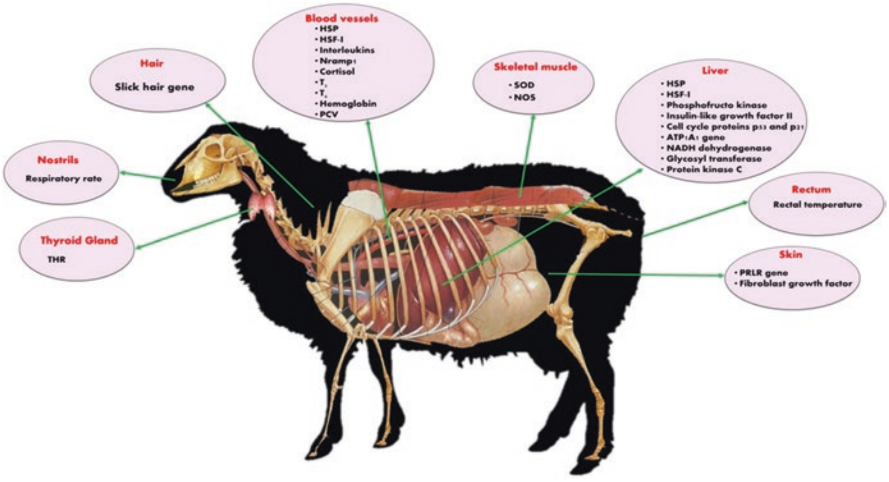
The thresholds are used to calculate the accumulated heat load (AHL) to which the animals are exposed. The AHL is based on the THI-hours concept of Hahn and Mader (1997). When an animal is exposed to an HLI above its threshold, then its core body temperature increases. The longer the duration of exposure to an HLI above the threshold, the greater is the stress and the AHL. The AHL also accounts for any potential recovery during nighttime cooling. It gives an indication of the total heat load on the animal, and is a better indicator of heat stress than a spot measure of HLI. This HLI is also applicable for assessing heat stress in sheep.

Critical levels of comfort indexes need to be established for all species of domestic animals, including sheep. The estimation of critical values of TCI would allow the realization of a bioclimatic zoning for sheep production in Pernambuco, as demonstrated by Barbosa and Silva (1995). These critical values can be generalized to the region where the study was carried out, except for the specific microclimates of some sites that may be more advantageous or more adverse, although it is in a certain zone, as reported by Barbosa et al. (2001).

14.5 Physiological Indicators of Heat Stress in Sheep

During heat stress, the primary physiological responses are accelerated, of which the foremost affected are respiratory movements. The respiratory rate is a good indicator of heat stress, and the normal range of RR in sheep is between 25 and 30 breaths per minute at thermo-neutral condition (Sejian et al. 2010a; Indu et al. 2014). The increase in respiratory frequency above 40 breaths per minute, denoted as panting, facilitates the heat loss by exhaling water vapor in the breath (Wojtas et al. 2014). Hence, the respiration rate can be used for assessing the level of heat stress based on the scale proposed by Silanikove (2000) and McManus et al. (2015) as follows: fewer than 40 movements per minute indicates absence of stress; 40–60 movements per minute indicates low stress; 61–80 movement per minute indicates medium to high stress; 81–120 movements per minute indicates high stress; 121–192 movements per minute indicates very high stress, and more than 193 movements per minute indicates severe stress. Therefore, heat stress in animals can be determined by respiratory frequency, and this can serve as an easy method as it does not involve sophisticated tools (Wojtas et al. 2014). Further, rectal temperature may also serve as an appropriate indicator of heat stress in sheep (Sejian et al. 2016). Generally, the increased body temperature due to prolonged exposure to summer stress will generally reflect in the increased rectal temperature, and it has been established that the rectal temperature can serve as a representative of body temperature in several livestock species. Hence, the increased rectal temperature can reflect the stress level in sheep (Indu et al. 2015). Figure 14.1 describes the various indicators for heat stress in sheep.

There are several blood parameters which can help to reflect the stress level in sheep. These variables are hemoglobin (Hb), packed cell volume (PCV), cortisol, thyroxin, and triiodothyronine (Sejian et al. 2013a, b). The Hb and PCV have been



THR- Thyroid hormone receptor, HSP- Heat shock protein, HSF-1- Heat shock factor 1, Nramp 1- Natural resistance associated macrophage protein 1, PCV- Packed cell volume, SOD- Superoxide dismutase, NOS- Nitric Oxide Synthase, T_3- Triiodothyronine, T_4- Thyroxin, PRLR gene- Prolactin receptor gene

Fig. 14.1 Different indicators for heat stress in sheep

established to have a strong positive correlation for heat tolerance in Brazilian sheep (McManus et al. 2009). During severe dehydration, both Hb and PCV increased in heat-stressed sheep. The increased cortisol level was correlated with the stress level in domestic ruminants, including sheep. Further, environmental temperature was established as one of the major regulators of thyroid gland activity (Rasooli et al. 2004; Sejian et al. 2010b). Heat stress suppresses the thyroid gland activity, resulting in lowering of thyroid hormone levels (Rasooli et al. 2004; Saber et al. 2009; Sejian et al. 2014).

The advancement of molecular technologies, such as genomics and proteomics tools, is providing promising results to understand the hidden intricacies of the adaptation process of sheep to environmental stresses. These tools are providing valuable information about the various genes that are associated with thermo-tolerance in sheep, and this information may pave the way for identification of animals that are genetically superior for coping with stress in near future. Such identified genes can be the ideal indicators for quantifying the heat-stress response in sheep. These advanced tools enable us to improve the accuracy and the efficiency of selection for heat tolerance.

14.6 Conclusion

Abnormal increase in cardinal weather parameters due to climate change causes severe heat stress in sheep particularly during summer. Apart from temperature and humidity, other cardinal weather parameters like solar radiation and wind speed also influence the severity of heat stress in sheep. Modern weather indices account for the degree of heat stress in sheep more accurately compared to regular temperature-humidity indices. Further, physiological indicators like respiration rate, rectal temperature, Hb, PCV, cortisol, T_3, T_4, HSPs, and other thermo-tolerant genes may also be used in assessing the heat in sheep. Although sufficient efforts have been made toward assessing the heat stress severity in sheep, still further research efforts are needed to develop an agroecological-zone-specific index for the accurate quantification of heat stress in sheep.

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Biological Markers for Climate Change: Impact in Sheep

15

Russell E. Lyons

Abstract

This chapter is intended to provide an overview of previous studies into heat stress and markers that are associated with thermo-tolerance in sheep, as well as other ruminant species that may be considered models for biological processes in sheep. The chapter is divided into two major parts. The first part examines the roles of well-documented heat stress-related biological markers such as heat shock proteins and genes associated with favourable phenotypes such as coat colour and texture. The second part looks at research using methodologies such as microarray, transcriptomics and genomics that have been employed for the identification of novel genes or markers associated with traits of interest. Finally, the chapter concludes with a summary of the observed and expected impacts that climate change will have upon disease. Advances in our understanding of the physiological and biochemical challenges associated with heat stress in sheep and other ruminants, and utilizing this information to deliver increased thermo-tolerance, will be critical to the continued productivity of dairy, meat and fibre sectors in livestock globally.

Keywords

Biological markers • Genomics • Heat stress • Sheep • Thermo-tolerant genes

Contents

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15.1 Introduction

The adverse consequences of heat stress on livestock production under both extensive and intensive management systems are now well understood. There are numerous publications discussing the effects of heat on a range of physiological processes in ruminants, most especially in Holstein-Friesian dairy production systems. A number of different haematological, physiological and behavioural traits and indicators are used to evaluate physiological adaptation to heat stress, including respiratory frequency, heart rate, ruminal movement frequency, rectal and body surface temperatures and the sweating rate (Mader et al. 2010; Gaughan et al. 2013; Dunshea et al. 2013). There are fewer but still substantial studies in smaller ruminants, including goats and sheep (Marai et al. 2007; Romero et al. 2013; Salama et al. 2014).

However, there remain large gaps in the understanding of these processes and most particularly in the identification of robust and reproducible informative markers of heat tolerance in all ruminant species. Identification of such markers is required for accelerated genetic gains in thermo-tolerant traits and associated productivity in these animals. The diversity of sheep breeds, and range of environments in which they prosper, offers unique opportunities to gain fresh insights into the molecular processes that underpin thermo-tolerance in ruminants and integration of this knowledge in future genomic selection programmes. The chapter will explore current research in marker development for heat resistance in livestock, including sheep, and how recent technological advances can be employed to increase our understanding of the processes. Genomic selection strategies can then be employed to maintain and potentially improve resilience and productivity in livestock species in spite of the challenges imposed by changes in global weather patterns.

15.2 Heat Shock Proteins (HSPs)

As discussed previously, increase in body temperature as a result of raised temperature and humidity has severe consequences for a range of livestock species, affecting cellular functions throughout a range or organs (Collier et al. 2008). Gene expression studies, including microarray and transcriptomics, can be employed to assess changes in the expression of key genes due to these environmental challenges. It allows the quantitative measurement of a large number of gene products within one or more tissues under different conditions, and therefore demonstrates the changes in gene expression that underpin phenotypes of interest (Stoughton 2005). To this end, the technologies have been employed to assess thermal stress in a range of animal species. Earlier research demonstrated the elevation of heat shock proteins, including HSP70 and HSP9O in bovine, equine, ovine and chicken lymphocytes following heat stress, but also noted that expression changes across a range of other heat shock proteins were different between these species (Guerriero and Raynes 1990). Surprisingly, there have been few studies of global gene expression in ruminants under heat stress, with those performed, focused heavily upon lactation and the dairy industry. In 2006, Collier and colleagues carried out microarray studies on the effects of heat stress on cultured bovine mammary epithelial cells (BMEC) (Collier et al. 2006). A total of 304 genes were identified as having statistically significant differences in expression in the heat challenged cells compared to thermo-neutral control cells. Genes upregulated in stressed cells in the first few hours were predominantly associated with cellular and protein repair, with an inducible HSP70 gene expression dramatically upregulated. The upregulations of HSP70 peaked at around 4 h, and thereafter the authors noted increased expression of genes involved in apoptosis. In other words, a relatively small number of genes were utilized for adaptation to the heat stress challenge. Conversely, genes that were downregulated included those involved in bovine mammary epithelial cell (BMEC) differentiation and milk synthesis, and supports the premise that milk yield losses in lactating dairy cows exposed to total solids are due in part to direct repression of genes associated with milk synthesis. This is generally supported by a more recent study of the response of bovine mammary epithelial cells under heat stress, where caspases (Caspase-3, -7 and -8), as well as heat shock proteins (HSPs), anti-apoptotic gene Bcl-2, Bcl-2A and Mcl-1 were markedly upregulated by heat stress before returning to normal levels at 8 h as measured using by quantitative real-time polymerase chain reaction (Hu et al. 2016). Using peripheral blood leukocytes derived from heat exposed *Bos indicus* cattle, Kolli et al. (2014) identified 450 genes that are either up- or down-regulated due to heat stress. Bioinformatic analyses suggest that animals increased the stress regulating genes, while decreasing expression of energy metabolism genes in order to maintain the body homeostasis following heat stress. Similar gene expression profiles are evident in other livestock species including pigs, chickens and goats (Yu et al. 2010; Wang et al. 2015; Banerjee et al. 2014). Such conservation of genes across a diverse range of tissues and animal species highlights the critical roles that HSPs in particular play in all livestock during periods of heat stress.

Further characterization of these genes and identification of polymorphisms that are associated with heat tolerance have been undertaken in sheep and a range of other species. For example, a large number of polymorphisms have been identified in the promoter region of the cytoplasmic form of HSP90 (HSP90AA1) (Marcos et al. 2008; Oner et al. 2013). One single-nucleotide polymorphism (SNP) mutation (C/G at 660 bp upstream of the start codon) has been shown to be associated with differences in gene expression during heat stress in a range of sheep species, and therefore represents an important mechanism for environmental adaptation (Marcos et al. 2010), and further polymorphisms have since been identified and characterized (Salces-Ortiz et al. 2013; Salces-Ortiz et al. 2015). To date, there has been little study of the genetic variations observed in coding regions and promoter or regulatory domains of other heat shock proteins, including HSP70, although the presence of a cytosine deletion in the activating protein (AP2) box region of HSP70 promoter was identified in cattle, which may negatively affect the expression of Hsp70.1 mRNA in peripheral bovine mononuclear cells subjected to in vitro heat stress among Frieswal cattle breeds (Deb et al. 2013). This study showed that cows with homozygous wild types had significantly better summer tolerance and higher total milk yield, peak yield, yield at 300 days, and protein and fat percentages than the deletion type. It therefore suggests that the promoter region of bovine Hsp70.1 gene may be useful in the selection of dairy cows for both higher thermo-tolerance and milk production.

It is likely that there are many polymorphisms yet to be identified in other HSPs or genes that are differentially expressed during heat stress, and that these can be utilized to accelerate the adaptation of sheep for warmer environments or more extreme thermal challenges.

15.3 Genes Affecting Hair and Coat Characteristics

During periods of elevated temperature, evaporative heat loss (EVHL) is an important mode of heat loss (Collier et al. 2008). While external factors will have a significant effect on EVHL including wind speed, ambient temperature and relative humidity, the phenotype will also have a role. Phenotypes that are important include coat characteristics such as density, thickness, hair length and colour. Similarly, skin properties such as sweat gland density and function, skin colour and regulation of epidermal vascular supply have been implicated (Finch 1986; Klungland and Våge 2003; Olson et al. 2003, 2006). For example, in the *Bos inducus* cattle breeds that dominate tropical climates and in a smaller number of tropically adapted *Bos taurus* breeds light coloured, sleek and shiny coats are common and have been associated with greater heat resistance (Finch et al. 1984; Da Silva et al. 2003; Hutchinson and Brown 1969).

SLICK is a dominantly inherited phenotype of tropically adapted *Bos taurus* cattle that is characterized by very short, smooth and sleek hair coat, naturally found in Senepol, Carora, Criollo Limonero and Romosinuano breeds (Brenneman et al. 2007; Landaeta-Hernández et al. 2010). This naturally selected trait is considered a very interesting feature for breeders and researchers due to its significant role in thermo-tolerance, as well as potential association with higher productivity and disease resistance (O'brien et al. 2010; Scharf et al. 2010; O'Neill et al. 2010; Dikmen et al. 2008). As a result, selective breeding for tropically adapted *Bos taurus* with characteristics such as SLICK could contribute to improved thermo-tolerance, especially in the dairy industry. Hence, a number of studies are underway to determine the gene or genes responsible for heat tolerance in SLICK cattle in order to introduce it into the dairy industry in hot environments (Huson et al. 2014; Flori et al. 2012; Mariasegaram et al. 2007).

In 2014, Littlejohn and his colleagues (Littlejohn et al. 2014) reported the presence of an autosomal dominant mutation located in the prolactin receptor (PRLR) gene and was suggested to be the cause of the SLICK phenotype and heat resistance trait. Sequencing of the PRLR gene from a purebred Senepol sire revealed the presence of a novel one base pair deletion in exon 10 of the PRLR gene. This single-base deletion mutation resulted in a premature stop codon (p.Leu462*) and loss of 120 C terminal amino acids of the receptor. Results strongly support this PRLR p.Leu462* mutation as the causative mutations for the SLICK phenotype. The mechanism by which the PRLR p.Leu462* mutation affects SLICK phenotype and thermo-tolerance is still unclear, although the mutation had a significant association was found between the PRLR mutation and coat length and possibly lactation phenotypes. This result is consistent with the mouse studies, where PRLR knockout mice show slightly increased hair diameter (Craven et al. 2001) and mammary gland development (Brisken et al. 1999).

In sheep, there is a range of coat types and colours ranging from fine wool to hair across breeds, and these variations have been identified previously as being very important for heat resistance as well as resistance to parasitic infections, an associated risk of warmer temperatures and discussed further below. McManus and colleagues (McManus et al. 2011) recently demonstrated that white-haired sheep were more heat resistant than darker animals of the same breed, and that hair length and thickness also affected heat tolerance. Supporting evidence of the importance of white coats for adaptation to thermal stress has since been provided in other breeds including West African Dwarf sheep (Fadare et al. 2013). A number of genes associated with coat colour have been previously characterized in sheep, including the tyrosinase-related protein 1 (TYRP1) gene in Soay sheep (Gratten et al. 2007). A non-synonymous substitution in exon IV of TYRP1 was observed to be perfectly associated with coat colour with the observed polymorphism affecting a critical cysteine residue of functional significance. Agouti signalling protein (ASIP) has also been implicated as a gene candidate for coat colour in a range of livestock species including sheep (Royo et al. 2008; Feeley et al. 2011; Fontanesi et al. 2009), including identification of a gene duplication within ASIP associated with white coat colour in Merino sheep (Norris and Whan 2008). Missense mutations in the MC1R gene (p.M73K, p.D121N and p.R67C) have been identified in a range of sheep species and shown to lead to black pigmentation of the skin and coat (Våge et al. 1999; Fontanesi et al. 2011). All three gene candidates have been previously demonstrated to interact to determine coat colour in a range of species including horse (Rieder et al. 2001). Further comparative studies such as genome-wide association studies have proven the relevance of these genes in sheep breeds (Li et al. 2014). Given the previous research supporting white coat colour as being beneficial for thermo-tolerance, these three gene candidates and others yet to be identified could be exploited in the future selective breeding strategies for breeds of economic importance. Shedding of hair or wool is also an important adaptive strategy to seasonal changes for many sheep breeds, but in other breeds either naturally or through the selective breeding shedding has been reduced or eliminated. The Australian Merino is an example where non-shedding occurs, allowing the harvest of high-quality fleece only through shearing (Slee and Carter 1961). Both environmental and genetic factors contribute to fleece shedding or retention, with the genetic component suggested to be a complex trait that is influenced by a dominant gene of major effect (Pollott 2011; Matika et al. 2013). Confirmation of the causative mutation or mutations that underpin shedding in sheep breeds may allow the selective breeding or future genetic engineering of sheep that retain favourable meat, fibre and milk traits, yet have the capacity to shed in response to increased and extended periods of thermal stress.

15.4 Genomic Studies in Livestock Species

Genomic selection enables the estimation of the genetic merit of an animal using thousands to tens of thousands of SNP markers scattered throughout the genome. Recent advances in fabrication to allow hundreds of thousands of polynucleotides at high spatial resolution in precise locations on the surface of a chip, together with laser scanning technologies for accurate SNP identification (Lipshutz et al. 1999). The livestock industries, especially dairy, chicken and pig production, have embraced the opportunities, and genomic selection is now routinely used to estimate genomic breeding values for a range of traits at or soon after birth (Hayes et al. 2013; Dekkers 2010). These same technologies allow the identification of chromosomal regions (QTLs) through genome-wide association studies (GWASs), and in many cases identify genes or markers associated with traits of interest. A recent example is a genome-wide association study (GWAS) analysis of body weight in Australian Merino sheep, resulting in identification of a major QTL region on chromosome 6 and detection of 39 SNPs associated with the trait (Al-Mamun et al. 2015). A comparative genomics approach was recently utilized to identify genomic regions conserved amongst goat and sheep breeds that are indigenous to arid environments in Northern Africa (Kim et al. 2015). As a result, eight and seven signatures or candidate sweep regions were identified in goats and sheep, respectively. Of the 119 genes identified as potential gene candidates for adaptation to these harsh environments, 8 were shared across both goat and sheep. These genes may be critical for survival in hot, arid environments; and included energy and digestive metabolism, muscular function, autoimmune response and embryonic development and reproduction. Interestingly, signatures were identified around the bone morphogenetic protein 2 (BMP2) and fibroblast growth factor (FGF) genes, which are known to be important in the formation of melanin and skin pigmentation. GWAS methodologies have been applied to understand the genetic mechanisms underlying adaptation to different environments in a range of animals, including the identification of genomic signatures associated with that environment (Andersson and Georges 2004; Elferink et al. 2012; Xu et al. 2015). In sheep, this approach has been undertaken by Lv and colleagues (2014) who identified 230 SNPs (192 with significant correlations) that are potentially under climate-mediated selection pressure. These SNPs were located nearby or within 17 candidate genes. The authors, particularly noted one allele (OAR22_18929579-A) and a nearby signature haplotype (haplotype TBC1D12-CH1) associated with the gene *TBC1D12,* and observed differences in both allele and haplotype frequencies in sheep breeds from cold versus hot climates. *TBC1D12* has been proposed to participate in the regulation of Rab GTPase, which together with HSP90 has important functions involving protein trafficking and secretion, including during cellular stress (Taipale et al. 2010). In goats, GWAS for heat stress tolerance in Florida Dairy Goats identified several significant SNP in candidate genes involved in milk composition such as kappa casein (CSN3), acetylcoenzyme A carboxylase alpha (ACACA) and malic enzyme 1 (ME1), as well as mutation in heat shock 27 kDa associated protein 1 (HSPBAP1) which may contribute to the regulation of HSP27 and the adaptation at a cellular level to heat stress in these animals (Serradilla 2014).

GWAS analysis was performed on cattle have also identified numerous genes that may be expected to have similar roles in sheep. One early study utilized production records, genomic data and weather records from nearby weather stations to perform association studies to identify QTL and candidate genes associated sensitivity of milk production to temperature humidity index (fibroblast growth factor 4; Hayes et al. 2009). Using unrelated animals of mixed breeds and gender, researchers were able to identify genes putatively associated with body temperature either during winter or summer (Howard et al. 2013). These included genes implicit in the response to cellular and heat stress, either through protective roles of pentose phosphate pathway, heat shock proteins or apoptosis. Different sets of genes were associated with body temperature during winter and summer. A GWAS of heat stress in Holstein cattle by Dikmen et al. (2013) identified a number of QTL and SNP associated with genes of large effect on rectal temperature, as a marker of heat stress susceptibility. For example, a region between 28,877,547 and 28,907,154 bp on chromosome 24 was identified as explaining the largest proportion of variance, with genes encoding U1 spliceosomal RNA (*U1)* and cadherin-2 (*NCAD*) identified as potential candidates in the region. No clear relationship between cadherin-2 and heat stress is reported, although U1 small ribonucleoprotein is involved in mRNA regulation and post-transcriptional modification, both of which could be related to changes in cellular gene expression during stress. A number of other genes identified across various QTL studies appear to be associated with heat stress, including genes involved in RNA metabolism (LSM5, SCARNA3 and SNORA19) and protein ubiquitination (KBTBD2 and RFWD12); and SLC01C1 is known to play a role in the processes controlling body temperature. While genotyping at medium to high density (50,000 SNP or greater) is an excellent tool for GWAS, its utility for sheep in general may be reduced by the fact that there remains significant diversity both within and across breeds, and this is reflected at the genomic level. Applying GWAS across breeds is therefore problematic due to the unpredictability of shared chromosome regions and therefore inherent inaccuracies in imputation of genomic data against a small number of unrelated sheep. Whole genome sequencing offers opportunities to improve accuracy. Following the initial sequencing of a male and a female Texel sheep to create a domestic sheep reference genome assembly OARv3.1 (Jiang et al. 2014), whole genome resequencing from other breeds or related species (Kardos et al. 2015; Miller et al. 2015) has been undertaken for the better understanding of the genetic basis of fitness and adaptation in sheep.

15.5 Disease and Parasites

Increased outbreaks of disease and changes in the distribution and burdens of parasites and vectors of viral and parasitic pathogens have been recognized as a consequence of climate change and associated heat stress in humans (Medlock and Leach 2015) as well as sheep and other livestock (Morgan and Van Dijk 2012; Bosco et al. 2015; Rose et al. 2015). Significant changes in the frequencies and distribution of diseases including dengue, bluetongue, leishmaniasis and trypanosomiasis have been reported. Similarly, there is a growing body of evidence for the spread of *Fasciola* *hepatica* (liver fluke) in cattle and sheep (Fox et al. 2011), while modelling predicts that significant changes to seasonal and annual infections pressures for gastrointestinal nematodes such as *Haemonchus contortus*, *Teladorsagia circumcincta* and *Ostertagia ostertagi* in sheep and other ruminants (Rose et al. 2015). Conversely, the increased temperatures anticipated by global warming may reduce the incidence of some infections, such as *Nematodirus battus* as timing of egg hatching and lambing season changes (Gethings et al. 2015). Compounded by the physiological impacts of heat stress upon immune function of the host, including impairment of cellular immune function and cytokine production (Caroprese et al. 2015; Sgorlon et al. 2012; Sevi and Caroprese 2012), the higher incidence of heat stress will assuredly increase risk and incidence of disease in sheep. Therefore, there is a significant need to identify genes associated with resistance to these pathogens; both that minimize impacts of outbreaks and reduce costs associated with the management of these pathogens.

Due to geographic isolation and adaptation to different pathogens, many species of sheep, cattle and goat are naturally resistant or more tolerant of parasite, bacterial and viral diseases such as trypanosomiasis, tick and tick-borne diseases, internal parasites, dermatophilosis or foot rot (Bishop et al. 2002). Therefore, opportunities avail themselves should one be able to identify QTL or genes that control disease resistance, and using this knowledge in future marker-assisted selection (Gibson and Bishop 2005). Such breeding may also directly or indirectly improve tolerance to heat stress in these lines, through improved immune function resilience and associated physiological adaptations. A number of studies have been published linking nematode resistance to QTLs across a number of chromosomes, as summarized by a recent review by McManus and colleagues (2014). Comparative genomics studies across these regions amongst a diverse range of sheep species could provide further insight into mechanisms of resistance and application of this knowledge in other breeds to manage the risk of increased parasite burden due to heat stress.

15.6 Conclusion

Advances in genetic and genomic research have the potential to greatly increase our understanding of the physiological and biochemical challenges associated with heat stress in sheep. As the costs associated with whole genome sequencing decline, it is anticipated that increasing numbers of breeds, each with unique phenotypic attributes including differences in thermo-tolerance, will become available for study. Recognizing both the opportunity and the complexities associated with these large and often disparate projects, animal geneticists have recently established the FAANG Consortium, which stands for Functional Annotation of Animal Genomes whose stated aim is to produce comprehensive maps of functional elements in the genomes of domesticated animal species based on common standardized protocols and procedures (Andersson et al. 2015). Combining genomic, transcriptomic and epigenetic studies, together with extensive phenotypic records, that has the potential to provide novel insights into the evolution and adaptation of animals, and benefit the agricultural and biomedical sciences as humankind faces the challenges associated with a warming climate.

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Ideal Housing Systems for Sheep to Cope with Climate Change

16

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Abstract

Defining single unequivocal means of housing requirement for sheep is difficult as sheep is a versatile species in terms of geographical distribution and morphological conformation. However, many of the environmental components such as solar radiation, temperature, humidity, wind velocity, and precipitation have serious effects on sheep productivity. Under the changing climatic scenario, the impact may be erratic and accentuated especially in the warm tropical regions. Further, sheep rearing based on pastoral and mixed farming system will be more affected by global warming than the industrialized system. Concentration of sheep is relatively congregated at hot arid and semi-arid regions of the tropics, where nomadic grazing type is the predominant sheep rearing system. Nonetheless, practices of providing shelter to sheep around the globe are highly varying in feature, which range from folding of sheep at open space with or without fencing to insulated shed that controls ventilation, lighting, feeding, and watering artificially. Spatial climatic conditions and socioeconomic status of the sheep farmers, including their legacy from community and tradition, are the major factors connected with the principles of housing requirement for sheep and the housing practices adopted by the sheep farmers. If spatial climate is the single most principal factor that decides the housing principles and practices, the types of sheep sheds can broadly be categorized as (1) *open sheds*, (2) *semi-open sheds*, and (3) *enclosed sheds*. However, in India and some other developing countries, different types of animal houses are constructed for sheep production without any careful planning and designing. Nonetheless, practically very little

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research work has been carried out especially in the tropics to assess the relative suitability of type of housing to sheep production. Though isolated reports on the effect of housing on physiological response, behavior, and growth are existing, no long-term studies on housing system with respect to the production of sheep and economy of flock production have been conducted. Whatever little evidence is available indicated that providing suitable shelter during warm climate may provide more comfort to the animals by protecting them from direct solar radiation and improve their productive performance.

Keywords
Sheep housing • Climate change • Tropical region • Rearing system

Contents

16.1 Introduction

Sheep are geographically, climatically, and morphologically versatile species; they are distributed over all the continents of Northern and Southern Hemispheres, and so the animal is spread through cold temperate, warm temperate, subtropical to hot desert, and from high-altitude mountainous region to low-lying marshland. They vary in body size, fineness and density of wool or hair covering, shape of tail, and seasonal breeding performances. All or some of these feature traits in addition to production or rearing systems have influence on housing requirements of sheep. On the other hand, climatological factors *such as* solar radiation, temperature, humidity, wind velocity, and precipitation are both spatially and temporally more varied. Further, the current global warming may lead to erratic changes of these elements at microlevel. Thus, it can be inferred that very little geographical area is persisting in the world where optimum livestock production is possible in the changing climate scenario. Many of the environmental components impose serious effects on animals' physiology and behavior; however, their production potential is compromised in the process. Therefore, climate is one of the considerable limiting factors of sheep production especially in the tropical environments.

It is expected that the livestock systems based on grazing and mixed farming system will be more affected by global warming than an industrialized system. This will be due to negative effect of lower rainfall and more droughts on crop and on pasture growth and of the direct effects of high temperature and solar radiation on the animals (Nardone et al. 2010). These changing events as a result of climate change warrant developing appropriate housing system to improve the production potential of these animals. However, the majority of farmers in developing nations like India are poor and marginal, and they rely on small flock size for their livelihood security (Nagpal et al. 2005). Hence they do not provide elaborate shelter to their animals. This smallholder production system mainly exists in developing countries where the human demand for animal product is increasing due to the continuous growth in the population and per capita consumption (Delgado 2003), and that augments the prospects for industrialized production with elaborate housing and in-house fittings. The climate of the Indian subcontinent is extremely tropical though a large part of India is located north of the Tropic of Cancer. Nonetheless, since climatic conditions vary considerably from place to place within the country, defining unequivocal animal needs of housing becomes extremely difficult. Investigations on animal housing have also been limited mainly due to high expenditure involved. Many types of traditional sheep housing systems have been evolved in course of time. They need to be evaluated in the light of changing climatic scenario, augmented productivity, and paradigm shift in the production system by progressive sheep farmers. In hot, humid coastal regions of India, the mean daily temperature is generally low, but the difference between the maximum and minimum temperatures may be only 5–8 °C with the minimum temperature above 25 °C. In such climatic regions of tropics and subtropics, generally distribution of sheep population is little. Concentration of sheep is relatively congregated at hot arid and semi-arid regions of the tropics. In India, more than 70% of the small ruminant population is found in arid and semi-arid areas of western and southern peninsular regions (Sejian et al. 2013).

16.2 Types of Sheep Sheds

Practices of providing shelter to sheep are highly versatile entities that vary from folding of sheep flock at open space with or without fencing to insulated shed that controls ventilation, lighting, feeding, and watering artificially. Two major factors connected with principles of housing requirement for sheep and the housing practices adapted by the sheep farmers are:

1. Foremost single factor is spatial climatic condition and its recent change of pattern and intensity. It comprises of climatic elements, viz., air temperature, humidity, precipitation level, speed of air movement, and vegetation cover. Accordingly, the climate of the region may be hot arid, hot semi-arid, hot humid, temperate, or extreme cold. Nevertheless, the climate of the region is not constant throughout the year, and the temporal changes are usually rhythmic in nature or sometimes they are erratic, especially under the changing climatic scenario.
2. Another crucial factor that is linked with the sheep housing practices is the socio-economic status of the sheep farmers, including their legacy from community and tradition, system of rearing (sedentary flock, nomadic, migratory), educational level or neo-entrepreneur, and degree of sheep farming entrepreneurial skill.

However, other minor factors associated with sheep housing practices and principle are flock size, land topography (high land, valley, low-level land, or marshland), single species sheep farming or one of the multispecies animals farming or complementing with crop farming, perhaps predation too.

If spatial climate is the single most principal factor that decides the housing principles and practices – considering core aspects of housing requirement – then the types of all sheep sheds could broadly be categorized into three principal models, and other peripheral aspects of requirement could be established by supplementary fittings and improvisation.

16.2.1 Open Sheds

In this system, a roof and fencing are constructed to protect the animal from direct solar radiation and precipitation, and also to keep the sheep under confinement, against predation and theft, if any. This shed provides ample natural light and free ventilation. If the air temperature exceeds, ephemerally, body temperature or drops below the lower critical temperature (LCT) of the animal, supplementary fitting in the form of pad or canvas curtain is required to facilitate cool incoming air or protect against wind chill accordingly. This shed is appropriate for hot arid and semi-arid regions with little rainfall and extremely high seasonal fluctuation of air temperature.

In the semi-arid regions of India, temperature varies from 4 to 48 °C, and majority of the sheep are kept in open corrals or inside small thatched roof sheds. The animals are exposed to a wide variety of environments during different seasons of the year. The organized farmers house their sheep in asbestos-roofed sheds with open sides during monsoon and summer, and covered sides during winter. Summer and monsoon are the most stressful conditions for sheep in semi-arid region. Sheep kept in open with a corner covered area with thatch made of locally available material is better than the asbestos-roofed shed during summer and monsoon. Skin temperature of ewes remained higher in asbestos-roofed shed as compared to thatch-roofed shed. Similarly, heart rate, respiration rate, and energy expenditure are higher in asbestos-roofed shed as compared to thatch roofed (Bhatta et al. 2005). Provision of housing is rather stressful during monsoon and summer, whereas it protects the sheep from severe cold during winter in semi-arid region. Vandenheede and Bouisson (1993) also reported that sometimes housing and management can be a source of stress for sheep. In semi-arid region, the summer facilities for animals should be that it must give animals maximum protection from direct solar radiation during day and allow maximum cooling at night by radiation. At higher temperature, most of the heat loss occurs through evaporative cooling. The radiation from the roof of the shed during summer at night may be an additional stressor to the sheep. The increase in energy expenditure and heart rate in shaded animals is to increase blood flow to the skin to support evaporative cooling (Sleiman and Saab 1995). In semi-arid region, housing system had no significant effect on nutrient intake utilization and blood parameters in adaptive breeds of sheep (Bhatta et al. 2004).

In any type of shed, it is necessary to have the provision of animals to express their behavioral needs that reduces their frustration. Adequate environment enrichment reduces the negative emotional states like fear and stress related with adaptation to the new environment (Hughes and Duncan 1988; Nicote 1992). Environment modifications encourage movement of skeletal muscle and cardiovascular fitness that improve physical health (Klont et al. 2001). Generally, at rest, sheep skeletal muscle utilizes considerable glucose, and with an increase in activity, the liver releases additional glucose for muscle utilization (Maurya et al. 2012). In mild exercise, the rate of glucose release by the liver and uptake by muscle is sustained. More activity of lambs during rearing period increases the capillary density in muscle that helps the animal to cope stressful events better (Klont et al. 2001). If the lambs remain in chronic stress, the nonesterified fatty acid (NEFA) level increases, and this could be due to a lack of behavioral activity and physiological frustration (Hughes and Duncan 1988). The elevated level of NEFA reflects breakdown of fat due to higher energy demand (Adewuyi et al. 2005). Stresses due to psychological depression on a long run increase NEFA level and reduce blood glucose (Olleta et al. 2014). There is also immune suppression during the psychological stress (Lama et al. 2010). Nonetheless, the psychological boredom of lambs can be overcome by environment enrichment through providing wooden platform with ramps and cereal straw as bedding materials (Olleta et al. 2014). The lambs reared in enriched environment show efficiency to consume more feed, which allows them to grow faster. This leads to better carcass characteristics and produces quality meat (Olleta et al. 2014). These types of environmental enrichment are possible as well as necessary in organized farms, which help the adaptation process of lambs to the new environment. In India, most of the sheep are reared in extensive and semi-intensive system, where they have ample scope for their behavioral expression and physiological exercise. But in the future, organized intensive system may emerge as an integral part of sheep husbandry to satisfy the increasing demand of meat and other animal products. This requires a paradigm shift in the housing management practices through environmental enrichment, and such an effort might lead to better productive output.

16.2.2 Semi-open Shed

In this system, either one side of the shed is walled or all sides of the shed are walled up to the level of animals' height, and the remaining portion is left open till the roof. This system is suitable for hot semi-arid region with considerable monsoon rainfall. With some improvisation such as raised and slatted floor, this type of shed may also be suitable for hot and humid region; nonetheless, by and large distribution of sheep at hot humid part of the world is little.

The animal shelter would normally buffer the extremes of climatic conditions to reduce peak stress and protect the animals from inclement weather. Besides, the shelter should be conducive to the expression of normal behavior by the animals, and effective shelter management for sheep should be designed to meet the requirements of health and comfort of the animals, convenience and comfort of the operator, efficiency of laborers and material handling, and compliance with applicable animal welfare regulation. Further, scale of sheep enterprising operation also has an influence on housing practices.

16.2.2.1 Small Scale

Small-scale commercial producers need improved management, as they produce sheep in business perspective. The first and foremost importance is spacing of the shed must be in compliance with the flock size. Packed earth floor or sandy floor is desirable in dry areas as moisture buildup is little in these areas, whereas raised-floor house is preferable in humid areas to keep animals clean through natural waste removal. The walls may be open, semi-open, or closed, and the height of the roof may be decided according to the prevailing climatic conditions. Height of roof at eave from the floor level is preferably 1.8 m in humid climate and 2.5 m with an open ridge of 0.2–0.3 m along the shed at arid climate.

16.2.2.2 Large Scale

It requires more detailed units of various building structures other than animal sheds as compared to the small-scale producers' housing requirement. It also needs different sheds for various age classes of sheep along with a pen for sick animals and a storage house. Adequate floor space should be provided for expected number of animals inside the shed. The dimension and orientation of the building change as per the flock size and local environment. A shed measuring 20 m × 6 m can accommodate about 120 numbers of medium-size adult sheep.

16.2.3 Lean-to-Type Shed

It is the traditional hut-type shelter for sheep. Generally, it is an extension of human residential building. In India, sheep rearing is community and caste bound; therefore, the management and housing practices are ancestral legacy. In hot arid and semi-arid regions, the sheep keepers follow different types of housing within limited availabilities, ranging from primitive system to semi-migratory system in southern and northeastern parts of the country. The sheep flocks are maintained in stationary habitat. They are grazed during the daytime in community fallow land and housed in mud huts during the night hours. These typical mud huts are generally attached to the outside of the owners' living place. The roofs are mostly thatched with long rough grass. In northern and western parts of India, most of the flocks are nomadic or seminomadic. In semi-migratory system, the sheep are kept on continuous grazing for 2 days and kept on open field (crop fallow land) during the night hours. Then the sheep return to their native for watering. In certain parts of world, the flocks are stationary, and in some others, they are semi-migratory. The semi-migratory flocks move about 6–10 km from their residential village for grazing.

Depending upon the availability of materials, the traditional sheep housing is of different designs and structures. The sheep shed is commonly located at a corner of the flock owner's residential building or beside the house with an overhang attached to the roof of the house or in open yard without roof or at the basement of family residence or sometimes in a separate house (detached from human residence) with thatched roof. Commonly, lambs are kept in the bamboo dome that restricts the young lambs to mix up with the adult flock except during milk suckling, which is once in the early morning and again at evening. These domes are kept outdoor if it is not raining during the daytime. Nonetheless, these traditional sheep shelters are poorly lit, inadequately ventilated, and poorly drained. Such an environment is more prone to disease spread and makes the enterprise less remunerative.

Small traditional sheep producers usually keep a few animals that are largely maintained on the community pasture but with little external input to maintain the animals, and often productivity from this flock is very low. Overall, the enterprise is called low-input-and-low-output system. Low cost is the principal factor for the traditional sheep producer to build a thatched-type shed in attachment to the residential building.

Depending on the climate, they construct the sheds with locally available inexpensive materials which provide minimum shelter to protect against climatic stress. The small producer uses the sheds for multipurpose, like roof space to keep farm implements, feed, crop seed. Thatched-roof house is mostly constructed by the smallholder traditional sheep producers.

16.2.4 Bamboo Dome

During winter, lamb mortality and slow growth rate are the major constraints in sheep rearing in semi-arid region. As the farmers are poor and marginal, they need a low-cost rearing system that can protect the lambs from cold. They generally keep the lambs inside bamboo domes to protect them from cold (De et al. 2015). The domes are made of bamboo or other locally available material. Generally, the migratory or small farmers that own small flock use these domes to keep their lambs in a covered area. This prevents the exposure of lambs to cold stress as it maintains higher minimum temperature during extreme cold and provides comfortable microclimate. This helps to gain better body weight and growth rate. But it should be of sufficient space and height so that the lambs can move and stand comfortably. Figure 16.1 describes the bamboo dome-shaped housing for newborn lambs.

Fig. 16.1 Lambs housed under bamboo dome structure

16.2.5 Enclosed Shed

In this system, the shed is roofed, walled, and shuttered to control the ambient air temperature inside the shed considerably against extremely high or low environmental air temperature. In extreme cold environment of high-altitude mountain range of India, north European countries, and other parts of the world where similar climate is prevailing, this system of housing is required especially during winter months. These sheds may be insulated and provided with mechanized ventilation and artificial light or alternatively provided with sufficient natural opening which may facilitate ventilation and lighting without much harm to the animals. Housing and environmental modifications are important tools to alleviate climatic stress as housing practices necessarily involve modifications of one or more modes of energy transfer between the animals and their surroundings. The important physical parameters governing heat transfer are body surface of the animals, temperature of surface (skin), temperature of the surroundings, ambient temperature, velocity of air, atmospheric humidity, and emissivity of animal surface and conductivity of surroundings. To alter effectively the microclimate of an animal through housing and environmental modifications, one or more of the above factors must be altered. At cold temperate regions, sheep are usually kept indoor in warm insulated buildings during the winter season (Simensen et al. 2010; Holmoy et al. 2012). Housing the sheep in an insulated warm building with controlled mechanical ventilation, which maintains an ambient temperature of 1.5–8.6 °C, involves high building costs (Flaten and Ronning 2013). In a similar climatic region in Norway during the winter, housing sheep in an uninsulated house having natural opening for ventilation did not affect the proportion of barren ewes and neonatal mortality. The variation in the reproductive performance of ewes may be attributed to the experience of the farmer, degree of supervision during lambing, control of colostrum intake, feeding frequency, and type of roughage (Holmay et al. 2012).

16.3 Winter Protection for Lambing

Winter protection is necessary in sheep farming as the newborn lambs encounter the inclement weather, which causes lamb mortality. Therefore, it is essential to provide either individual pen or shelter or field shelter to the expected ewes. Individual lambing pen improves the lamb survival during winter. Generally it was observed that lamb loss during winter in partial or complete shelter mainly depends upon weather conditions and twinning in the flock. However, it is important to provide the ewes and the newborn lambs confinement to protect from chilled weather. Even the organized farm also may sometimes fail to provide individual pen and extra heat source to the ewes and newborns during chilling night. So it is needed at least to provide a curtain with canopy or jute bag to cover from all sides of the shed to protect from the chilling wind. During the migration process, the marginal farmers who keep their animal in open area usually create fire at night to protect the newborn lambs and mother from cold weather.

In colder parts of the world, sheep are usually kept indoor inside the warm insulated buildings during winter. Further, it was observed that there was no significant difference in the proportion of barren ewes and lamb born per ewes, neonatal mortality, and growth performance of lambs when compared between warm and cold housing. In addition, it has been reported that getting access to outdoor area reduced health problems in sheep. Group size had an effect on resting and feeding. It is obvious that large group size decreases the individual feeding opportunity as per their requirements. Space allowance is an important part in animal welfare, but limited information is available on how additional space affects the reproductive performance.

16.3.1 Cold- and Heat-Protected Shed

Environmental enrichment has an effect on the physiology and behavior of different animal species (Young 2003). To enrich the environment, an animal shed can be constructed which provides comfortable microclimate to the animals during both summer and winter. In this type of shed, floor is at a slightly lower level than the outside earth. It helps to maintain temperature inside at the desired level. Besides, the roof is made up of three layers: the upper layer is of asbestos, the middle layer is of thermocol, and the lower layer is of polyvinyl sheet. The doors are also made up of polyvinyl sheet (upper and lower) and thermocol (middle layer). This shed helps to maintain maximum temperature at lower level during summer and minimum temperature at higher level during winter as compared to conventional shed. Ensuring appropriate ventilation in the protected shed may provide comfortable environment inside the shed, which helps the lambs for better behavioral expression as well as better growth rate than the lambs kept in normal asbestos-roofed shed in well-managed farms (De et al. 2015). Figure 16.2 describes the cold- and heat-protected thermocol-roofed sheep shed.

Side view Front view

Fig. 16.2 Cold- and heat-protected thermocol-roofed shed for sheep

16.4 Hot Arid Climate Shed

Extreme hot desert climate also may require enclosed shed with improved pattern or air-conditioning and fan ventilation. In spite of a much higher daily mean temperature, the mercury falls sufficiently within a comfortable range of the animal at night in hot dry climate. A diurnal variation of 20–22 °C in air temperature allows the animal to restore thermal balance during the latter half of the night before encountering hazards of high environmental temperature the next day. But faulty enclosed house in the hot dry region imparts continuous thermal stress on sheep in the same way as the hot humid tropical climate. In such a house, the direct solar radiation is cut off and the average air temperature gets reduced. The increased humidity, radiation from the walls and floor, and reduced air movement make such housing extremely uncomfortable for sheep. For such an arid and semi-arid region, the long axis of the shed should be oriented to east-west so that shade inside the shed remains throughout the day. Further, protection could be provided with gunny bags or thatching materials and bamboos. Desert cooler may be used to cool the sheds depending on economy. The roof of shed should be made of asbestos sheet supported by tubular or angular steel, but wooden rafters and thatching materials could also be used. Height at ridge should be 3 m in order to provide sufficient air space and ventilation. At night, the animals may be kept in an open yard. Trees that provide shade may be planted and maintained around the shed to ameliorate the heat stress.

16.4.1 Yagya-Type Shed

Yagya-type shed is also constructed to protect animals during extreme summer. It is a structure where yagya is performed in Hindu rituals. It is quite a pagoda-style roof which provides better ventilation. The modification in this shed is that the walls are double walled with a hollow space in the middle which is filled up with sand, and the sand remains moist by continuous water drips. This innovative strategy protects

Fig. 16.3 Yagya-type sheep shed

the animal from direct hot wind as well as provides extra evaporative cooling that keeps the microclimate inside the shed comfortable (De et al. 2013). In any type of shed, this type of wall can provide extra cooling to the shed. Figure 16.3 describes the yagya-type sheep shed for countering climatic stresses.

Preparing a mat of locally available dry grasses at the open side of the wall and sprinkling water three to four times a day on the mat may be another option for providing evaporative cooling. This creates a better microclimate for the lambs during extreme summer. Similarly, as a winter protection, canopy curtain may be used in the open side of the wall to provide protection in the chilling cold nights.

16.5 Floor and Stocking Density

Thermal conductivity of the floor has an influence on the thermoregulatory behavior of the animals, under both cold and warm climatic conditions. The thermal conductivity and the softness of the floor are often be correlated, as soft floors usually are well insulated and have a low thermal conductivity. However, farm animals generally prefer a floor that maximizes the heat loss (high thermal conductivity) while the temperature is above the comfort zone. Nevertheless, straw bedding significantly reduces the lower critical temperature (LCT) compared to bare concrete. In sheep, however, the thickness of the fleece has an influence on LCT and most likely also their preference for different flooring materials. For a fully coated fine wool sheep, the LCT is very low (−40 °C); after shearing, the LCT will rise to 13 °C (Færevik et al. 2005). Expanded metal floor, solid wooden floor, rubber mats, and straw do have different thermal conductivity and softness. Expanded metal floor, which is the hardest of these flooring materials, will give the largest heat loss, and straw which is the softest will give the lowest heat loss (Nilsson 1988).

Sheared ewes preferred softer floors with low thermal conductivity like straw and wood. Availability of straw as a flooring material improves the animal welfare by increasing the dramatic reduction of lying time after shearing (Færevik et al. 2005). However, sheep prefer straw than the wooden slats for lying. Straw is recommended as a suitable surface for lying. But sometimes and in some parts of the world, straw is expensive and not available in plenty; in such situations, wooden chips may be used as bedding materials for sheep. Studies found that wooden chips are also preferred by lambs, and they also do not affect their performance through changes in the proportion of lying, standing, or eating times (Wolf et al. 2010). Nowadays in modern intensive system of rearing, the lambs kept in confined pens have recycled plastic slatted flooring, but the problem is that it increases the liver Cu accumulation that raise the Cu toxicity risk when lambs are reared on concentrate diet as compared to straw-bedded floor (Day et al. 2006).

Farm animals compete for food, space, water, attractive lying places, and freedom of movement. It is generally considered that increased space allowance improves the welfare of farm animals. Ewes generally prefer to be next to wall; hence, perimeter length is always important. Studies reported (Bøe et al. 2006) that a reduction in lying space from 1.0 to 0.5 m^2/ewe reduces the lying time, less synchronized resting, and increased number of displacements. Floor space is also important for lactating dairy ewes. With an increase in stocking density, the concentration of micro-organism and coliform bacteria increases in the air that increases the chances of subclinical mastitis. Low stocking density gives better fat content than the higher stocking density ewes. It is suggested that space allowance <2 m^2/animal may adversely affect the performance and health of lactating ewes (Sevi et al. 1999).

16.6 Roof and Ventilation

In animal housing, the roof determines the thermal exchange to a great extent (Liberati and Zappavigna 2004). Especially in the hot climate of arid and semi-arid regions, roofing material protects from solar radiation. But the problem is that the thermal resistance of roof negatively radiates heat on animals during night hour. Recent studies in Egypt indicate that the high thermal conductivity of iron sheet does not enable the roof to reduce both temperature and relative humidity (RH) during the day compared to concrete roofing, which significantly reduces the negative effect of environmental variables and can be effective in hot humid environment than iron sheet (Hatem et al. 2015). In tropical climate, thatch and agro-net are better to prevent from hot and humid environment in comparison to asbestos (Kamal et al. 2013).

To a great extent, the thermal exchange between animals' surface and environment, and the removal of air pollutants originated from animal excreta depend upon ventilation. Ventilation controls fresh air for breathing, freedom from drafts, room temperature, humidity in the air, and levels of contaminants. Other than that, provision of ventilation during the warmest hour of the day and night at a mean ventilation rate of 66 m^3/ewe per h may adequately sustain animal welfare and performance of lactating ewes during summer in Mediterranean climate (Sevi et al. 2002).

Improper ventilation inside the shed increases the viable concentration of microbes, CO_2, and NH_3 in the air that reduces feed intake and leads to aggressive interactions in animals (Averos et al. 2008; Minka and Ayo 2009). Ventilation at a rate of 1.22 m^3/h/kg body weight is recommended for keeping the gaseous pollutants within acceptable limits inside the animal house (Sevi et al. 2002). The fan ventilation during extreme summer removes the metabolic heat produced by the animals and replaces with cooler external air. Fan ventilation has a direct convective cooling effect if there is forced air involvement close to the animals (Kolarman and Daskiram 2011). Although sheep are heat resistant, still the lambs born during the warmer part of the year have lower growth performance due to high temperature. Koluman and Daskiran (2011) showed that a ventilation system operated over upper critical temperature and RH is effective in maintaining sheep productivity and sustaining welfare and performance of crossbred lambs raised in Eastern Mediterranean climates during summer. The extra benefit is that ventilation prevents accumulation of toxic gases, which improves health and reduces mortality of young animals.

In winter, only a small volume of fresh air is required to provide O_2, reduce humidity, and control pollutants, whereas in summer a large volume of air is required to control temperature. Mature sheep with full fleece are not susceptible to winter draft, but the newborn lambs exposed to draft are at risk for hypothermia.

Naturally ventilated sheds depend on wind speed and direction. To keep ventilation proper, instead of warming the entire shed, radiant-type heating is used during lambing in advanced management system. The RH should be ideally maintained between 50 and 75%. If the shed becomes too dry, the lung tissue will dry and the animals will be susceptible to diseases, whereas if the shed becomes too humid, it will help to proliferate molds and fungus. The fog occurs inside the shed when the RH is more than 90%. A mature ewe and lamb produce 2.2 L/day and 0.9 L/day humidity through respiration, respectively. The recommended ventilation to control humidity is 10 cfm/ewe and 3 cfm/lamb; this may lead to three to four air changes per hour to ensure good-quality air inside the shed.

16.7 Group Size and Housing Requirement

Group size of sheep has an effect on the synchrony of resting and feeding. In general, the level of aggression in sheep is relatively low compared to other female ungulates (Fournier and Festa-Bianachet 1995). Social behavior of sheep is less dependent on group size (9 ewes vs. 36 ewes) than in other farm animals. But it is documented that the level of aggression in ewes is sensitive to change in space allowance (1.4 m^2/ewe vs. 0.6 m^2/ewe), especially in resting area (Bøe et al. 2006). Recommendations for space allowance in confinement sheep production vary a lot from 0.6 to 1.1 m^2 (Hutson 1984); however, there is little scientific evidence for how space allowance affects the performance and social behavior of sheep (Færevik et al. 2005). The sheep barns are usually designed to satisfy the space allowance for pregnant ewes per se, and the space allowance is often 0.7–0.9 m^2 per ewe for cold temperate Norwegian sheep (Simensen et al. 2014). For tropical and subtropical sheep of India, the floor space recommended is 1 m^2 per adult ewe and 0.4 m^2 per lamb (ICAR 2002). Ewes have a distinct preference for lying next to a wall; hence, wall space due to additional pen walls in the resting area might be regarded as an important source of resting space for ewes (Bøe et al. 2006; Jorgensen et al. 2009).

Recent studies (Villenenve et al. 2009) have indicated that growth performance remains unaffected by housing in pairs or alone, when visual, auditory, and tactile contacts are permitted. In any type of housing, frequency of bleating remained higher in the first 2 days. The visual, tactile, and auditory contact with other lambs allows the single-penned lambs to experience no extra stress; it suggests that weaned lambs can be raised individually with partial isolation without affecting the growth performance (Villenenve et al. 2009).

In advanced countries where cost of land is high, confinement strategies are useful (Urano et al. 2006). Generally, sheep remain in groups, and it has the advantage of social relationship that helps the animals to counter the environmental effects (Veissier et al. 1998). But too large groups initiate competition, aggression, and stress that reduce the growth performance (Barnett et al. 1983; Tan et al. 1991; O'Connell et al. 2004). In addition, the excessively large area increases the energy expenditure of animals in search of food and water (Turner et al. 2000). In pen, the incidence of aggression/aggressive behavior increased with the increase of lambs or adult animals (Van et al. 2007; Kondo et al. 1989). The reason may be that increased population density violates their individual space that increases the agonistic interactions and social stress (Da costa and e Silva 2007). Therefore, the number of animals in the feedlot influences the behavioral pattern and feed intake, and fewer animals in pen can improve the weight gain.

16.8 Shelter in Different Agro-ecology

16.8.1 Highland

High rain fall and low temperature are the characteristic features of highland. This condition demands a house with a raised floor, gable roof with sufficient overhang to protect from heavy driving rain, and solid lower wall. High humidity inside the shed can be avoided by allowing sufficient air movement through the upper portion of the wall for proper ventilation. In highlands where rainfall is low, a well-drained packed earth or concrete floor may be used.

16.8.2 Mid-altitude

In humid area, houses with raised or slit floors are desirable. Ventilation should be proper to prevent accumulation of humidity. The drop of urine and feces through slit minimizes the parasite and other disease problems as well as reduces humidity accumulation. In drier areas, packed earth or concrete floor can be used. The floor should be kept clean, and the wall should be dry.

16.8.3 Low Land

The nomadic flocks are raised in the low land in pastoral or agro-pastoral production system. Most of the flocks are raised in open yards in nighttime enclosure. During daytime, natural shades of tree and land shrubs provide protection against direct solar radiation. Intensive and semi-intensive systems require partially covered long walls with roofing. The roofing should not create a hot condition inside the shed at the time of high ambient temperature. The low land areas generally have low humidity; therefore, packed earth is sufficient.

16.9 Closing Remarks

Housing systems for sheep depend on the system of sheep rearing and the socioeconomic status of flock owners. The theoretical economic principle of the animal enterprise advocates that investment on animal shed construction should be on lower possible limit, and it should be constructed from locally available cheap materials. However, in India and some other developing countries, we find different types of animal houses constructed for sheep production without any careful planning and designing. Nonetheless, practically very little research work has been carried out especially in the tropics to assess the relative suitability of one type of housing or other in sheep production. Though isolated reports on the effect of housing on physiological response, behavior, and growth exist, no long-term studies on housing system vis-à-vis production of sheep and economy of flock production have been conducted. Whatever little evidence is available, it is clear that providing shelter to the animals in warm climate protects them from solar radiation and leads to more comfort to the animals as judged by their physiological reactions.

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Management Strategies to Reduce Heat Stress in Sheep

17

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Abstract

Sheep are an important socio-economic activity in many countries, where sheep are produced for the production of protein and fibre resources. Heat stress is a worldwide phenomenon that is associated with reduced animal productivity and welfare, particularly during the summer months. Animal responses to their thermal environment are extremely varied. Given the socio-economic role of sheep in developing nations, it is important to ensure sustainable production during all seasons. However, it is clearly evident that the thermal environment plays a significant role in influencing livestock productivity and well-being. The impact of heat stress on sheep production is likely to continue into the future due to climate change. The impact of climate change on sheep populations will be somewhat confounded by producer selection for increased growth and production traits. However with improved management the impact of heat stress on sheep can be minimised. The purpose of this chapter is to provide information regarding the management of sheep to reduce the negative impact of heat stress.

Keywords
Animal management • Climate monitoring • Climatic indices • Housing management and mitigation strategies

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Contents

17.1 Introduction

Heat stress results in a significant economic burden to livestock producers globally (St-Pierre et al. 2003). The negative impacts of heat stress on animal agriculture are well reported for numerous species. For sheep heat stress is reported to negatively impact animal growth, carcass performance, milk production and quality, animal health and reproduction (Marai et al. 2007; Sejian et al. 2010a; Alhidary et al. 2012b; Sevi and Caroprese 2012; Mahjoubi et al. 2014).

Traditional heat stress alleviation methods have included providing shade and/or sprinklers and genetic selection of heat-tolerant breeds (Godfrey et al. 2013). Current research tends to suggest that the nutritional management of sheep (Beatty et al. 2008; Sevi and Caroprese 2012; Godfrey et al. 2013) and dietary supplements (Alhidary et al. 2012a, 2015; Chauhan et al. 2014) have become focal areas for heat stress alleviation. The impact of heat stress on livestock production is likely to increase in intensity due to the forecasted impact of climate change. The potential effects of climate change are difficult to quantify due to the complex relationship that exists between animals and their environment. The impact of climate change on animal production may be further confounded through performance-based selection of livestock.

In the future producers will continue to select replacement breeding stock based on the individual's performance for economically important traits. However, by selecting animals with superior productivity, there is the potential that these selection pressures may increase an animal's susceptibility to heat stress, due to the relationship that is observed between animal productivity and metabolic heat production (Rhoads et al. 2013). Although somewhat unknown, the implications of forecasted climate change on heat stress in sheep are particularly concerning for developing nations (Macías-Cruz et al. 2015; Marino et al. 2016). Figure 17.1 describes the various management strategies to sustain sheep production in the changing climate scenario.

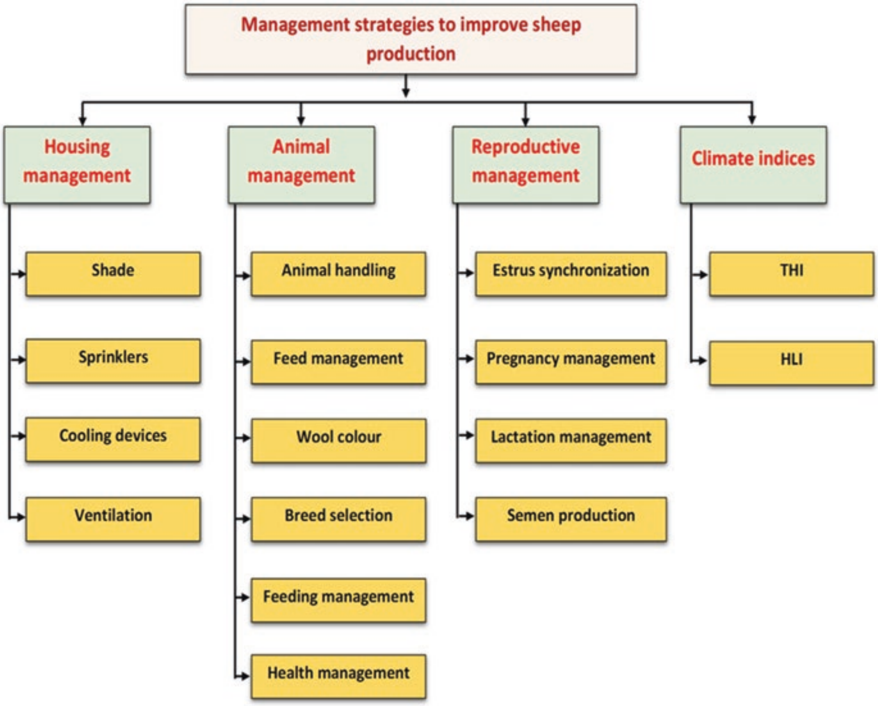

Fig. 17.1 Different management strategies to sustain sheep production in the changing climate scenario

17.2 Housing Management and Mitigation Strategies

Climatic trends differ from summer to summer, and future predictions suggest that there will be considerable variability in the climatic behaviour during summer (Robinson 2001; Westcott 2011). There are numerous considerations that need to be accounted for whilst managing sheep during periods of hot weather. Maintaining core body temperature within a physiologically acceptable range is fundamental in reducing the impact of heat stress on the body. Once an animal initiates thermoregulatory mechanisms, i.e. increased respiration rate, energy is diverted from growth and production towards maintaining homeostasis. This transcribes to an approximate 7–25% increase in energy requirement, due to the initiation of thermoregulatory mechanisms (Sevi and Caroprese 2012). Thus the energy efficiency of the animal is considerably compromised during heat stress (Ames et al. 1971).

Given that sheep production occurs in semiarid and arid regions (Macías-Cruz et al. 2015), the negative impact of heat stress is exacerbated by restricted water supplies and nutritional deficiencies (Sejian et al. 2010a). Therefore any heat stress management strategy needs to consider the effect of additional stressors. By improving the management of sheep during periods of heat stress, the negative impacts of heat stress on sheep welfare and production can be reduced (Caroprese et al. 2012).

Reducing the impact of heat stress on sheep requires knowledge and understanding of thermal exchange mechanisms. The development of alleviation strategies and the management of heat stress are reliant on the regulating heat accumulation and dissipation between the animal and their thermal environment. Thus the use of air movement and water application has been features of animal housing for numerous years (Hassanin et al. 1996).

17.2.1 Shade Availability

Thermal radiation is delivered in electromagnetic waves from the sun and is reflected by surrounding structures and absorbed by the animal (Bond et al. 1967; Berman and Horovitz 2012). Absorbance of radiation though shortwave radiation (from the sun) and long-wave radiation (from the terrestrial environment) has the potential to exceed the amount of heat produced by metabolic processes (Brown-Brandl et al. 2005b). It has been established that the provision of shade within intensive animal production systems is advantageous. The provision of shade reduces the animals' exposure to direct solar radiation; however, the provision of shade does not alter ambient temperature or relative humidity (Gaughan et al. 2004b).

The advantage of shade is that the application is passive, where animals are able to utilise shaded areas voluntarily (Johnson 1991; Eigenberg et al. 2005). Cain et al. (2008) observed desert bighorn sheep using shaded areas and caves as bedding sites during the heat of the day over the summer months. Sevi et al., (2001) observed lactating ewe's utilising shade for approximately 85% of the observation period. Shaded rams had lower ($P < 0.05$) rectal temperatures (39.9 ± 0.07 °C versus 40.1 ± 0.08 °C) and respiration rates (94.7 ± 3.75 bpm versus 113.1 ± 4.74 bpm) at 1400 h, when compared with unshaded rams, respectively (Hassanin et al. 1996). Similarly unshaded (AM fed) ewes had higher ($P < 0.001$) rectal temperatures (41.1 °C) compared with unshaded (PM fed) ewes (39.8 °C); however, unshaded ewes had higher ($P < 0.001$) rectal temperatures compared with shaded ewes (39.5 °C) irrespective of time of feeding (Sevi et al. 2001).

Providing shade alters the microclimate, potentially providing an area of reduced thermal loads (Mitlöhner et al. 2002; Sevi et al. 2002; Cain et al. 2008). Sevi et al. (2001) concluded that maximum ambient temperature and relative humidity were 3.9–6.8 °C and 6.3–12.3% lower in shaded areas compared with unshaded areas. Similarly Caroprese et al. (2012) concluded that average ambient temperatures were between 2.3 and 5.6 °C higher in unshaded areas. Providing shade reduced the temperature-humidity index by between 4 and 7 points, compared with unshaded areas (Sevi et al. 2002). Providing shade reduces exposure to thermal radiation and provides a temperature gradient between the sheep and their environment, thus supporting thermal balance (Sevi et al. 2001; Mitlöhner et al. 2002; Cain et al. 2008; Eigenberg et al. 2010; Berman and Horovitz 2012). The provision of shade and changes in microclimates may potentially reduce the degree of thermoregulatory mechanisms evoked by sheep, thus reducing the energy demands associated with thermoregulation.

17.2.2 Air Movement

The thermal properties of an animal's coat are influenced by the quantity of air held between the hair follicles, where air accounts for 90% of the coat's volume (Kimmel et al. 1991). Air movement influences the rate of convective heat loss from the skin and hair surface of the animal (Silanikove 2000). During hot climatic conditions, one of the primary responses of animals is a redistribution of blood from the internal organs to the periphery, stimulating an increase in pulse rate and skin temperature (Sejian et al. 2010a; Chauhan et al. 2014; Macías-Cruz et al. 2015). The redistribution of blood flow towards the periphery facilitates a temperature gradient between the skin and the environment, thus increasing convective and radiant heat dissipation (Chauhan et al. 2014; Macías-Cruz et al. 2015).

Using air movement there are two types of convective heat dissipation: (1) free and (2) forced. Free convective heat dissipation occurs when air temperature increases and air density decreases resulting in air movement upwards and away from the animal (Robertshaw 1985). Forced convective heat loss refers to increased air movements and can be due to natural winds or artificial air movement, e.g. fans. Modifying the environment by increasing air movement enhances the movement of air over the animals' body (Berman 2008). However when skin temperature surpasses ambient temperature, the animal is no longer able to dissipate heat to the surrounding air via convection (Silanikove 2000). In order to maintain homeothermy, sheep will evoke other thermal exchange mechanisms, such as increasing respiration and sweating (Macías-Cruz et al. 2015). However heat dissipation due to air movement is proportional to the surface area of the animal exposed to air movement and not the entire surface area of the animals' body (Mader et al. 2010).

Providing heat dissipation opportunities through forced ventilation does not directly modify the ambient conditions. However producing air flows at a velocity of 1 m/s is associated with airstreams of between 0.3 and 0.6 m/s over an animal's surface (Berman 2006), whereby the influence of relative humidity on thermal exchange is minimised when air velocities are between 1.5 and 2.0 m/s (Berman 2005). However during periods where ambient temperature is high, there is a reduced ability to dissipate heat via convection (Silanikove 2000). Furthermore, when ambient conditions surpass skin temperature, the animal is no longer able to dissipate heat to the surrounding air via convection (Silanikove 2000).

17.2.3 Water Application

Water application can be utilised in two methods: (1) direct application to the animal and (2) application to the pen surface. Soil temperatures were between 6 and 15 °C lower in pens that had received sprinkling, thus altering the microclimate and allowing heat dissipation (Mader et al. 2007). When conditions are hot and dry, water applied directly to dry skin increases the rate of evaporative heat dissipation (Kimmel et al. 1991; Brown-Brandl et al. 2010). When water is evaporated from the air surrounding the animal, the ambient temperature within the animal's microclimate decreases, therefore increasing the temperature gradient allowing for greater heat dissipation (Mader et al. 2007). Leibovich et al. (2011) reported that water misters and fans were able to decrease the temperature humidity index (THI) by 3.8 units, thus reducing the respiration rate and rectal temperature of lactating ewes. A decrease in THI was associated with an 8.4% increase in dry matter intake (DMI) and a 7.4% increase in milk yield (Leibovich et al. 2011). When handling cattle, water application did not stop an increase in body temperature; however, it reduced the rise (°C) in body temperature and reduced the time to return to normal baseline body temperature (Brown-Brandl et al. 2010). Caution needs to be exercised when using sprinklers as animals may become reliant on sprinklers for thermoregulation, whereby when not applied the animals may become more susceptible to a rapid accumulation of heat (Gaughan et al. 2004a; Mader et al. 2007). This rapid accumulation of heat is thought to occur as the animals are not required to initiate normal physiological responses, i.e. respiration rate and sweating, to cope with heat stress whilst being wetted (Gaughan et al. 2004a).

In tropical and subtropical regions, water application may intensify heat stress conditions, whereby the microclimate becomes more humid inhibiting thermal exchange (Mader et al. 2007). Mader et al. (2007) concluded that sprinkling pens resulted in an increase in relative humidity; however, there was no increase in THI. Lowering ambient temperature within the pen microclimate may potentially offset the increase in relative humidity associated with wetting pens (Mader et al. 2007). Therefore concerns regarding the increase in microclimate relative humidity due to water application may be unwarranted (Mader et al. 2007). It is likely that wetting animals after peak ambient temperature is reached is more beneficial in supporting the thermal equilibrium, rather than applying cooling prior to and during peak ambient temperature (Gaughan et al. 2008a). The use of water application has the potential to become a beneficial management tool (Mader et al. 2007); however, water is becoming an increasingly precious commodity, and availability is likely to change with the changing global environment. Where water is used to cool animals, it must be done so in a manner that is efficient and effective.

17.3 Animal Management

It is clear that a dynamic relationship exists between animals and their thermal environment. There are a number of factors that influence how an animal will respond to heat load conditions including coat characteristics, breed, feeding and health status. Reducing the accumulation of heat from the environment is an important strategy in managing heat stress. Thus understanding how animal management influences thermoregulation is an important consideration during heat stress.

17.3.1 Animal Handling

The accumulation of heat also occurs from metabolic processes, including digestion and locomotion. As locomotion occurs there is a rapid and sustained increase in metabolic heat production, whereby when the animal is unable to dissipate heat fast enough, therefore there is an increase in body temperature (Brown-Brandl et al. 2010). Beatty et al. (2008) observed that core (abdominal) body temperature increased in shorn and unshorn sheep during animal handling (transport, shearing and sorting). Moving cattle over distances between 150 and 900 m was associated with an increase in body temperature of between 0.3 and 0.8 °C (Mader et al. 2005). However the increase in body temperature post-handling will be delayed, reflecting the time required for metabolic heat to be distributed around the body (Brown-Brandl et al. 2010). Therefore it is important to consider the effects of animal handling, as well as climatic factors, on body temperature especially as an elevated body temperature may provide a misdiagnosis regarding an animal's health status (Mader et al. 2005). During hot climatic conditions, particularly heat wave events, avoiding animal handling during the hottest hours of the day would be advantageous.

17.3.2 Fleece Management

Thermal exchange with the environment is altered by the fleece, particularly fleece length (Beatty et al. 2008). The fleece provides insulative protection to the animal by reducing convective heat loss in cold environments and reduces radiative heat gain in hot environments (Piccione et al. 2002). However, when ambient temperature is lower than body temperature, heat dissipation is enhanced by the absence of the fleece (Piccione and Caola 2003). By shearing the sheep, the outer coat layer is removed, thus altering the thermal conductance of the skin (Al-Ramamneh et al. 2011). Evaporative heat loss from the respiratory tract accounts for approximately 65% and 59% of total heat dissipation in fleeced and shorn sheep, respectively, during hot climatic conditions (Hofman and Riegle 1977).

Shearing enhances the rate of thermal exchange between the sheep and their environment; however, the fleece plays an essential role in the thermoregulatory abilities of sheep (Dikmen et al. 2011). Numerous authors have indicated that shorn sheep have lower body temperatures when compared to their unshorn counterparts (Aleksiev 2008; Beatty et al. 2008; Al-Ramamneh et al. 2011; Dikmen et al. 2011). Beatty et al. (2008) reported that the core body temperature (abdominal; °C) and rumen temperatures of fleeced sheep were greater (0.5 °C; $P < 0.001$) than shorn sheep. Dikmen et al. (2011) concluded that shorn lambs (39.8 ± 0.03 °C) had lower rectal temperatures compared with unshorn lambs (40.06 ± 0.09 °C). Furthermore, Aleksiev (2008), Beatty et al. (2008) and Al-Ramamneh et al. (2011) showed that body temperatures decreased when sheep were shorn. Prior to shearing rectal temperatures were greater (39.3 ± 0.2 °C; $P < 0.001$) in unshorn sheep compared with shorn sheep (38.8 ± 0.1 °C), however after shearing rectal temperatures declined (38.8 ± 0.2 °C; $P = 0.865$) (Al-Ramamneh et al. 2011).

Respiration rate increases in both shorn and unshorn sheep; however, the increase of unshorn sheep is greater than that of shorn sheep. Shearing also results in a decrease in respiratory rate (Beatty et al. 2008; Al-Ramamneh et al. 2011). Additionally, Beatty et al. (2008) reported that unshorn sheep consumed more water. However, the authors suggested that this may be a reflection of increased evaporative cooling from increased respiration and panting (Beatty et al. 2008). These results indicate that shearing may reduce the increase in respiration rate and allow for improved regulation of body temperature during hot conditions. In terms of managing sheep during hot climatic conditions, the benefits of shearing are largely dependent on environmental conditions (Hofman and Riegle 1977; Al-Ramamneh et al. 2011). However, these studies suggest that the fleece is an important contribution to the overall thermoregulation of the sheep, highlighting the role that the fleece and fleece length in sheep has on heat accumulation and dissipation during periods of hot weather.

17.3.3 Wool Colour

Wool colour is likely to influence the heat tolerance of sheep during the summer months (Acharya et al. 1995). Wool colour is typically associated with skin pigmentation, i.e. sheep with brown- or black-coloured wool are associated with darker skin pigmentation (McManus et al. 2010). Fadare et al. (2012) indicated that wool colour had a significant effect ($P < 0.05$) on physiological parameters, specifically highlighting that sheep with black-coloured wool had higher average rectal temperatures. The authors concluded that the rectal temperature of sheep with black wool may be indicative of the amount of solar radiation absorbed by the dark pigmentation of the wool (Fadare et al. 2012).

The degree of radiation absorbed by an animal is a reflection on a number of individual physiognomies including body surface temperature, wool colour, hair follicle characteristics and wool surface texture (Silanikove 2000). It is thought that animals with light-coloured wool and darker skin pigmentation are more tolerant of hot climates (da Silva et al. 2003; McManus et al. 2008). Cattle with white- or lighter-coloured coats absorb approximately 40–50% less radiation, when compared with animals of darker- or black-coloured coats (King et al. 1988). Darker skin pigmentation impedes penetration of ultraviolet rays, thus protecting deep tissues against excess exposure to solar shortwave radiation, whilst white-/light-coloured hair reflects heat due to infrared radiation (Castanheira et al. 2010; McManus et al. 2010). McManus et al. (2008) concluded that brown (38.70 °C; 41.21 bpm)-, black (38.74 °C; 39.66 bpm)- and white (38.65 °C; 34.38 bpm)-coloured wool influenced rectal temperature and respiration rates of Santa Ines sheep, indicating a greater thermotolerance in sheep with white wool. However it is important to consider that animal performance is related to numerous characteristics (McManus et al. 2010). Whilst it is important to acknowledge the influence of wool colour and coat characteristics associated with the thermotolerance of sheep, it is also equally important to consider the influence of other animal and environmental influences on the heat tolerance of sheep.

17.3.4 Breed Selection

An animal's genotype is a major factor contributing to its susceptibility or tolerance to heat stress. The effectiveness of thermoregulatory mechanisms in sheep varies based on breed and individual gene combinations (Sevi and Caroprese 2012). Animals that are identified as heat tolerant are characterised as those individuals or breeds that are able to maintain production, reproductive efficiency, disease resistance and low mortality rates (McManus et al. 2008). The identification of heat-tolerant animals is not a new concept, as there are numerous breeds within livestock species that are already known for their thermal tolerance (Gaughan et al. 2010). Piccione et al. (2002) suggested that adaptation to hot climatic conditions during summer in conjunction with mild winters may enhance thermoregulatory mechanisms for heat dissipation. However the authors also suggested that the enhancement of thermoregulatory mechanisms for heat dissipation may occur at the expense of thermoregulatory mechanisms for heat conservation (Piccione et al. 2002). There is considerable variation in heat tolerance not only between breeds but also within breeds. Alhidary et al. (2012b) concluded that there were large variations in respiration rate and rectal temperature between individual Merino wethers when exposed to heat stress. Additionally, McManus et al. (2008) concluded that Santa Ines (38.69 °C) sheep had lower rectal temperatures compared with Bergamasca (39.12 °C) and Santa Ines × Bergamasca (39.04 °C). These results indicate that hair breeds such as the Santa Ines may be more tolerant of hot environmental conditions (McManus et al. 2008).

Performance-based selection of livestock has been used for decades. In the future, producers will continue to select replacement breeding stock based on individual performances for traits that are deemed important. The selection pressures placed on animals have the ability to influence the genetic composition throughout successive generations. Modern sheep breeds are genetically different from previous generations; however, the selection methods have resulted in progeny that are suited to the environments in which they are raised (Alhidary et al. 2012b). Therefore the identification of individual heat-tolerant animals within a breed may become a useful selection method if these animals are able to maintain productivity during hot climatic conditions (Gaughan et al. 2010), providing adaptations for successive generations. The development of heat-tolerant breeds, combined with improved nutritional management, can be considered as a fundamental strategy to improve sheep performance and well-being during heat stress (Sevi and Caroprese 2012).

17.3.5 Feeding Management

During hot weather sheep will decrease their dry matter intake. Chauhan et al. (2014) reported a 13% decline in feed intake when conditions changed from thermoneutral (18–21 °C) to hot (28–40 °C). Abdalla et al. (1993) suggested that the reduced feed intake of pregnant and lactating ewes was associated with decreasing the accumulation of heat in an attempt to inhibit hyperthermia. Therefore the reduction of dry matter intake by sheep is considered as a strategy to reduce the heat increment associated with digestion (Godfrey et al. 2013; Mahjoubi et al. 2015). However digestion and absorption processes carried out by the animal are affected by the thermal environment. During periods of heat stress, absorbable nutrients are diverted from growth and development towards maintaining body temperature (Mahjoubi et al. 2014). However the biological pathways by which heat stress influences post-absorptive metabolism are not yet defined and/or well understood (Mahjoubi et al. 2015). However it is clear that this diversion of nutrients is an adaptive characteristic to hot conditions and to ensure survival.

Currently the main feeding management strategies for sheep during hot conditions are focused on (1) using high-energy diets, to account for reductions in dry matter intake and the associated increase in energy requirements to maintain homeostasis (Gómez-Cortés et al. 2008; Caroprese et al. 2011), (2) using supplements of dietary antioxidants to support immune function and oxidative status (Alhidary et al. 2012a, 2015; Chauhan et al. 2014) and (3) altering feeding time to reduce metabolic heat loads during the hottest hours of the day (Brosh et al. 1998; Sevi et al. 2001; Beatty et al. 2008; Dikmen et al. 2011; Sevi and Caroprese 2012; Godfrey et al. 2013). Nutritional interventions to improve sheep production during heat stress will be covered in a subsequent chapter of this edition. However it is important to consider that the nutritional management of sheep extends beyond nutritional supplementation.

Hot climates influence the activity budgets of numerous species. During periods of heat stress, sheep are likely to reduce the time spent on grazing (Cain et al. 2008). Dikmen et al. (2011) reported that heat-stressed lambs showed a preference for eating during night-time hours. Similar findings have been reported in cattle, where the cattle compensate for hotter conditions by shifting feed intake to the cooler hours of the day (Brosh et al. 1998; Brown-Brandl et al. 2005a). These studies suggest that feeding in the afternoon could be beneficial as this shifts the heat production of metabolism to later hours of the day, where conduction and radiation thermal exchange are more efficient.

17.3.6 Health Status

Heat stress is known to have a negative impact on growth, milk production and reproductive efficiency (Mahjoubi et al. 2014). Microorganisms associated with clinical and subclinical udder infection are suspected to increase during summer (Sevi and Caroprese 2012). Additionally heat stress can decrease mammary infection resistance, thereby increasing susceptibility to bacterial colonisation (Sevi and Caroprese 2012). Furthermore, if left unmanaged, mortalities associated with disease or excessive heat load may result (Mahjoubi et al. 2014). Thus increasing the health and production costs (Mahjoubi et al. 2014), where these costs are associated with the negative influence of heat stress on normal physiological functions of sheep (Sevi and Caroprese 2012). Maintaining the health status of sheep prior to heat stress events will improve their ability to withstand the hot conditions. Animals that are immunocompromised are more vulnerable and susceptible to the negative impacts of heat stress (Brown-Brandl et al. 2006). Illness is typically associated with elevated body temperatures, where the combined effects of illness, fever and exposure to heat stress may result in mortalities (Silanikove 2000).

17.3.6.1 Disease Management

During summer there is a trend for increasing health concerns; whilst these concerns may not be directly associated with heat stress, an animal's health status can be confounded by hot conditions. Hyperthermia as a result of heat stress can compromise cellular function and result in physiological changes (Hansen 2004), thus influencing animal welfare and performance. Sevi et al. (2001) indicated that providing shade to lactating ewe's increased mammary defence and improved milk quality. Additionally Caroprese et al. (2011) identified feeding lactating ewes with flaxseed decreased somatic cell count by ≈57% ($P < 0.001$). Ensuring that animal health is maintained is essential as animals with compromised immune systems are more vulnerable to heat stress (Brown-Brandl et al. 2006).

17.3.7 Reproduction and Physiological Status

The reproductive efficiency of sheep is associated with adaptations to their environmental surroundings (Cruz Júnior et al. 2015). Sex may have an influence on physiological responses to hot climatic conditions. Fadare et al. (2012) concluded that rectal temperatures and respiration rates were higher ($P < 0.05$) in females (38.83 ± 0.02 °C; 59.94 ± 0.45 bpm) than males (38.69 ± 0.02 °C; 56.09 ± 0.58 bpm). Irrespective of sex, hot climatic conditions have a negative impact on the reproductive performance of sheep. When the thermal balance of sheep is disrupted, nutrients are diverted from growth and production towards maintaining homeostasis resulting in decreased milk production and milk composition (Abdalla et al. 1993; Sevi et al. 2001; Leibovich et al. 2011; Sevi and Caroprese 2012) and reproductive efficiency (Gomes et al. 1971; Dufour et al. 1984; Marai et al. 2006a, b, 2007; Nichi et al. 2006; Sejian et al. 2010a; Macías-Cruz et al. 2016). Animal management to ensure good nutrition, sustaining optimum body condition score and provision of shade will support the reproductive success and production capacity of sheep flocks during hot climatic conditions (Sejian et al. 2010b).

17.3.7.1 Female Management

It is somewhat difficult to define the impact that heat stress has on the reproductive performance of ewes, as heat stress is typically further confounded by other stressors (Sejian et al. 2010a). Heat stress and nutritional deficiencies influence the productive performance of ewes (Sejian et al. 2010a). Hot conditions also influence the seasonal reproduction of ewes (Marai et al. 2007, 2008; Macías-Cruz et al. 2016). Elevated core body temperature of ewes during heat stress impairs hormone synthesis and metabolism (Regnault et al. 1999; Marai et al. 2008). Therefore the reproductive depression observed during summer is a reflection of the impact of heat stress on follicular development and oestrus (Macías-Cruz et al. 2016). Heat stress is also associated with embryonic mortality as well as failure of fertilisation (Marai et al. 2006b). However, nutrient deficiencies have the potential to further confound reproductive efficiency (Maurya et al. 2004).

17.3.7.1.1 Oestrus

Heat stress can result in a delay in the onset of oestrus (Naqvi et al. 2004) and a reduction in the duration of oestrus (Sejian et al. 2014). However, Sejian et al. (2011) found that the length of the oestrus cycle increased in ewes exposed to heat stress (20.28 ± 0.74 days) and combined stress (heat stress and nutrient restriction; 22.25 ± 1.67 days), compared to control ewes (18.17 ± 0.31 days). However there was a reduction in the duration of oestrus in ewes exposed to heat stress (23.40 ± 3.34 h) and combined stress (heat stress and nutrient restriction; 18.75 ± 3.75 h), compared to control ewes (38.00 ± 2.41 h) (Sejian et al. 2011). Naqvi et al. (2004) reported that the ovulatory response of superovulated ewes was not significantly ($P > 0.05$) affected by heat stress. However this is likely to be influenced by the use of exogenous $PGF_{2\alpha}$ and ovine follicle-stimulating hormone to ensure oestrus synchronisation and ovulation (Naqvi et al. 2002, 2004). Sejian et al. (2014) identified that the mineral and antioxidant supplementation was able to reduce ($P < 0.05$) the impact heat stress on the ewe oestrus cycle, suggesting that the impact of heat stress on follicular development may be associated with oxidative stress. Oestrus synchronisation combined with dietary supplementation may improve successful follicular development and subsequent pregnancy during heat stress.

17.3.7.1.2 Pregnancy

Exposure to heat stress during placental development alters circulating hormone concentrations having a negative impact on foetal growth and development (Regnault et al. 1999). Marai et al. (2006b) reported lower ($P < 0.05$) conception rates in summer (THI = 25.6) compared to autumn (THI = 24.7) and winter (THI = 14.5). Additionally Naqvi et al. (2004) concluded that there was an increased incidence of embryonic abnormalities in heat-stressed ewes. However heat exposure occurred prior to oestrus synchronisation and mating, suggesting that thermal stress during follicular development resulted in the ovulation of oocytes with decreased developmental competence (Naqvi et al. 2004). Sejian et al. (2010b) showed the higher ($P < 0.05$) conception rates in ewes with a body condition score of 3 to 2.5 compared with ewes with body condition scores of 2.5 and 4, indicating that the nutritional status of the ewe is also a contributing factor in pregnancy success.

Alterations to the embryonic environment during early pregnancy influence subsequent foetal development, highlighting the importance of the early embryonic period (Kleemann et al. 1994). Progesterone supplementation during early pregnancy is thought to enhance foetal growth and birthweight; however, the response to progesterone supplementation is inconsistent (Kleemann et al. 1994, 2001; Kenyon et al. 2005). It has been established that there is an association between plasma progesterone concentration and embryo survival in the ewe (Ashworth et al. 1989). Furthermore progesterone has an important role in mediating changes in the uterus necessary for the development of the conceptus (Kleemann et al. 1994). Progesterone supplementation may support embryonic survival during heat stress. However this will not alter the impact of heat stress on oocyte development or quality. The impact of heat stress on the oestrus cycle was able to be reduced by mineral and antioxidant supplementation (Sejian et al. 2014), suggesting that there is a need for further research that encompasses the entire reproductive cycle of the ewe and the development of management practices to support reproductive efficiency during hot climatic conditions.

17.3.7.1.3 Lactation

Under thermoneutral and hot conditions, lactation is a greater stress stimulus compared to pregnancy in sheep (Leibovich et al. 2011). When exposed to a THI ≥ 80, ewes exhibit a considerable reduction in milk production, as well as altered milk protein and fat composition (Sevi et al. 2001; Leibovich et al. 2011; Sevi and Caroprese 2012). The impact of heat stress on milk production is highly variable and appears to be related to breed adaptations (Sevi et al. 2001, 2002; Caroprese et al. 2011). Gómez-Cortés et al. (2008) observed that supplementation with olive oil increased milk yield (1946 ± 20.7 g/day; $P = 0.04$), compared with non-supplemented ewes (1713 ± 20.7 g/day); however, the authors also noted that the increase was not associated with a great dry matter intake (DMI) (2.33 ± 0.30 versus 2.46 ± 0.30; $P > 0.10$), suggesting that the increase in milk yield was associated with the increased dietary energy content from the olive oil supplement (Gómez-Cortés et al. 2008). Caroprese et al. (2011) reported that supplementing heat-stressed ewes with flaxseed increased ($P < 0.001$) milk yield and milk composition (fat, protein and casein) compared with heat stress non-flaxseed-supplemented ewes. Furthermore the authors reported that flaxseed supplementation increased milk production by approximately 18% in shaded and unshaded ewes (Caroprese et al. 2011). Incorporating lipid supplements within ruminant diet is intended to increase dietary energy (Gómez-Cortés et al. 2008), potentially compensating for the reduction of feed intake observed during heat stress. However the response to lipid supplementation on milk production and quality is variable (Gómez-Cortés et al. 2009; Caroprese et al. 2011).

17.3.7.1.3.1 Somatotropin

Recombinant bovine somatotropin (rbST) treatments increased the average daily gain and final body weight in growing lambs (Nour El-Din et al. 2009). The results could suggest that rbST may increase the average daily gain and improve the physiological status of growing lambs by increasing the concentration of insulin-like growth factor 1 and serum total protein (Nour El-Din et al. 2009). Further, Shakweer et al. (2008) conducted an experiment in Rahmani rams and concluded that rbST treatment improved the semen characteristics in hot semiarid Egyptian environment. In an another study, Andrade et al. (2008) reported that the milk yield in bST-treated Manchega ewes was 98% greater than that in control ewes, and further they observed seasonal influence on the effect of rbST, with higher milk yield recorded being during spring. Recombinant bST is efficacious in increasing both actual milk yield and 6% fat-corrected milk over the dose range of 80–240 mg/14 d without adverse effects for lactating ewes (Fernandez et al. 1995). The possible explanation for lactation induction by bST in dairy ewes seems to be associated to their endogenous levels of prolactin and growth hormone (Andrade et al. 2008). Although the use of rbST supplementation for promoting growth during heat stress condition was well established in dairy and beef cattle, such efforts are very scanty in dairy sheep. Hence, efforts are also needed to establish the heat stress amelioration effects of such supplementation in sheep.

17.3.7.1.4 Male Management

Testicular thermoregulation is imperative for the production of healthy viable spermatozoa. Heat stress adversely affects sperm motility and sperm concentration and increases spermatozoa abnormalities, leading to decreased ram fertility during summer (Gomes et al. 1971; Dufour et al. 1984; Marai et al. 2006a; Nichi et al. 2006). Testicular hyperthermia caused by elevated subcutaneous scrotal temperature has been associated with poor semen quality and spermatozoa damage (El-Darawany 1999; Marai et al. 2007; Cruz Júnior et al. 2015). In rams exposed to 40 °C for 5 h, scrotal temperature increased from 35.1 to 37.0 °C (Maloney and Mitchell 1996). Rams may be exposed to ambient temperatures ≥50 °C during the summer months in many sheep-rearing regions (Rasooli et al. 2010). Scrotal temperatures increase with increasing ambient temperature across both seasons and during daily variation (Marai et al. 2007). Histopathologic examination of rams housed in outdoor conditions indicated severe testicular degeneration during the nonbreeding season, where maximum ambient temperature ranged between 43 and 50 °C (Rasooli et al. 2010).

The decreased fertility of males observed during hot climatic conditions may be a result of testicular oxidative stress (Nichi et al. 2006). Testicular oxidative stress is associated with a number of fertility conditions in males (Turner and Lysiak 2008). Dietary antioxidants, such as vitamin B, vitamin E and selenium, have been reported to negate the negative effects of heat stress by improving/maintaining the oxidative status of sheep (El-Darawany 1999; Alhidary et al. 2012a, 2015; Chauhan et al. 2014). However there is limited literature on the effect of feeding dietary antioxidants on the reproductive characteristics of rams and other species. Studies on feeding seaweed for the carbohydrate, protein, vitamin, mineral and biological compounds have been reported to have positive (Yates et al. 2010) and negative (Samara et al. 2013) impacts on male reproductive status, suggesting that further investigation into the management of males during hot climatic conditions to minimise the effect of heat stress on semen quality is required.

The negative effects of heat stress on spermatogenesis are reversible (Gomes et al. 1971; Cruz Júnior et al. 2015; Alves et al. 2016). However recovery time is likely to incorporate a full spermatogenesis cycle (Cruz Júnior et al. 2015), which is approximately 47 days in the ram (Hochereau-de Reviers et al. 1987). Cruz Júnior et al. (2015) observed a 70–77-day period for semen characteristics to return to normal after insulating rams' testicles. Alves et al. (2016) observed a recovery period of between 35 and 63 days, suggesting that the recovery of semen characteristics may be variable between individuals. Irrespective of the impact of heat stress on male fertility, subfertility can have a major impact on a breeding population. This highlights the importance of conducting breeding soundness evaluations in rams, irrespective of seasons, particularly in extensively managed herds (Chacón et al. 1999). Ensuring the reproductive soundness of the ram, regardless of the impact of heat stress, will reduce reproductive losses associated with ram subfertility.

17.4 Climate Monitoring and Developing Climatic Indices

The thermal environment influences animal performance through the net effects of heat energy exchanges between an animal and their surrounding environment. The net thermal exchange that the animal undergoes is dependent on environmental conditions, animal factors and the animal's surroundings (Hahn 1985). Thus it becomes important to monitor and predict climatic conditions. The ability to forecast hot climatic conditions on livestock is important to producers in terms of welfare and performance, as it provides an opportunity to implement abatement strategies (Gaughan et al. 2008b). The development of climatic indices is difficult as these models require knowledge and understanding of the complex relationship that exists between animals and their thermal environment (Parsons et al. 2001; Gaughan et al. 2012). For livestock species the most commonly used model of thermal comfort is the THI (Marai et al. 2007; Sevi and Caroprese 2012; Macías-Cruz et al. 2015). The THI exists in various forms, which account for the net impact of ambient temperature and relative humidity (Buffington et al. 1981; Bohmanova et al. 2007; Sevi and Caroprese 2012). For sheep the THI can be calculated using the following equation: $\mathrm{THI} = T_{db} - [(0.31 - 0.31\ \mathrm{RH})(T_{db} - 14.4)]$, where T_{db} is the dry-bulb temperature (°C) and RH is the relative humidity (RH %/100) (Marai et al. 2007). The THI equation produces a unit value that is associated with stress categories in order to provide an indication of the severity of heat load conditions. When calculated in degrees Celsius, the THI thresholds are ≤ 22.2 no stress, indicating thermoneutral conditions; 22.2–23.3 alert, mild to moderate stress; 23.3–25.6 danger moderate to severe stress; and >25.6, emergency, extreme stress (Marai et al. 2007).

Whilst the THI is an important indicator of thermal stress, there are some limitations to its use. Primarily the model does not account for WS or SR (Mader et al. 2006, 2010; Gaughan et al. 2008b; Dikmen and Hansen 2009) nor does the model account for animal (i.e. genotype, coat characteristics, age, production status and reproductive status) or management (i.e. housing, shade availability, fans and nutritional management) factors to be accounted for (Gaughan et al. 2008b). Therefore the THI as a model implies that all animals respond to environmental stimuli in exactly the same manner (Gaughan et al. 2012). This is clearly not the case as the response of animal to hot climatic conditions is highly variable across and within studies for all livestock species. Attempts have been made to develop more comprehensive climatic indices incorporating other climatic variables and biological differences of animals. In particular, Gaughan et al. (2008b) developed a heat load index

(HLI) for feedlot cattle. Like the THI, the HLI generates a single unit value which represents the thermal load an animal is experiencing (Gaughan et al. 2010). The benefit of the HLI is that it combines the effects of relative humidity (%), wind speed (m/s) and black globe temperature (°C). In the development of the HLI model, thresholds and adjustments (+ and −) were identified, allowing for numerous animal factors (genotype, coat colour and health status) and management strategies (shade availability, days on feed, manure management and drinking water temperature) to be incorporated within the index (Gaughan et al. 2008b). Thus the HLI is able to account for the impact of climatic conditions, biological factors and management on thermal exchange mechanisms. Additionally, the HLI allows for the determination of accumulated heat load (AHL) describing the effect of intensity × duration on the thermal comfort of animals (Gaughan et al. 2008b). Although developed for feedlot cattle, the HLI is an example of a climatic index that is able to incorporate climatic, management and animal factors.

Considering the non-climatic influences on thermoregulation in animals, it is important that climatic indices are dynamic and comprehensive to be able to reflect the interactions between animals and their thermal environment. Whilst each consecutive index has provided a better understanding of (1) the impact of the thermal environment on animals and (2) animals' responses to the thermal environment, each index cannot completely account for biological and physiological responses of each individual animal, therefore highlighting the importance of recognising animal responses. Furthermore predictive climatic indices are not absolute, where the prediction is only as reliable as the weather forecast (Gaughan et al. 2012); therefore it is important to use climatic indices as management tools. Climatic indices should be used in conjunction with animal responses to implement informed mitigation management strategies during periods of hot climatic conditions. Future indices need to be able to reflect the dynamic relationship that exists between animals and their thermal environment. Future work with climatic indices must be expanded across species. Future development needs to focus on models that are better able to reflect the dynamic relationship that exists between biological factors, the thermal environment and management strategies.

17.5 Future Considerations

Climate change has the potential to exacerbate the impact of hot climatic conditions on sheep performance and well-being. Traditionally mitigating heat stress has been considered as an engineering issue where the solution has been focused on physical manipulation of the animals' environment with the use of air movement, water application and shade availability (Mahjoubi et al. 2014). The response of animals to heat stress is dynamic and complex. It is difficult to completely define the impact of heat stress on sheep as a singular stressor. Sheep in particular are potentially exposed to nutritional and thermal challenges simultaneously. Therefore it is important to consider the impact that other stressors, i.e. nutritional, social and physiological status, have on the performance and welfare of sheep, in conjunction with heat stress, highlighting that it becomes difficult to define the impact of heat stress alone. It remains unclear the impact of simultaneous stressors on the biological functions of the body. In future years, maintaining animal's performance and well-being during hot weather conditions requires continuing advancement in nutrition, mitigation management and selection of animals for thermal tolerance. Although not covered within this chapter, there is a growing body of evidence in support for the use of feed additives in heat stress diets. For example, supranutritional doses of dietary antioxidants, such as vitamin E and selenium, have been reported to negate the negative effects of heat stress by improving/maintaining the oxidative status of sheep (Alhidary et al. 2012a, 2015; Chauhan et al. 2014; Sejian et al. 2014) and other species. It is likely that supplementation of dietary antioxidants and other feed additives will become a key focus of heat stress research.

17.6 Conclusions

The impact of hot conditions cannot be completely removed where animal production occurs in tropical and subtropical regions. However, as knowledge regarding the impact of heat stress on biological functions advances, the alleviation methods become more sophisticated. Managing animals during heat stress is as much about the people as it is about the animals (Gaughan 2012). With the implementation of management strategies, producers are able to reduce the impact of heat stress. Better management of sheep, and other species, may reduce the initiation of thermoregulatory mechanisms which allows for better energy utilisation for growth and/or production. In the face of climate change, the continued development of heat stress management tools is needed to ensure the sustainability of animal-based agricultural enterprises.

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Nutritional Strategies to Alleviate Heat Stress in Sheep

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Abstract

Heat stress is the most intriguing factor negatively influencing sheep production. Heat stress management in sheep requires multiple strategies. There are several recent research findings which help to understand the hidden intricacies of nutritional intervention ameliorating the effects of heat stress in sheep. Applications of feed additives in particular were found to be the most widely adapted methodology to alleviate heat stress in an economical way. The commonly attempted feed additives include antioxidants, betaine, chromium, insulin mimics, and manipulation of concentrates to slow fermentation. These applications were either proved to be effective, or are currently being evaluated for their potency in reversing some of the effects of heat stress in sheep. Therefore, this chapter is an attempt to review different viable nutritional strategies to ameliorate heat stress in sheep.

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Contents

18.1 Introduction

Heat stress (HS) is an increasing problem for the livestock industries in the changing climate and reducing production, animal health and thereby the economy of the productive systems in tropical areas around the world (Silanikove 2000; St-Pierre et al. 2003). Sheep, especially European breeds, are relatively susceptible to HS because of the large amount of heat produced during feed fermentation and digestion (Goetsch and Johnson 1999; Roy and Collier 2012). The projected increase in global temperature warrants improving sheep production in tropical areas and promoting selection for both adaptive and productive genotypes for sheep. In this context, HS is considered to be both, the current and emerging challenge for sheep production.

There are several strategies that are available to mitigate HS impact in sheep. The current heat amelioration strategies such as provision of shade and high-quality water were found to be the foundation for sheep production systems. The currently available technologies for accurate weather predictions allow the formulation of suitable strategies using feed additives and nutritional interventions. The accuracy in weather forecasting allows the producers to prepare themselves for countering the heat events by promoting the use of summer-specific rations to ameliorate HS (Papanastasiou et al. 2015). This will be assisted by the ability to track individuals and developments in feeding systems (Greenwood et al. 2014).

HS amelioration is considered metabolically an expensive process for ruminant animals, with the National Research Council arbitrarily suggesting that mild to severe HS increases maintenance requirements by 7–25% (Baumgard and Rhoads 2013). The increased energy and micronutrient requirement during HS associated with reduced feed intake can lead to micronutrient deficiencies and altered metabolism, which ultimately result in reduced growth performance. There are few studies pertaining to nutritional strategies which are economically viable in ameliorating HS in dairy cattle, beef cattle, and pig production (Dunshea et al. 2013; DiGiacomo et al. 2014a; Cottrell et al. 2015). Hence this chapter is an attempt to review different viable nutritional strategies to ameliorate heat stress in sheep. In doing so, we will not focus on the physiology of HS as this is covered elsewhere in this book and in other reviews (Marai et al. 2007), except where it pertains to the mode of action of the nutritional strategies suggested.

18.2 Physiological Targets to Ameliorate Heat Stress

During HS condition, the animal body heat is gained from the environment as well as produced through metabolic activity, and to create equilibrium of the body temperature, the excess body heat must be dissipated. The radiant and evaporative heat losses are the primary mechanisms by which the animal dissipates the body heat. The redistribution of blood flow from the core body to the periphery characterizes the heat loss to the atmosphere. However, the prolonged exposure to high heat load in sheep might bring in a heat-stressed state which is characterized by insufficient heat dissipation leading to elevated body temperature, resulting in initial thermal injury that if unattended may lead to heat shock. The sequence of events associated with HS in sheep includes reduced feed intake, reduced growth rate, increased mortality, reduced fertility, reduced milk yield, and reduced lambing rate (Baumgard and Rhoads 2013).

The animals exposed to HS tend to show redistributed blood circulation from core parts of the body such as the splanchnic bed enclosing gastrointestinal tract (GIT) to the body surface (Bell et al. 1986; Hall et al. 2001). Functioning of GIT is an energy-consuming process, using approximately 25% of O_2 taken up by the body, while it only represents 5% contribution regarding the whole body weight (Linington et al. 1998). Of this 25% O_2 supply, 50% (12.5%) is being deviated only for liver functioning and this predisposes all the visceral organs in the hypoxic condition. Therefore, dietary agents such as antioxidants that can protect the GIT and other visceral tissues against hypoxia and oxidative stress (OS) could be useful in mitigating HS. Also, dietary additives such as insulin mimics that can increase blood flow to the skin or respiratory organs, including chromium (Cr), zinc (Zn), vanadium (V), and thiazolidinediones (TZDs) (DiGiacomo et al. 2014a) could be useful in mitigating HS.

The higher respiration rate and panting in heat-stressed animals would cause decreased pCO_2 and increased pO_2 in blood. Sequentially, decreased buffering of blood pH with CO_2 and bicarbonates generates lower blood pH, and thereby respiratory alkalosis. Considering the higher evaporative cooling requirements of animals in HS condition, the normal responses involved in reducing alkalosis such as decreasing respiration rate decline, which in turn leads to disturbed acid-base balance. Hence, HS-induced higher H^+ excretion and urine acidification (Patience et al. 2005) and enhanced maintenance energy requirements are seen in animals for regulating renal pH (Baumgard and Rhoads 2013). Thus, dietary strategies that can ameliorate urine acidification may protect against HS.

Heat production derived from feed fermentation and digestion varies according to the nature and amount of feed consumed. Differences in heat increment among carbohydrates ingested are closely related to their fermentability and volatile fatty acids utilization by the animal (MacRae and Lobley 1982). Forages and roughages have a greater heat increment from fermentation compared to cereal grains, mainly due to the inefficient postabsorptive utilization of acetate compared to propionate (MacRae and Lobley 1982; Bernabucci 2012). However, consumption of rapidly fermentable grains like wheat is associated with digestive disorders and laminitis (Nocek 1997) and HS in feedlot cattle (Brosh et al. 1998; Mader et al. 1999).

18.3 Dietary Antioxidants

The coupled existences of HS and OS are well documented in cattle (Bernabucci 2012) and sheep (Chauhan et al. 2016a). Seeing that OS originates when there is an imbalance between concentrations of reactive oxygen species (ROS) and antioxidant power, additional antioxidant supplementation is proved as a viable management strategy to mitigate oxidative damage. Conventionally, antioxidants are mainly categorized into two classes as nonenzymatic and enzymatic and both contribute rigorously to antioxidant defense mechanism. The nonenzymatic antioxidants such as uric acid, glutathione, vitamin E (Vit E), vitamin C (Vit C), and polyphenols are reducing in nature, while the enzymatic antioxidants such as catalase, superoxide dismutase, and glutathione peroxidase (GSH-Px) neutralize the free radicals and their metabolites.

The Se and Vit E are found to act coordinately with reference to the metabolic functions. The most significant function of the Vit E is the protection of cells from OS by converting ROS and lipid hydroperoxides into nonreactive states (Hidiroglou et al. 1992). Similarly, selenium (Se), which is an essential component of GSH-Px, also provides protection against oxidative damage (Rotruck et al. 1973). Thus, both Se and Vit E prevent the oxidative damage to biological membranes by neutralizing oxidants or free radicals.

The HS-induced OS is likely to cause damage to mitochondria, which are the primary intracellular source of ROS. Metabolic alterations during HS may result from damaged or malfunctioning mitochondria, due to the effects of heat directly or by increased OS (Rhoads et al. 2013). While superoxide production can be reduced by uncoupling of the electron transport chain by uncoupling proteins, uncoupling proteins are themselves down-regulated during HS (Mujahid et al. 2006), which is potentially a protective mechanism to prevent further heat production. The ROS are produced during normal aerobic metabolism; therefore, the increased energy demands imposed by elevated ambient temperatures may also contribute to ROS generation and OS (Rhoads et al. 2013).

Recent research has shown that supplementation with Vit E, or Se, or their combination alleviated the physiological response to HS in sheep (Alhidary et al. 2012; Chauhan et al. 2014a, b), goats (Sivakumar et al. 2010), and dairy cows (Calamari et al. 2011). Supplementation of Vit E and Se, either individually or combined, at supranutritional levels can partially mitigate against the effects of HS, lowering respiration rate and rectal temperature and improving feed intake and oxidative balance in sheep (Sejian et al. 2014; Chauhan et al. 2014a). In an elegant study, Sejian et al. (2014) included supplemental inorganic Se and Vit E, in addition to the insulin mimics Cr and Zn, and saw profound reductions in the magnitude of the increase in respiration rate (−18%) and rectal temperature (−71%) in Malpura ewes (Table 18.1). A series of subsequent studies have now been conducted to determine the individual effects of some of these dietary antioxidants and additives, and the results of these are summarized in Table 18.1. The most consistent improvements in the ability of sheep to handle HS, at least when assessed as a reduction in the increment in respiration rate and rectal temperature, appear to be to supplementation with Vit E. In young Merino x Poll Dorset ewes, Vit E supplementation at 100 IU/kg DM decreased the magnitude of the increase in respiration rate (−26%) and rectal temperature (−41%) compared to those ewes receiving 10 IU/kg DM (Table 18.1). Physiological responses to supplemental Se (1.20 mg Se/kg DM as selenized yeast) alone were not as great as with Vit E, with the average reduction in the increases in respiration rate and rectal temperature being −14% and −6%, respectively, compared to those ewes receiving 0.24 mg Se/kg DM (Table 18.1). These findings with dietary Se supplementation are consistent with the work of Alhidary et al. (2012) where injection of up to 5 mg Se/d as sodium selenite reduced rectal temperature but not respiration rate during HS. However, feed intake was increased and live weight loss decreased in sheep receiving Se, and the increased heat production associated with the improved performance may have partially masked the improved physiological responses. When a combination of supranutritional dietary Se and Vit E was fed, there were very consistent decreases in the magnitude of the increase in respiration rate (−22%) and rectal temperature (−25%) in five comparisons (Table 18.1).

Most of the studies in Table 18.1 were relatively short-term studies (1–3 weeks) with various lengths of time (generally 2 weeks) of dietary preloading before the imposition of the cyclical (generally) HS conditions. In this context, it is important to note that supplementation with Se or Se and Vit E during a 22 day HS period decreased the magnitude of a loss of body weight feed efficiency but only if the sheep had been prefed the supranutritional diets before the HS period (Alhidary et al. 2015). In other words, the body reserves of Se and antioxidants need to be enhanced before HS occurs and so prophylactic use of antioxidants is recommended. Indeed, this most likely applies to any of the dietary strategies that may be used to ameliorate HS, and so the ability to predict when a HS event is likely to occur through web-based tools or meteorological bureau data will greatly increase the ability to use dietary manipulations to ameliorate the effects of HS (Dunshea et al. 2013).

While the physiological (respiration rate and rectal temperature) responses to Se do not appear to be as strong and consistent as those to Vit E, there do appear to be production responses to Se alone, as well as some synergies between the two antioxidants that indicate that combined supplementation is more effective in mitigating against HS (Chauhan et al. 2015). For example, when given at high doses individually, Se or Vit E had little effect on the acid-base balance of sheep. However, when combined, they ameliorated some of the negative effects of HS on acid-base balance. Also, while supranutritional Se and Vit E tended to individually decrease OS, the combined supplementation resulted in a synergistic action in preventing

Table 18.1 Effect of heat stress (HS) on various dietary additives on respiration rate and rectal temperature in sheep

		Respiration rate (breaths/min)				Rectal temperature (°C)			
Diet and study	Dose	Control	HS	HS + Diet	% protect	Control	HS	HS + Diet	% protect
Selenium									
Chauhan et al. (2015)	1.2 mg/kg DM*	90	232	216	11	39.59	40.64	40.62	2
Chauhan et al. (2016a)	1.2 mg/kg DM	81	231	205	17	39.60	40.61	40.50	11
Vitamin E									
Chauhan et al. (2015)	100 IU/kg DM	90	232	198	24	39.59	40.64	40.20	42
Chauhan et al. (2016a)	100 IU/kg DM	81	231	189	28	39.60	40.61	40.22	39
Selenium + Vitamin E									
Chauhan et al. (2014a)	1.2 mg + 100 IU/kg DM	98	208	191	15	39.55	40.46	40.31	16
Chauhan et al. (2015)	1.2 mg + 100 IU/kg DM	90	232	191	29	39.59	40.64	40.33	30
Chauhan et al. (2016a)	1.2 mg + 100 IU/kg DM	81	231	189	28	39.60	40.61	40.35	26
Chauhan et al. (2016b)	0.66 mg + 130 IU/kg DM	73	203	171	25	39.59	40.31	40.11	28
	1.16 mg + 228 IU/kg DM	73	203	183	15	39.59	40.31	40.14	24
Betaine									
DiGiacomo et al.(2016)	2 g/d	97	148	142	12	39.35	40.30	40.15	16
	4 g/d	97	148	155	−14	39.35	40.30	40.42	−13
DiGiacomo (2011)	35 g/d	40	96	130	−61	39.60	40.20	40.35	−25

Diet and study	Dose	Respiration rate (breaths/min)				Rectal temperature (°C)			
		Control	HS	HS + Diet	% protect	Control	HS	HS + Diet	% protect
Chromium									
Hung et al. 2014	400 ppb	72	218	207	8	39.30	40.39	40.19	18
	800 ppb	72	218	213	3	39.28	40.40	40.27	12
Mixture[a]									
Sejian et al. (2014)	Zn, Co, Cr, Se, Vitamin E	42	109	97	18	38.77	39.24	38.91	71

[a] zinc sulfate 164.0 mg, cobalt sulfate 0.95 mg, chromium acetate 1.2 g, selenium chloride 0.1 mg, and Vitamin E 40.0 mg

[*] DM = Dry matter

oxidative damage of cellular macromolecules such as proteins by reducing the OS index, as well as increasing the expression and activity of antioxidant enzymes such as GSH-Px (Chauhan et al. 2015). Finally, data from other species suggest that dietary Se alone can reduce the effect of HS on gut permeability and resistance as well as expression of GSH-Px, and that these effects are not enhanced by supplemental Vit E (Maseko et al. 2014, 2015).

While the effects of antioxidants such as supranutritional levels of Se are striking, there are some issues of using high levels of Se in some jurisdictions. Organic forms of Se such as selenized yeast, selenomethionine, or other protein-bound Se are considered safer than selenite or selenate with little chance of toxicity (Heard et al. 2007). Regardless, there is a need to consider other antioxidants where high levels of Se are not allowed. Obvious opportunities exist in utilizing plant-derived antioxidants (Rochfort et al. 2008) which can be provided by feeding high-quality forages such as lucerne, which contains Vit E in the natural form (RRR α-tocopherol), carotenoids, flavonoid, and phenolic compounds, which all exert antioxidant activities (Rochfort et al. 2008). Recently, Ponnampalam et al. (2014) were able to demonstrate that lambs grazing perennial pasture containing lucerne (alfalfa) could accumulate Vit E at sufficient levels to protect against oxidation of meat. Lucerne represents an important alternative to grass pasture especially over summer due to its drought tolerance and positive impact on animal productivity and carcass quality (Humphries 2012; Ponnampalam et al. 2014). A recent study has shown that finishing lambs on green lucerne hay improved color stability of fresh (1-day aged) meat compared to a diet containing supranutritional levels of Vit E and Se in lambs over summer (Baldi et al. 2015). This was possibly due to the higher bioavailability of Vit E provided through natural sources compared to the artificial form and the presence of other micronutrients influencing antioxidant activity in the muscle. Similar dietary approaches need to be evaluated in controlled HS conditions to determine whether they may effectively replace supranutritional Vit E and Se.

18.4 Chromium and Other Antidiabetic Agents

The influence of insulin on HS responses was first recognized in humans, through elevated mortality rates of diabetic patients during heat wave periods (Schuman 1972; Semenza et al. 1999). Although the specific mechanism by which insulin impedes HS is not fully disclosed, it can be partly explained by enhanced regional blood flow associated with high radiant heat dissipation. Hence, additional supplementation of insulin enhancers would be an effective strategy to ameliorate HS impacts. Compounds of interest include the antidiabetic compounds such as Cr, Zn, TZDs, and V (DiGiacomo et al. 2014a), and it is interesting to note that both Cr and Zn were components of the antioxidant and mineral mix that was very successful in protecting against HS in Malpura ewes (Table 18.1) (Sejian et al. 2014).

Chromium (Cr) plays a crucial role in carbohydrate, fat, and protein metabolism by enhancing insulin action efficiency (Mertz 1993). The Cr also influences glucose metabolism by determining the glucose tolerance factor. A strong correlation between chromium picolinate (CrPic) level and insulin activity was reported in animals. The elevated insulin sensitivity due to higher CrPic concentration was evident from higher glucose clearance rate and lower glucose half-life, which were clearly visible in both glucose tolerance and insulin challenge tests (Amoikon et al. 1995). Additionally, CrPic also augments the insulin internalization rates and improves the glucose intake by skeletal muscles (Evans and Bowman 1992). The Cr supplementation in sheep when subjected to external stresses such as transportation stress has been reported to have a positive influence on the physiological and production aspects (Al-Mufarrej et al. 2008; Kraidees et al. 2009) and in heat-stressed chicken (Sahin et al. 2002a, b). Further, increase in feed consumption has also been observed in quail supplemented with CrPic (Sahin et al. 2002a). Al-Saiady et al. (2004) reported that during high-temperature periods, feed intake and milk production in Holstein cows would increase when supplemented with CrPic. Hence, Cr supplementation offers a promising strategy to reduce HS impact in sheep.

Using an intravenous glucose tolerance test, Gentry et al. (1999) found that dietary supplemental CrPic decreased glucose clearance rate in lambs provided with a high-protein diet but not with a low-protein diet. Using a hyperinsulinemic and euglycemic clamp technique, Sano et al. (1999) found that dietary Cr (as Cr yeast) decreased maximal tissue responsiveness to insulin but that there was no effect of mild heat exposure (20 °C vs. 30 °C). Studies showed increased sensitivity of insulin to the ambient temperatures, with higher value in mild heat-stressed animals than the thermoneutral group. However, the insulin concentration did not vary between different diets. Achmadi et al. (1993) found that basal glucose decreased and plasma insulin increased during HS in Suffolk sheep fed with either a roughage- or concentrate-based diet. Using the hyperinsulinemic and euglycemic clamp technique, these authors found no effect of HS on the amount of glucose required to maintain glycemia or on the increase in insulin level at the endmost hour of the glucose and insulin infusion (Achmadi et al. 1993). Using the hyperglycemic clamp technique, these authors found no effect of HS on the amount of glucose required to achieve hyperglycemic conditions (50 mg/dL above basal), but that the increment in insulin concentration over the final hour of the glucose infusion was increased during HS (Achmadi et al. 1993). DiGiacomo (2011) found that basal plasma insulin was increased, whereas the quantitative insulin sensitivity check index was decreased during HS. Minimal modeling responses from an intravenous glucose tolerance test (IVGTT) indicted an increase in insulin resistance during HS (DiGiacomo 2011). Therefore, it appears that under some conditions HS can either increase or decrease insulin sensitivity in sheep, with responses perhaps depending upon the degree of HS and the technique employed to assess insulin sensitivity.

Recently, an experiment conducted by Hung (2013) in sheep evaluated the influence of different dietary Cr levels (0, 400, and 800 ppb supplemental nano-sized CrPic) during both control and cyclic HS conditions. Lower feed intake (P = 0.003) was recorded in the heat-stressed group (1163 g/day) than in the thermoneutral group (1343 g/day), while it was observed to be increased (P = 0.045) in both the thermoneutral and heat-stressed (1171 g/day) group under CrPic supplementation. A similar trend to that of feed intake was recorded for the live weight gain in sheep.

However, dietary CrPic supplementation reversed this condition by increasing the live weight gain. Dietary CrPic decreased the magnitude of the increase in respiration rate (−6%) and rectal temperature (−15%) compared to control ewes during HS (Table 18.1). While these effects of CrPic were not as pronounced as dietary antioxidant supplementation, the increased feed intake and live weight gain (or reduction in live weight loss) and the associated greater metabolism and heat production may have partially masked the improved physiological responses.

The IVGTT was used to assess the insulin sensitivity in sheep during the third week of HS treatment. The HS reduced basal insulin concentration, which was unaffected even after supplementation with CrPic. However, in sheep supplemented with Cr as well as those subjected to HS diet, the IVGTT recorded reduced plasma insulin response (Fig. 18.1). The effect of HS on insulin sensitivity is surprising and counter to the initial hypothesis, but may be a metabolic adaptation to increase microcirculation in the lung or periphery to enhance the dissipation of heat. Alternatively, the reduced insulin response to an IVGTT during HS may indicate a decrease in the ability of the pancreas to secrete insulin, and any improvement in peripheral tissue insulin sensitivity due to Cr may assist in handling HS. From the above-discussed data, it was evident that dietary Cr can reverse the HS impact in sheep, and some of these reversal effects could be through improving the insulin sensitivity.

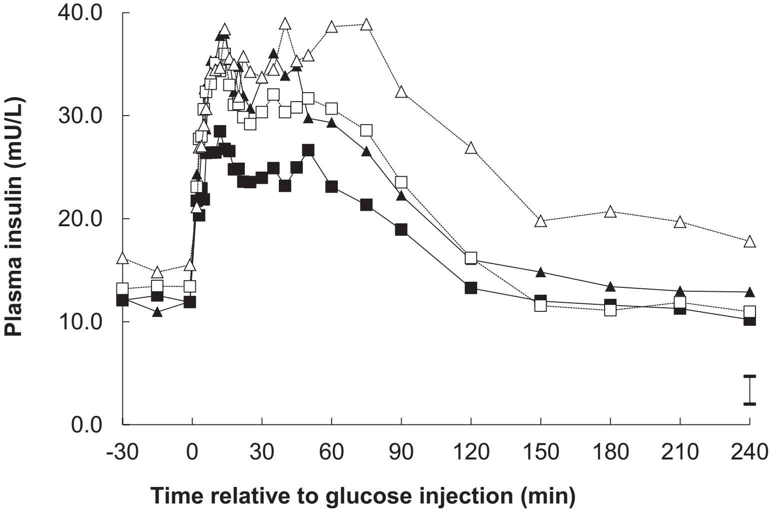

Fig. 18.1 Relationships between plasma insulin and time relative to an intravenous glucose tolerance test injection in lambs under thermoneutral conditions fed either a control- (Δ) or nano-CrPic- (□) supplemented diet and lambs under HS conditions fed either a control- (▲) or nano-CrPic- (■) supplemented diet. The standard error of the difference for the interaction between temperature, dietary nano-CrPic, and time is displayed at 240 min. The P-values for the effect of HS, nano-CrPic, time, HS × nano-CrPic, HS × Time, nano-CrPic × Time, and HS × nano-CrPic × Time were 0.004, 0.002, <0.001, 0.50, 0.002, <0.001, and <0.001, respectively (From Hung 2013)

The Zn also mimics the effect of insulin at a higher dose, and therefore dietary Zn has been proposed to be an important measure in controlling adipogenesis and marbling in heat-stressed cattle (Kawachi 2006). It has been observed that Zn has been used alone or in combination with insulin to control adipogenesis, and further it was established that Zn increased the rate of adipogenesis. This effect of Zn on adipogenesis was dose dependent and it was observed that its effect on the adipogenesis was not as high as insulin (Yano et al. 2004). However, whether this same effect of insulin can be mimicked under in vivo condition still remains to be elucidated. Further, it was observed that Zn supplementation did not affect either the plasma glucose concentration or glucose clearance in lambs (Wang 2006; Droke et al. 1993). However, Pearce et al. (2015) found that supplemental Zn could partially mitigate some of the negative effects of HS on gut integrity in pigs.

18.5 Dietary Betaine

Betaine is an amino-acid derivative (tri-methyl glycine) which is present naturally in many plants and invertebrate species. Betaine plays a significant role in controlling osmoregulation and serves as a methyl group donor via S-adinosyl-methionine pathway. Betaine was observed to have a growth-promoting effect through reducing the maintenance energy requirements as well as the need for sodium/potassium pumping to maintain cellular osmolarity when incorporated in pig diets (Schrama et al. 2003; Suster et al. 2004). Further, in poultry it has been observed that betaine supplementation can improve the integrity of gut mucosal cells as well as reduce the severity of enteric infections (Matthews and Southern 2000). Also Cronje (2005) established the role of dietary betaine in improving the gut integrity during HS condition. However, the majority of reports on the role of betaine during HS condition were more on pigs and poultry as compared to ruminants, but the limited studies on ruminants establish the clear evidence of the role of betaine in HS animals, thereby improving the feed intake and growth performance in beef cattle (Cronje 2005; Loxton et al. 2007). Further, the milk yield in dairy cows was found to be significantly higher after betaine supplementation in their diets during the summer season (Zhang et al. 2014; Dunshea et al. 2013).

There have been very few studies investigating the effects of betaine in sheep, and those that have been conducted have largely focused on sparing of methionine for wool growth. The role of dietary betaine in modifying the physiological response during HS in sheep was established by DiGiacomo et al. (2014a). This study was conducted in Merino sheep with three different betaine supplementation treatments (0, 2, and 4 g Betaine/day) and two temperature treatments (control and cyclical HS for 3 weeks). Results from the study indicated that the sheep fed with 4 g betaine per day were recorded with higher rectal temperature as compared to that of low-dose betaine-fed groups (Table 18.1). The same result as that of rectal temperature was established for respiration rate. Thus, 2 g betaine/day decreased the magnitude of the rise in respiration rate (−12%) and rectal temperature (−16%) compared to those ewes receiving no supplemental betaine, whereas 4 g betaine/day increased the magnitude of the increase in respiration rate (+14%) and rectal temperature (+16%). At very high levels of betaine supplementation, the increases in the magnitude of the rise in respiration rate (+14%) and rectal temperature (+16%) were even more profound (DiGiacomo et al. 2014a; Table 18.1). Interestingly, supplemental betaine at both 2 and 4 g/day increased growth rate under both thermoneutral and HS conditions (DiGiacomo et al. 2014a). Quadratic responses to dietary betaine have also been observed in beef cattle during summer conditions (DiGiacomo et al. 2014b). Therefore, it appears that dietary betaine does appear to improve growth performance and physiological responses to HS, but the response is very dose dependent.

18.6 Concentrate Feeding

The heat increment from fermentation accounts for approximately 8% of the total heat production of ruminants (Czerkawski 1980) and varies according to the nature of feed consumed. Forages and roughages have a greater heat increment from fermentation compared to cereal grains, mainly due to the inefficient postabsorptive utilization of acetate compared to propionate (MacRae and Lobley 1982; Bernabucci 2012). For example, Achmadi et al. (1993) found that an isoenergetic concentrate diet decreased the magnitude of the increase in respiration rate (−11%) with no change in rectal temperature (0%) compared to sheep consuming a roughage diet and exposed to HS (Table 18.2). On the other hand, Dixon et al. (1999) found that concentrate feeding increased the magnitude of the increase in respiration rate (+10%) and decreased the increase in rectal temperature (−11%) during HS (Table 18.2). It is likely that the increase in respiration rate in the concentrate-fed lambs of Dixon et al. (1999) during HS may have been due to increased metabolizable energy (ME) intake (+32%) and daily gain (+72%). On the other hand, supplementing roughage with fishmeal decreased the magnitude of the increase in respiration rate (−6%) but increased the increase in rectal temperature (+11%) during HS (Dixon et al. 1999) (Table 18.2).

Therefore, it appears that feeding dietary cereal supplements may be a way to increase or maintain ME intake and performance during HS in sheep and other ruminants (West 1999). In many parts of the world where HS is an issue for sheep production, the most readily available grain is often wheat (Sinclair et al. 2003). However, consumption of rapidly fermentable grains like wheat is associated with digestive disorders and laminitis (Nocek 1997) and HS in feedlot cattle (Brosh et al. 1998; Mader et al. 1999). For example, Gonzalez-Rivez et al. (2016a; b) compared the effect of feeding 50% wheat and 50% corn to sheep during thermoneutral and HS conditions and found that corn decreased the magnitude of the change in respiration rate (−22%) and rectal temperature (−26%) compared to wheat. This response was seen at a variety of different feed intakes from 1.3 up to 2.0 times maintenance (Table 18.2). Interestingly, there were clear differences in flank temperature and the difference between the right and left flank, indicating differences in the heat of fermentation between corn- and wheat-fed sheep; these findings are consistent with observations in dairy cows (Bland et al. 2013).

Table 18.2 Impacts of heat stress (HS) on various manipulations of diet on respiration rate and rectal temperature in sheep

Diet and study	Dose	Respiration rate (breaths/min)				Rectal temperature (°C)			
		Control	HS	HS + Diet	% protect	Control	HS	HS + Diet	% protect
Gonzalez-Rivas et al. (2016a, b)	Wheat vs. Corn (1.3 × M)	73	166	145	22.6	39.3	39.75	39.7	19.1
	Wheat vs. Corn (1.5 × M)	73	173	147	26.0	39.3	39.83	39.7	32.7
Gonzalez-Rivas et al. (2016a, b)	Wheat vs. Corn (1.7 × M)	75	188	156	28.3	39.4	39.79	39.7	23.3
	Wheat vs. Corn (2.0 × M)	75	199	175	19.4	39.4	39.93	39.8	28.1
	Wheat vs. Soda Wheat (1.7 × M)	75	188	174	12.4	39.4	39.79	39.9	−20.9
	Wheat vs. Soda Wheat (2.0 × M)	75	199	200	−0.8	39.4	39.93	40	−7.0
Dixon et al. (1999)	Roughage vs. concentrate	49	194	208	−9.7	39.20	40.10	40.00	11.1
	Roughage vs. fish meal	49	194	186	5.5	39.20	40.10	40.20	−11.1
Achmadi et al. (1993)	Roughage vs. concentrate	37	171	156	11.2	39.30	39.60	39.60	0.0

Treating whole wheat with sodium hydroxide (NaOH) reduces the rate of in vitro rumen fermentation (Tománková and Homolka 2004), and in vivo and in situ experiments have demonstrated that the treatment of wheat with NaOH can slow rumen starch fermentation to reduce the susceptibility to rumen acidosis (Schmidt et al. 2006; Deckardt et al. 2013). Recently, Gonzalez-Rivaz et al. (2016b) have shown that treating wheat with sodium hydroxide decreased the magnitude of the increase in respiration rate (−12%) but increased the magnitude of the increase in rectal temperature (+21%) during HS in sheep fed at 1.7 times maintenance. When fed at twice maintenance, there was no effect on respiration and a small increase in rectal temperature compared to sheep consuming the untreated wheat. However, it should be borne in mind that the sheep consuming the sodium hydroxide-treated grain had a greater feed intake when provided feed ad libitum and the increase in metabolic heat production, which may have masked the protective effects against HS. So treating wheat with sodium hydroxide may offer a means of providing concentrates to sheep that may be exposed to HS. In addition, fermentative heat generation from wheat can also be reduced by modifying wheat with starch binding agents to lower its rumen fermentation rate (Dunshea et al. 2012).

18.7 Conclusion

Recent advancements in the understanding of HS impacts on sheep physiology, nutrition, and metabolism signified the promotion of nutritional strategies for mitigating HS challenges. Nutritional strategies for amelioration of HS involve several approaches such as enhancing antioxidant defense, insulin reactivity, need of osmolytes to lower maintenance requirements, and use of concentrates with moderate fermentability. However, the above-mentioned different interventions can be effectively targeted through cost-effective feed additives for mitigating HS impacts on sheep production. While delivery may present problems in some extensive systems, this will be assisted by the ability to track individuals and developments in feeding systems.

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Significance of Body Condition Scoring System to Optimize Sheep Production

19

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Abstract

Body condition scoring (BCS) is a reliable measure of relative body fatness. Animals are systematically described and categorized into different groups based on the differences in BCS. BCS is a subjective system of scoring the animals. However, it also serves as a reliable tool for assessing body composition. The procedure of BCS is both simple and beneficial and provides an efficient way to make management strategies regarding the feed and nutrient requirements for better animal performance. The nutritional status of sheep at different production phases can be estimated with the BCS system, which allows the farmers to make decisions regarding the time and in what way to supplement the flock to attain a productive goal in an economic way. It is desirable to have ewes with 3.0 or 3.5 BCS at the time of mating to get higher lambing rates as well as higher birth weight of lambs per lambing. Similarly, the rams with BCS between 3.0 and 3.5 BCS also exhibited better reproductive efficiency than those with lower and higher BCS. The additional energy supplementation to obtain a higher BCS did not bring significant improvement in the reproductive performance of ewes and rams. This clearly indicates that maintaining an optimum BCS in sheep by providing optimum nutrition will reduce the feed wastage as well as the additional costs for the supplementary feeding. In this chapter, moderate BCS (3.0–3.5) is established as adequate for optimal performance at both mating and lambing

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stage of sheep maintained in hot, tropical areas. Hence, this proves that in order to get optimum return from sheep farms, efforts should be made to maintain optimum BCS in sheep rather than attempting to attain higher BCS.

Keywords
BCS • Heat stress • Nutrition • Reproduction • Sheep

Contents

19.1 Introduction

Small ruminants and in particular sheep play a major role in rural agriculture in the arid and semiarid tropics. Sheep possess unique characteristics to convert the unused residue of crops and poor grasslands to products such as meat, wool, milk, and skin having economic relevance. Sheep are natural grazers and are reared in an extensive management system. Sheep have the ability to cope with periods of harsh climate and feed scarcity by efficient mobilization of body reserves. Hence, in such situations simple and reliable methods like body condition scoring (BCS) can be used to assess the nutritional status of the animal in order to make management decisions regarding the nutrient supplementation needed to maintain the vital physiological functions of the body (Maurya et al. 2007, 2012a; Sejian et al. 2012a). BCS provides the sheep owners with the subjective knowledge of the well-being status of the flock, which tells the farmers to improve the production efficiency of the animals (Lowman et al. 1976). The sheep producers should be aware of the physiological status of the animals at different stages of the production cycle such as breeding, late pregnancy, and lactation. The numeric system of BCS is a reliable estimator of percentage of body fat in sheep. At each stage of the production cycle, the optimum condition required for each ewe in the flock will be different (Maurya et al. 2008, 2009b).

Knowing the optimum requirements of the flock can help the sheep farmers to reduce the feed wastage, as well as save input costs for the feed by making a suitable feeding program based on the requirement of the production stage in the animal.

BCS in sheep is a reliable tool to assess the nutritional status of breeding flocks. BCS is positively related to future success in conception, and avoiding dystocia and retained placenta and other illnesses. Optimum conditions during mating will enhance the ovulation rate and thereby increase the lambing percentage in ewes (Khan 1994; Maurya et al. 2009a; Sejian et al. 2010a). Generally the ovulation rate is higher in heavier ewes. Further, the fertility rate, litter size, and birth weight are higher in heavier ewes than lean ewes (West et al. 1989; Esmaeili-Zadeh et al. 2004). It has been established that BCS of ewes at lambing stage will influence the body weight of the weaned lambs. Lower lamb (Khan 1994) survivability and higher chance of mortality in the prenatal (West et al. 1989) and neonatal (Nordby et al. 1986) stages were reported in low BCS ewes. When the donor ewes are undernourished with low BCS and body weight, oocyte quality will be reduced, resulting in lower cleavage rate. Further, several reproductive functions in the ewes like hormone production, fertilization, and development of embryo will be impaired (Boland et al. 2001; Armstrong et al. 2003). Also, the breeding rams contribute significantly to the improvement of the reproductive performance and genetic potential of the flock. The BCS of the sheep drastically affects the manifestation of sexual behavior (Maurya et al. 2010a, 2012a), growth (Sejian et al. 2010b, 2015b), endocrine profile (Sejian et al. 2010c), and semen quantity and quality in rams (Maurya et al. 2016).

Reduced productivity in ewes is associated with lower BCS during periods of gestation or after lambing (Russel et al. 1969). Further, the undernutrition in ewes during late gestation or in early postnatal life results in permanent and irreversible decrease of lambing rates (Williams 1984; Gunn et al. 1995). The effects of lower BCS are also reflected in the live weight, carcass weight, and meat yield of the animals (Delfa et al. 1991). Hence, BCS serves as a useful tool to estimate the saleable sheep meat that can be beneficial for those engaged in sheep marketing. Every year sheep die due to scarcity of feed and high environmental temperature (Maurya et al. 2010a) conditions because they do not have sufficient body reserves to sustain them against the demand of the inclement weather, inadequate grazing, and pregnancy followed by rearing lambs. The combined stress (thermal, nutritional, and walking) negatively affects the growth and reproductive performance of sheep (Sejian et al. 2011; Maurya et al. 2012b). Underconditioned sheep are prone to health issues whereas the overcondition leads to difficulty in lambing. Therefore, feed should be reduced for the overconditioned animals. This can save some amount of feed that can be provided to improve the condition scoring in low-BCS animals. Hence, in order to optimize productivity, sheep producers should give priority to BCS in order to ensure adequate condition score at different production stages. Turnover from sheep especially in terms of reproductive efficiency will be higher only if the animals are maintained at appropriate BCS based on the different reproductive phases in sheep.

19.2 What Is Body Condition Scoring?

BCS is an index to measure relative body fatness. Animals are systematically described and classified as different BCS groups based on the differences in relative body fatness. BCS is a subjective system of scoring. However, body composition can also be assessed using the BCS system. The BCS system exactly evaluates the fatness or thinness of an animal rather than simply assessing the outer appearance (Russel et al. 1969; Maurya et al. 2008). BCS is a reliable indicator of body fatness and amount of muscle in the body. Assessing the condition score using the hands and feeling the animal's transverse process, spinous process, and fullness of the body will be useful to assess accurate BCS. Assessing the condition score through mere visual appearance must be avoided as the thick wool or skin hair can often be misleading. A standardized technique is generally used to assess the scoring that can be well understood by the livestock farmers, advisers, or veterinarians (Maurya et al. 2009b). Comparisons can be made between the sheep flocks and over the years since the scoring system provides a fairly reliable subjective measure of the body condition. BCS enables the sheep farmers to clearly monitor the progress of their flocks in their productive and reproductive performance. Using condition scores, the health status of individual animals can be assessed during routinely held animal management or welfare inspection of the animals. BCS is the best way to enhance the flock's nutrition, although it is usually overlooked. If this step is not considered, other farm activities like sampling of forage and formulation of balanced ration become a futile exercise. Sheep farmers should assess the response of the flock to the feed supplementation. Better flock nutrition is not a possibility if the farmers fail to practice BCS.

19.3 Different Condition Scores in Sheep

The 1–5 point condition scores for sheep are (1) Emaciated (Fig. 19.1), (2) Thin (Fig. 19.2), (3) Good (Fig. 19.3), (4) Fat (Fig. 19.4), and (5) Obese (Fig. 19.5).

19.3.1 Condition Score 1 for Sheep

Features The animal skeleton is characterized by little or no muscle. Flank hollows below the loin area are very concave.

Causes Inadequate nutrition, disease occurrence, parasitism, lactation, or a combination of any of these factors.

Problems Impaired growth in kids, stunting of growth in growing animals, reduced conception rate and abortion, neonatal mortality, weak newborns, pregnancy-related metabolic diseases, and high susceptibility to diseases.

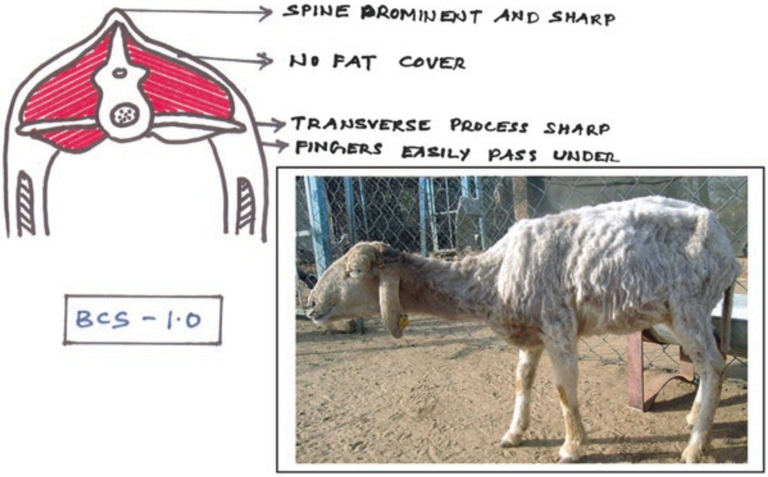

Fig. 19.1 Sheep with body condition score 1 (emaciated)

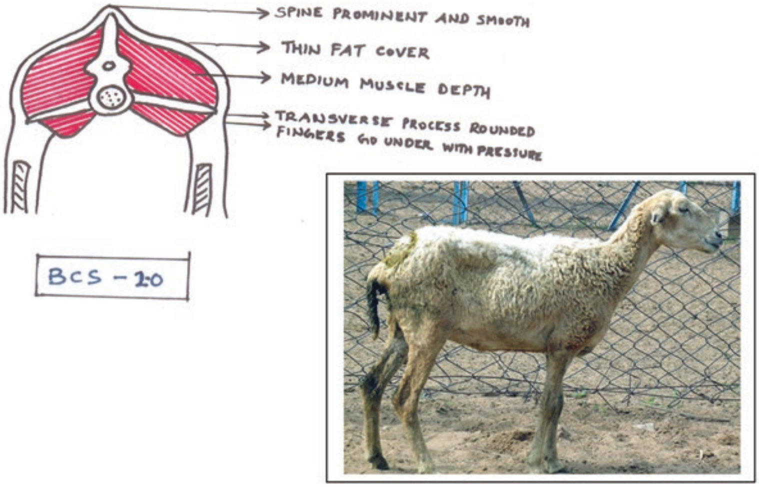

Fig. 19.2 Sheep with body condition score 2 (thin)

Solutions Optimum nutrition, management interventions and programs to improve herd health, and periodic evaluation of disease status in the animal.

19.3.2 Condition Score 2 for Sheep

Features Some muscle is present in the skeleton. Flank hollows are somewhat concave.

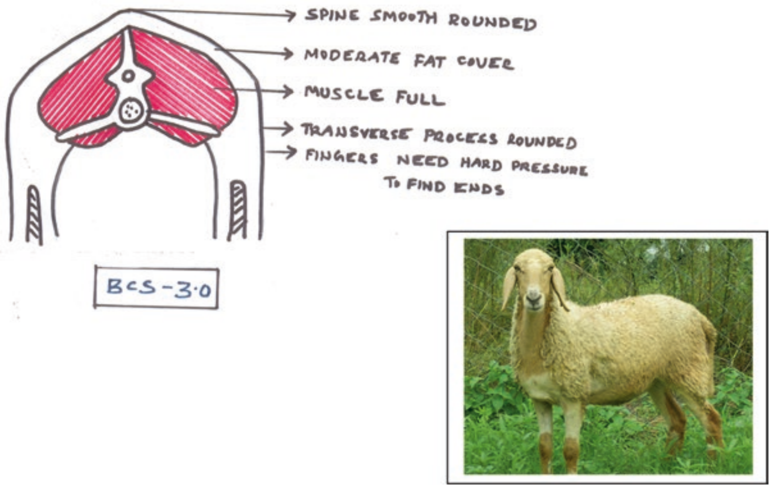

Fig. 19.3 Sheep with body condition score 3 (good)

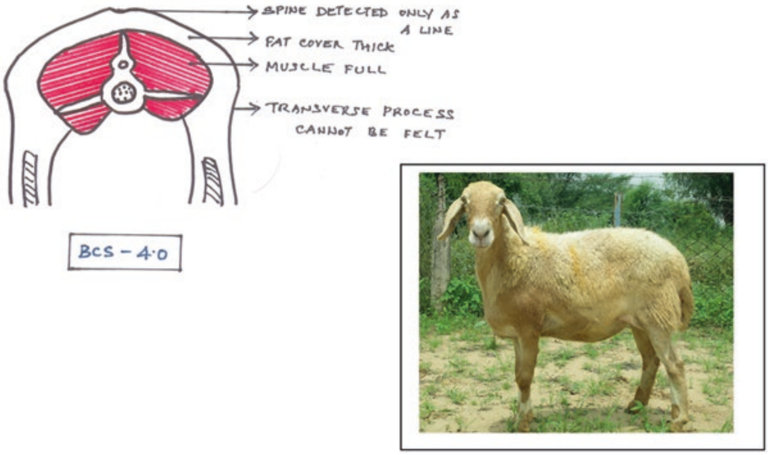

Fig. 19.4 Sheep with body condition score 4 (fat)

Causes Inappropriate nutrition, parasitism, disease occurrence, lactation, or a combination of any of these factors.

Solutions Optimum nutrition, management interventions and programs to improve herd health, and periodic evaluation of disease status in the animal.

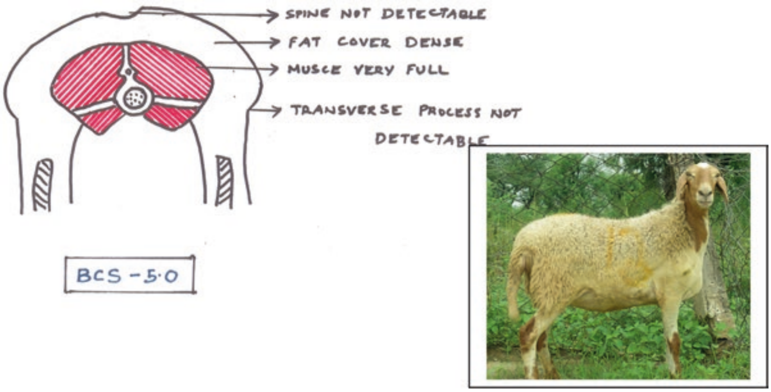

Fig. 19.5 Sheep with body condition score 5 (obese)

19.3.3 Condition Score 3 for Sheep

Features With gentle pressure, muscle above the skeleton can be felt by hand. Firm pressure need not be exerted to feel the bones. Hollows in the flanks are hardly concave or of the same level with that of the surrounding side areas.

Problems No problems are observed. Animals maintain BCS at 3 or slightly above, based on the age of the animals and production stage.

19.3.4 Condition Score 4 for Sheep

Features Hands should be pressed very firmly on the animal body to feel all the bones.

Causes Ad libitum feeding and lack of exercise.

Problems Impaired locomotion, lethargy, orthopedic-related abnormalities, difficult birth, and metabolic diseases.

Solutions Restricted nutrition and provision of exercise.

19.3.5 Condition Score 5 for Sheep

Features Bones are characterized by a thick fat layer over the muscles and are hard to feel with hands.

Causes Inadequate feeding and lack of exercise.

Problems Impaired locomotion, lethargy, orthopedic-related abnormalities, reduced fertility, dystocia, and metabolic abnormalities.

Solutions Restricted nutrition and provision of exercise.

19.4 How to Score Body Condition?

- Accuracy of the scoring system depends on how the animals are handled in the outlined areas. Unless the operators have earlier experience of assigning BCS by touch, it is not recommended to carry out scoring by visual appearance.
- Condition score is independent of body size. Hence, it is possible for a small-sized and medium-sized sheep breed to possess the same condition score. BCS indicates the amount of meat and fat cover over the bones in the body, and does not account for the body size.
- It is important to keep the animal standing in a relaxed state. The animals should be kept free from any sort of tension or stress like securing them from other animals so they are not hit or crushed. Feeling the short ribs is difficult if the animal is tense. Hence, in such situations accurate scoring is not possible.
- The 13th rib, which is the last rib, should be located. Feel the backbone and the short ribs following the last rib with the thumb and balls of fingers. Figures 19.6 and 19.7 describe the procedure for locating the backbone and feeling the transverse process respectively as part of scoring procedures.
- The cover of muscle and fat over the short ribs and backbone should be felt. Feel the muscle in the eye area. The procedure to feel the cover of muscle and fat around the bones is depicted in Fig. 19.8.
- The roundness of the bone ends, level of tissue between the bones, and degree of lattissimus muscle indicate the health status of the animal.

19.5 Body Condition Scores and Reproductive Efficiency in Ram

Physiologically, reproduction is an energy-seeking process and the mechanisms governing energy metabolism are closely associated with fertility. Metabolic activities are directly influenced by the feed intake and the metabolic status governs several physiological functions in the body (Martin et al. 2008; Sejian et al. 2015a). It has been reported that adequate energy supplied through feed is necessary for production and maintenance of functional gametes in animals. Variations in the energy balance and appetite endocrine axis directly influence the mechanisms of the hypothalamo-pituitary-gonadal axis. This indicates that in animals appetite and energy balance are intricately related to reproductive efficiency. There is a wide array of external factors influencing reproductive activity in sheep and goats including environmental factors (temperature, photoperiod), socio-sexual cues, and nutrition (Maurya et al. 2011a, b; Sharma et al. 2013). However, nutrition is established

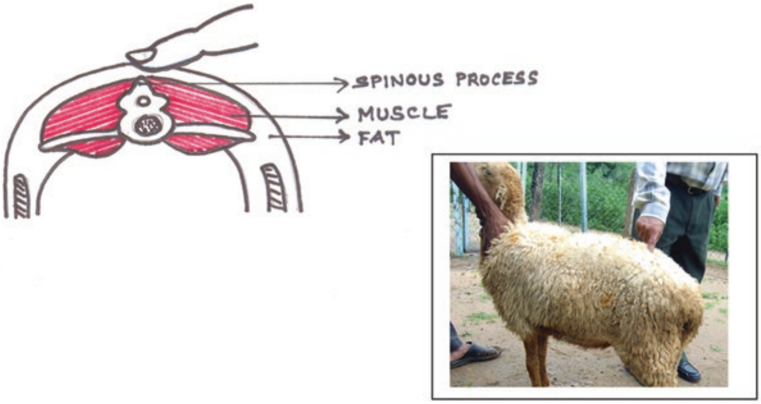

Fig. 19.6 Feel for the spine in the center of the sheep's back, behind its last rib and in front of its hip bone

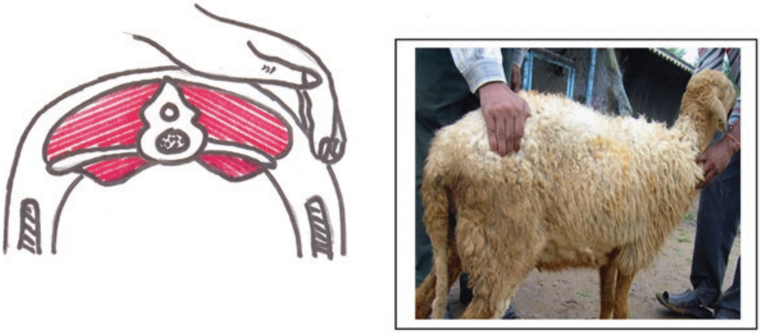

Fig. 19.7 Feel for the tips of the transverse processes

to be the most crucial factor affecting the reproductive performance in rams. During nutritional manipulations, rams elicit certain responses which can be categorized as short-term and long-term. Short-term responses affect the testicular activity of rams by influencing the neuroendocrine system (Martin et al. 1994; Blache et al. 2000), whereas testicular growth and semen production are affected through long-term responses (Oldham et al. 1978). In the extensive system of rearing, the plane of nutrition plays a significant role in reproductive efficiency in sheep compared to photoperiod (Maurya et al. 2004, 2016; Mukasa-Mugerva and Ezaz 1992; Perez et al. 1997).

Reproduction in animals involves the coordinated functioning of neurotransmitter systems, hypothalamic secretions, pituitary hormones, growth factors, and sex hormones. It is often a difficult process to maintain a normal physiology and development of reproduction in animals. Seasonal fluctuations are exhibited by rams in their sexual behavior, hormonal secretions, spermatogenesis, and volume and

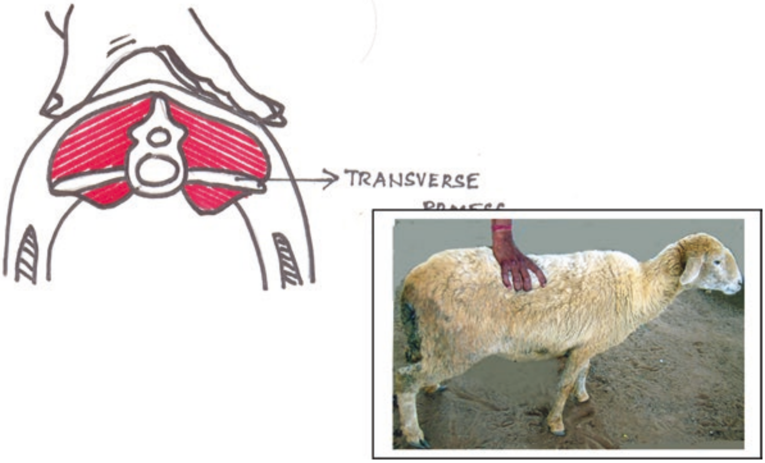

Fig. 19.8 Feel for fullness of muscle and fat cover

weight of testicles (Thiery et al. 2002; Tajangookeh et al. 2007). In rams, sperm production and size of testicles are directly linked to the nutrition level (Cameron et al. 1988; Murray et al. 1990). Reproductive functioning directly influences the size of the testicles. It has been established that the mating frequency, testicular size, concentration of reproductive hormones, and semen volume are closely associated in rams (Yarney and Sanford 1985). Sperm production is significantly influenced by the diameter of the testicles (Elmaz et al. 2008). However, the role of cortisol and thyroid hormones in semen attributes is not well understood. A study on rams has reported that reduced secretion of thyroid significantly impairs the reproductive hormone levels (Souza et al. 2002). In arid and semiarid areas, the major threats for sheep production are thermal stress and feed scarcity (Naqvi and Hooda 1991; Maurya et al. 2004, 2015). In such conditions, efficient management and utilization of available pasture is needed for maintaining normal reproductive performance in sheep. To attain this, focus should be on understanding the nutrition needed for reproduction and the energy partitioning among different physiological systems. BCS serves to provide such information on the nutritional status and requirement of the sheep that can be used to optimize productivity and save input cost. Studies pertaining to the influence of nutrition on fertility of animals are limited for males compared to females (Schwalbach et al. 2003). There is a significant contribution by the breeding male to enhancing the reproductive efficiency and improving genetic potential in a herd.

In ruminants, energy reserves are used for the metabolic maintenance of the body and for the production aspects including growth, production, and reproduction. It has been proved through several experiments that when the dietary energy available undergoes specific variations in animals, it can lead to desirable and long-term changes in their physiology (Martin et al. 2008). Reproductive performance responds differently to different levels of dietary energy intake. A considerable amount of energy is required for maintaining normal reproduction in animals. However, during periods of feed scarcity and reduced dietary energy, the animal utilizes most of the energy for maintaining normal brain functions, thus hampering reproductive performance. Reports pertaining to nutritional effects on sexual behavior of rams are scarce (Wierzbowski 1978). BCS has a major impact on and manifestation in sexual behavior in rams. The rams with 2.5 BCS had significantly higher reaction time, higher "time taken" for first and second ejaculation, lower semen volume, and lower progressive motility of spermatozoa than the rams with 3.0–3.5 BCS and 4.0 BCS. This signifies the intricate linkage between the energy status of the body and reproductive performance in rams. In rams with poor condition score, the reason for abnormal sexual behavior could be the altered morphological attributes of the scrotum and testicle and also the decrease in the testosterone level (Maurya et al. 2012a, 2016).

In male ruminants, reproductive efficiency is predictable from the morphological characteristics of the scrotum and testicles (Bielli et al. 1997; Sarder 2005). Scrotal circumference and testicular weight show drastic variations between rams with high and low BCS. The proper feeding level is directly proportional to scrotal and testicular measurements. In rams, scrotal circumference, a strongly heritable trait, serves as a potential indicator of sperm production (Kafi et al. 2004). It has been reported that the daily body growth and nutritional status of the body have a direct influence on the scrotal circumference (Cameron et al. 1988). However, there are contrary reports in young rams, suggesting the nonsignificant influence of nutrition level on scrotal and testicular parameters such as scrotal circumference, scrotal weight, scrotal fat, testicular weight, and volume (Fourie et al. 2004). Undernourished animals had lower scrotal volume (Thwaites 1995, Maurya et al. 2010b, 2012a). The size and development of testicles is considered as a direct indicator of fertility in rams (Schoeman and Combrink 1987). However, it is not reliable to evaluate fertility merely on the basis of scrotal circumference when high dietary energy feed is supplied to the animals before taking measurements. In such situations, there would be an accumulation of scrotal fat, which would often be misleading. The testicular tissue is highly sensitive to the fluctuations in the plane of nutrition and responds by changing weight in quick action compared to other organs. This was evident from decreased scrotal circumference in rams with poor BCS (Oldham et al. 1978; Masters and Fels 1984).

Live weight and testicular size in rams are closely related (Braun et al. 1980; Murray et al. 1991), with adult and heavier rams generally having bigger testes. The nutrition-driven abnormalities in testicular size are evident from the production of sperm from each testis as well as from each gram of testicular parenchyma cells (Oldham et al. 1978; Maurya et al. 2012a). Further, the influence of protein and energy levels in the diet on testicular size was also reported by Braden et al. (1974). It has been identified that scrotal circumference and testicular size serve as indices for spermatogenic functioning (Pisselet et al. 1984; Fernandez-Abella et al. 1999; Elmaz et al. 2008). In rams, a significant relation between body weight and testicular measurements has been reported by Raji et al. (2008). Appropriate nutritional interventions can lead to increase in testicular size and enhanced production of sperm up to 100%. Scrotal circumference, testosterone concentration, body weight of the animal, morphological and physiological characteristics in the prepubertal stage, and reproductive performance in the postpuberty stage are all found to be closely associated with one another (Gherardi et al. 1980; Maurya et al. 2012a).

Feeding amount is a major factor influencing sperm output in rams (Braden et al. 1974). Hotzel et al. (1992) reported supporting result in rams showing reduced spermatogenesis and sperm output in the feed-deprived group compared to the ad libitum-fed group. Poor-quality feed results in an increased number of abnormal spermatozoa (Dana et al. 2000). The secretion of reproductive hormones, concentration of luteinizing hormone, and follicle-stimulating hormone in serum have shown significant reduction when the animals are deprived of feed, affecting the testicular growth and thereby reducing the sperm count in young rams (Martin and White 1992). Another study reported the positive influence of improved nutrition on testicular efficiency in rams (Oldham et al. 1978). However, ad libitum feeding leads to reduced reproductive performance in sires (boars, bulls, and rams). The author also reported that compared to protein intake, energy intake has more influence on sperm output (Walkden-Brown et al. 1994; Fourie et al. 2004). Furthermore, the report suggests that the action of nutrition level on spermatogenic functions or on testosterone level is not direct, but is rather carried out by influencing the gonadotropin release (Walkden-Brown et al. 1994; Fourie et al. 2004). In young bulls, the impact of nutrition deprivation has been reported to impair fertility (Labuschagne et al. 2002; Coulter et al. 1997). Quantitative and qualitative impacts on semen are established when animals are fed with a high-energy diet.

A significant difference in plasma concentration of testosterone was established between rams with high condition score (3.0–3.5 and 4.0) and low condition score (2.5) (Maurya et al. 2012a). Testosterone concentration is a potential indicator of production and quality of semen. Hafez (1993) reported that spermatogenic activity is directly influenced by the testosterone level, as normal sperm is directly correlated to the sertoli cells that govern the normal functioning of sperm. Testosterone level significantly influences the reaction time, volume of semen, sperm count, and motility in rams (Kishk 2008). Schanbacher and Lunstra (1976) reported that during the summer the level of testosterone is lower. Secretion of testosterone was identified to be greater in high-BCS animals than in low-BCS animals (Malau-Aduli et al. 2003; Maurya et al. 2012a). Glucocorticoid concentration in plasma acts as a potential index of the stress response and reproductive performance in animals (Bamberg et al. 2001; Mostl et al. 1999; Mostl and Palme 2002). Cortisol is the glucocorticoid produced in sheep, which acts as the major antistress hormone (Fırat and Ozpınar 2002). Cortisol is greatly influenced by the diet of the animal (Rhind et al. 1992). The restricted feeding regimen induced a significant reduction in plasma cortisol (Ates et al. 2008; Maurya et al. 2016) in rams. This reduction in cortisol level could be attributed to the insufficient amount of fat and cholesterol in the diet leading to a reduction in the metabolic conversion of fatty acids to acetyl CoAs, in turn decreasing the cholesterol synthesis. As cholesterol acts as the precursor for cortisol, reduction in cholesterol level directly affects cortisol secretion (McDonald and Pineda 1989). It was further reported that the maternal hypothalamo-pituitary-adrenal axis gets suppressed during nutrient deprivation in sheep. This would stimulate the adrenocorticotropic hormone to decrease, leading to reduced cortisol secretion (Bloomfield et al. 2004).

In ruminants, thyroid gland secretions are directly correlated to the feed intake and nutritional status of the animal (Riis and Madsen 1985). Feed intake is directly influenced by triiodothyronine (T_3) secretion at the hypothalamic level (Kong et al. 2004). Further, the feed quality and quantity are strongly correlated to the hormonal level of plasma thyroid (Dauncey 1990). There are numerous studies reporting the reduced level of both T_3 and T_4 when the animals are deprived of energy (Zhang et al. 2004; Abecia et al. 2001; Rae et al. 2002; Todini, 2007). An earlier study in sheep in our laboratory reported reduced thyroid hormone concentrations in plasma when animals were feed restricted (Naqvi and Rai 1991). A study by Todini (2007) reported that the energy balance directly influences the thyroid level in plasma.

19.6 BCS and Ewes' Reproductive Efficiency

Mortality rate in prenatal and neonatal ewes was reported to be higher in ewes with poor BCS (Nordby et al. 1986). Further, survivability rate was also reported to be decreased in low-BCS ewes (Khan 1994). Oocyte quality is hampered when the donor ewes face nutrient deficiency and possess low BCS. This is accompanied by impaired cleavage rate, hormonal secretion, fertilization, and development of embryo (Boland et al. 2001; Armstrong et al. 2003). Further, undernutrition in ewes during late gestation or in early postnatal life results in permanent and irreversible decrease of lambing rates (Williams 1984; Gunn et al. 1995). Nutritional status of the animal is identified as a primary factor regulating reproductive performance (Armstrong et al. 2003; Webb et al. 2004). A significant influence of BCS has been established on the reproductive efficiency in ewes at the mating stage (Esmaeili-Zadeh et al. 2004, Sejian et al. 2010a). The synchronization has been very effective in ewes with 3.0–3.5 BCS in comparison to 2.5 and 4.0 BCS ewes (Sejian et al. 2012b). Anoestrus condition was reported to be higher in 2.5 BCS ewes (Dunn and Kaltenbach 1980). Further, the excess nutrition in high-BCS ewes also has a negative influence on estrous activity (Bocquier et al. 1993; Sejian et al. 2012c).

The effect of BCS on conception frequency has been established through several studies (Torre et al. 1991; Flores et al. 2007). They described that ewes and cows with moderate BCS showed a higher conception rate than lower-BCS ewes and cows respectively. The results of our study were in agreement with the study conducted by Ptaszynska (2001) which reported the direct relation between conception rate and BCS. Maurya et al. (2011b) reported that BCS had a significant effect on fetal sac volume. Lower-BCS ewes had low fetal sac volume in comparison to higher-BCS ewes. BCS influences fetal growth in ewes (Osgerby et al. 2003). A positive relationship was also reported between BCS and lambing rate in Merino ewes by showing the increased lambing rate in 3.0–3.5 BCS ewes at pregnancy. Thomas et al. (1987) and Sejian et al. (2010a) also revealed that ewes maintained at 3.0–3.5 BCS showed maximum lambing rate. Also, optimal response to flushing was observed in ewes with medium BCS compared to those with poor BCS (Ptaszynska 2001). In follicle stimulating hormone (FSH) superovulated embryo donors, proliferation was observed to be greater in 3.5 BCS ewes when compared to those with 2.9 BCS (Alabart et al. 2003). In addition, when high-BCS ewes were mated with ewes of 3.2 versus 2.9 BCS, ovulation was observed to be higher in ewes with higher condition scores than lower scores, but litter size showed no much variations.

Condition scoring has a direct correlation with fetal growth and parturition behavior in sheep (Maurya et al. 2011b). The fetal nutrient supply and intrauterine environment are the major determinants of fetal growth (Harding and Johnston 1995). Various consequences of fetal undernutrition present at birth, with low-birth weight lambs, for example, having an increased incidence of death from hypothermia, infection, and starvation (Alexander 1974). Nutrients provided directly from the maternal compartment, via the placenta, are derived either from products of digestion after ingestion or as mobilized components of the maternal body reserves (McCrabb et al. 1992a, b). Inappropriate maternal nutrition in early to midpregnancy can disrupt placental development, which also depends on the BCS of mothers (McCrabb et al. 1992b). Osgerby et al. (2003) reported that the fetal weight and fetal weight:crown-rump length ratio was higher in fat ewes than in ewes of moderate condition. The placentome size was also lower in moderate-BCS ewes.

Endocrine factors within the maternal circulation may also influence fetal substrate availability, regulating nutrient partitioning between the maternal, placental, and fetal compartments (Wallace et al. 2001). Two closely related glucose transporters, GLUT1 and GLUT3, transport glucose across the placenta by facilitated diffusion. Glucose regulates the expression of these transporters in a time and concentration-dependent fashion (Das et al. 2000). Insulin promotes lipogenesis within the maternal compartment, mediating glucose and amino acid uptake by the adipose and muscle tissue. IGF-1, in contrast, influences the placental transfer of glucose and amino acids (Liu et al. 1994). The uterine milk proteins are the most prevalent proteins in the pregnant ovine uterine luminal fluid, and are considered to offer nutritional support to the fetus, in addition to providing other binding, carrier, and immunomodulatory actions within the uterine space (McFarlane et al. 1999).

Birth weight in lambs is greatly influenced by their condition score. Sejian et al. (2010a) reported that lambs of donor ewes with 2.5 BCS had the lowest average birth weight compared to ewes with higher condition scores. A similar result was reported by Al-Sabbagh et al. (1995) in a comparative study between ewes with 2.5 and 3.5 BCS. There have been some studies showing reduced birth weight when the animals were feed deprived at mid-gestation or late-gestation (Russel et al. 1981; Thomas et al. 1988). Also, the average weaning weight showed higher values in lambs with 3.0–3.5 and 4.0 BCS than those with poor BCS (Sejian et al. 2010a).

19.7 Impact of Body Condition Score on Carcass Quality of Sheep

BCS is closely related to body weight, carcass weight, and yield from the edible tissue in animals. The influence of feed level on the carcass and meat quality is explained mainly in terms of variations in body conformation and amount of fat tissue (Priolo et al. 2002), and color of meat and fat (Joy et al. 2008). It was observed that lambs deprived of any supplementation in diet possessed low fat depots due to lower availability of energy (Priolo et al. 2002). The degree of fatness is directly linked to energy consumption (Chestnutt, 1994). Carcass fat is greatly reduced during energy deprivation as a result of the increased utilization of fat, particularly the subcutaneous fat in grazing lambs (Butterfield et al. 1983). Hence, maintaining BCS is a major consideration for sheep meat producers.

The increment in BCS of sheep increases the carcass yield as well as the profit of the sheep farmers (Heelsum et al. 2003). It is a general finding that live weight, carcass weight, dressing percentage, degree of fatness, longissimus muscle area, and numerical yield grades increased as BCS increased from 3.0 to 5.0. In an experiment conducted on Malpura ewes, carcasses of sheep with 2.5 BCS are graded as cutter or lower, and carcasses from sheep with 3.0–4.0 BCS are graded as utility. Absolute gross and net values of carcasses were affected by the different BCS. Carcasses from sheep with 2.5 BCS had the lowest and carcasses from sheep with 4.0 BCS had the highest gross and net values. Ewes with condition scoring 4 yielded gross values higher than those ewes with 2.5, 3.0, and 3.5 BCS. Across both cutter and utility grades, the gross and the net value of the carcass increased linearly as BCS increased from 2.5 to 4.0. Moreover, sheep with 3.0–3.5 BCS had higher gross and net values than sheep with 1.0 and 2.0 BCS.

Although sheep carcasses with 4.0 BCS had the highest gross and net values, carcasses from this grade had the lowest yields of trimmed or denuded subprimal cuts. Additionally, carcasses with 4.0 BCS would incur the greatest labor costs associated with trimming subprimal cuts. Sheep assigned a BCS of 2.5 had the greatest by-product values. Moreover, sheep with 2.5 BCS produced the least valuable carcasses and also had the lowest gross, net, and live values among all BCS. Sheep designated with a BCS of 2.5 would require additional feed inputs to improve carcass quality traits, carcass value, and, ultimately, the live value; however, feeding sheep can introduce a substantial amount of risk due to increased feed costs. However, economic returns get significantly higher when the sheep flock is maintained and marketed at a condition score of 3.0–3.5. Further, this would also improve the carcass grading utility and lean content in sheep. Sheep with a condition score of 3.0–3.5 were lean and would produce subprimal cuts requiring minimal trimming to achieve a marketable fat-trim level.

Table 19.1 The recommended BCS for different productive phases in sheep

Class of sheep	Optimum condition score
Breeding	3.0
Mating	3.0–3.5
Early to midgestation	3.0
Late gestation	3.5
Lambing	3.5
Lactation	2.5
Rams at mating	3.5
Weaners	2.5 or more

Maurya et al. (2009b); Source Indian farming 2009 publication

19.8 Recommended (Optimal) Condition Score for Different Productive Phases in Sheep

Every stage of production requires specific BCS. This may help to optimize the sheep production by minimizing the input cost. Table 19.1 describes the specific BCS required for different production phases in sheep.

19.9 Management Strategies to Improve Body Condition Score and Carcass Traits

Several management strategies can help in maximizing profit by improving the BCS of sheep to increase the carcass yield.

- Stocking rate should be adjusted during the periods of limited stocking rate in order to ensure optimal forage for the animals.
- Lambing season should be targeted based on the forage and supplements availability, marketing and managemental plans.
- Unproductive animals should be culled.
- Ensure protection from diseases and parasites.
- Offer the flock a mineral-free choice throughout the year.
- Sheep should be fed with forage having crude protein content below 7 or with total digestible nutrients to crude protein ratio above 7 on a daily basis.
- To enhance rebreeding, supply appropriate protein to the younger ewes. To attain this during winter, first and second lamb ewes should be managed in different herds.
- The sheep flock should be divided into different groups based on the age and nutritional status including weaned ewes, yearling ewes, young and adult ewes, and first lambed ewes. The purpose of each group will be different during different months of the year.

- In sheep with BCS below 3, provision of good-quality forages or increased energy supplementation balanced with protein should be made in order to decrease the body weight loss and increase BCS to a higher level.

19.10 Conclusion

The BCS system is practiced worldwide and has provided promising progress in the productive and reproductive performance of sheep. Several reports have established the appropriate BCS for optimizing sheep productivity to be 3.0–3.5. This offers great scope for sheep producers from an economic perspective. The BCS system helps farmers to evaluate the well-being status of the animals at different production phases. This provides a way to increase sheep productivity by helping farmers to take appropriate management actions and make adjustments in the feeding program. The application of BCS is particularly beneficial in hot, arid and semiarid tropical environments where the availability of feed is not constant throughout the year. It could be concluded that optimizing BCS in sheep will be an economically relevant system for sustainable sheep production.

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Adaptation Strategies to Counter Climate Change Impact on Sheep

20

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Abstract

Climate change has proved to impose potential negative effects on species survival, ecosystems stability and sustainable livestock production around the globe. Among the various environmental factors, heat stress is well known for its harmful effects on livestock and related production losses. Sheep exposed to heat stress show lower body growth and hide quality and compromised reproductive functions in both males and females. Adapting to the changing climate requires appropriate manipulations in the production system by taking into account the positive effects and attempting to diminish the negative effects of climate change.

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The highly adapted indigenous breeds identified by marker-assisted selection can be used as an efficient tool for developing thermotolerant breeds through improved breeding programmes. Promotion of such breeds can improve production efficiency and may lead to fewer greenhouse gas emissions. Further, the local people, especially women, are good managers of natural resources and possess excellent skills to utilize the natural resources efficiently. Hence, occasional training and a participatory research approach into the roles of women assist the tackling of climate change in the rural areas. In addition, well-organized early warning systems avoid severe damage due to unexpected disasters by providing sufficient time to prepare effective responses. Development of skilled disease surveillance supported with effective health services may effectively control the spread of climate change-related diseases in sheep. Furthermore, the production system requires improved water resource management to provide sufficient water for sheep production in the arid and semi-arid regions. Cultivation of drought-tolerant fodder varieties in extremely hot areas is an efficient adaptive strategy to ensure sufficient supply of feed during scarcity periods. Finally, strengthening extension services and building awareness through capacity-building programmes helps the livestock keepers to improve their adaptive capacities against climate change. Adaptation strategies related to cold stress include advanced cold-tolerant breeding programmes, migration in extreme winter and adoption of proper cold management practices. According to the predictions by various international bodies, the consequences of climate change will be on the rise in the future. Hence, adequate cost-effective management strategies appear to be the immediate need of the hour for adapting sheep production systems to the changing climate.

Keywords
Adaptation • Climate change • Cold stress • Drought • Early warning system • Heat stress • Sheep

Contents

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20.1 Introduction

Climate change seems to threatening the habitat and survival of many species and hampering sustainable livestock production. Nevertheless, there is huge demand for livestock products in the market and this is expected to double by the end of 2050 mainly to meet the food demands of the rapidly growing population. The extreme climatic conditions impose various stresses on animals which adversely affect their growth as well as productive and reproductive performance. Agriculture and livestock are the two major sectors which face severe economic losses in the changing climate. Hence, rural poor farmers in the developing countries, who depend solely on those sectors for livelihood, are the usual victims of climate change. The already existing problems due to environmental extremes would be further intensified by the vagaries of projected climate change. The incidences of drought, snowstorms and blizzard-like events have risen. Other factors which would further exacerbate the situation include poverty, inequalities in distribution of land and other resources, relying hugely on rain-fed agriculture, lack of proper infrastructure, shortage of capital and technology, and inadequate weather forecasts and extension activities. The important environmental stresses include *heat stress* due to the increasing environmental temperature, solar radiation and relative humidity, and *cold stress* at high-altitude regions, both resulting in *nutritional stress* due to the negative effects on pasture growth, decreasing the feed quantity and quality, and *disease stress* due to spreading of harmful micro-organisms into new regions.

20.2 Heat Stress

According to the Intergovernmental Panel on Climate Change (IPCC), the world is facing an unequivocal warming of the climatic system. Incidences of weather extremities areincreasing. The twentieth century witnessed an average global temperature rise of 0.74 °C, sea level rise of 17 cm and shrinking of the snow cover in the Northern Hemisphere (IPCC 2007). The IPCC (2001), by foreseeing the future climatic scenarios, reported that global warming impacts would be significant especially at high altitudes. Comparatively rapid (3–5 times) warming is observed particularly in the tropical and sub-tropical regions which are mostly covered by the Himalayan range. One of the reliable indicators of climate change is the Himalayan Alpine glaciers. As per thereport in 1999 by the Himalayan Glaciology working group of the International Commission for Snow and Ice , the Himalayan glaciers are diminishing at a rapid pace and are very likely to vanish by the end of 2035 if the current rate prevails. It was reported in 2007 that the overall glacier area had diminished from 2077 km^2 to 1628 km^2. Further, a 21% increase in deglaciation has also been revealed but the fragmentation process has led to an increase in the overall number of glaciers (IPCC 2007). This is going to create a catastrophic situation for India.

20.3 Cold Stress

The high-altitude region in India comprises the Himalayas (Trans Himalaya, Eastern and Western Himalayas) and the Deccan Plateau bordered by the Eastern and Western Ghats. Here, the climate is extreme and windy with intense solar radiation and rapid changes in daily average temperature (maximum 25 to −40 °C). By 2030, the following climate changes are predicted in the Himalayas (Indian Network for Climate Change Assessment (INCCA) 2010): increase in the annual global temperature from 0.9 to 2.6 °C. As per the projections, global minimum and maximum temperatures would increase in the range of 1–4.5 °C and 0.5–2.5 °C respectively. Further, it is likely that in the 2030s, the annual precipitation would vary in the range of 1268–1604 mm. There would be a 5–13% increase in the overall rainfall between 1970 and 2030. The hilly regions in the temperate and sub-temperate areas encompass a substantial portion of land area in the high-altitude areas. The high-altitude rangelands of the Himalayan plateau are remarkable grazing ecosystems, with 85% of the landmass lying above 3000 m. The primary vegetation comprises alpine meadows, alpine steppes and desert steppes. The growing season for vegetation lasts about maximum 3 months in summer.

20.4 Climate Change Impact on Sheep

Sheep are found to be highly sensitive to the changing climate as the poor, underprivileged landless or marginal farmers are usually associated with the rearing of these animals in the extensive system. Sheep rearing is most pronounced in the semi-arid tropics where pasture conditions and water availability are highly determined by climate change (Sejian et al. 2013). In addition, desertification is an issue of concern, and there is a likelihood that it would be aggravated by the changing climate, which poses a risk for sheep flocks. Sheep can thrive well in the escarpment and around the perennial rivers where the grazing resources are relatively good. Increasing rainfall is undesirable for the grazing animals as this could lead to the grasslands transforming to forests, rise in the vectors causing harmful diseases and also a transformation from livestock to agricultural crops (IPCC 2007). During drought conditions, sheep husbandry is preferred mostly by the large ruminant farmers as sheep require only minimal quantity of feed. Sheep are also most suitable for rearing in the hill and mountain farming system.

20.5 Adaptation Strategies Against the Changing Climate

Adapting to the changing climate is the key solution to tackle climate change by reducing the severity of the impacts. There are huge potential benefits for the global sheep industry of finding adaptation strategies that could be applied in pastoral systems without decreasing their productivity. Adapting to climate change requires appropriate manipulations of the production system by taking into account the positive effects and attempting to diminish the negative effects of climate change. As per the IPCC (2007) definition, the adaptation process involves resonding to the prevailing or expected climatic conditions through manipulations of the natural systems that would maximize the beneficial opportunities by curtailing the harmful impacts. There are three primary objectives that can be drawn out from the adaptation process: to decrease the severity of the impact, to develop the ability to withstand the inevitable effects and to efficiently utilize the new opportunities (Sejian et al. 2015). The traditional means of livestock farmers in adapting to the changing climate is developing in-depth knowledge of the local climatic conditions and the surrounding environment in which they survive.

20.6 Impact of Heat Stress on Sheep

Higher temperatures lead to change in species composition kept by pastoralists; the domestic animals, mainly sheep, which are highly susceptible to heat stress, will reduce in number.

20.6.1 Impact on Sheep Growth

Growth, which is an irreversible increase in the live body mass, is governed by both genetic and environmental factors (Marai et al. 2007). During heat stress conditions, the anabolic activities in sheep would be reduced and the catabolic activities would increase, stimulated by the increased level of catecholamines and glucocorticoids.

This could be the reason for the impaired growth performance in heat-stressed sheep (Marai et al. 1999). The sheep subjected to heat stress, in an attempt to drive away the excess body heat, elicit several cop mechanisms in their body such as augmented respiratory rate and body temperature, reduced feed intake and increased water consumption (Padua et al. 1997; Marai et al. 2007; Pereira et al. 2008), and decline in feed conversion ratio (Padua et al. 1997). The reduced feed intake in animals during heat stress is due to the stimulation of the peripheral thermal receptors in the body which would pass on a signal to the appetite centre in the hypothalamus to reduce feed consumption through suppressed nerve impulses (Marai et al. 2007). The reduced feed consumption during high temperatures could be the attempt of the sheep to reduce metabolic heat generation, thereby adapting to the condition. Reduced feed consumption and especially the deficit of potassium content result in hyponatremia and hypo-osmolar conditions in the animals due to restrained uptake of sodium from the reticulorumen during heat stress (Holtenius and Dahlborn 1990).

20.6.2 Impact on Sheep Production

Sheep are considered consumer and market goods and have good demand in the export market. They are reared for leather, wool, fibre and meat production. Sheep leather is produced from sheep skin or lamb skin and is valued by luxury fashion for its softness and stretchability, and it is thinner than beef leather. The highest-quality sheep leather comes from ‘hair sheep’ breeds as opposed to wool sheep. It is light-weight, warm and delicate, and it is typically used in the production of luxury products such as garments, footwear and bags. Sheep are generally a versatile form of livestock and hair sheep’s coarse coat may inherently make them more adaptable to a changing climate. Yet, sheep can be sensitive to temperature extremes and humidity, and the quality of grazing pasture can affect hide quality. Climate impact on sheep skin production will be complex, vary by region and include increased risk of disease. Much of the sheep leather comes from small-scale producers who do not have the resources to adapt to changing conditions. Higher temperatures lead to increased incidents of pests like lice and ringworm, which cause marks on the skin and reduce the quality of sheep hides. Large inter-annual variation in weather, particularly precipitation, can decrease the quality of grazing pasture, which in turn can affect hide quality.

20.6.3 Impact on Sheep Reproduction

Reproductive capacity of both female and male animals is hampered during hyperthermic conditions, with the most evident impacts being reduced fertility in females and impaired sperm count and quality in males. In heat-stressed ewes, significant effects are reported in estrus percentage, estrus duration, estrus cycle length, rate of conception and lambing, and weight of lambs at birth (Maurya et al. 2004). The effects on ovaries are particularly influenced by nutrient deficiency, which can impose potential impacts on the ovulation rate and reproductive behaviour. The association between the nutritional status of the animal and reproductive functioning is mostly governed by the IGF-1 system (Roberts et al. 2001). When acute nutrient deficiency results in reduced secretion of IGF-1, expression of FSH receptors is affected. This would hamper the response of the developing follicles towards Follicle Stimulating Hormone (FSH) secretion (Kiyama et al. 2004). The nutrition-driven effects on ovulation are mostly associated with the disturbances in folliculogenesis in the final stages and not with the variations in Gonadotropin Releasing Hormone (GnRH), Luteiniziing Hormone (LH) and FSH secretions. It has been reported that severe nutritional deficiency would decrease the number of sex steroid receptors in the uterus as well as the concentration of steroid hormones, thereby affecting the rate of conception (Sosa et al. 2006). In heat-stressed sheep, the embryo is found to be the most sensitive to heat exposure (Thwaites 1971). Heat stress significantly influenced the concentration of plasma estradiol and progesterone in Malpura breed (Sejian et al. 2011; Sejian et al. 2012). Reduced response of super-ovulation and impaired embryo production have also been reported in Bharat Merino ewes during heat exposure (Naqvi et al. 2004).

20.7 Adaptation Strategies Against Heat Stress

Figure 20.1 describes the various strategies to sustain sheep production in the changing climate.

20.7.1 Breeding Strategies

20.7.1.1 Promotion of Indigenous Breeds

Local breeds usually possess an innate ability to adapt to the local climatic conditions, various stressors and available feed resources. However, in developing countries, advancement in animal breeding and agricultural activities which could have otherwise helped to augment the adaptation process is at a slow pace. The adaptation strategies take into account not only the ability of the animal to tolerate the climatic stressors, but also their survivability, growth and reproductive performance during periods of feed scarcity, parasite load and disease occurrence (Hoffmann 2008). The presence of high fecundity factor, i.e., the Booroola fecundity (FecB) gene, favours the evolution of sheep breeds such as Garole in any harsh condition in the state of West Bengalin India (Banerjee et al. 2010). Several programmes are being undertaken such as genetic upgradation of sheep, encouraging breeding of sheep for livelihood security, etc., in different states.

20.7.1.2 Identification of Animals with Resilient Capacity to Cope with Climate Change

Maintaining diversity in genetic resources and approaches is the basic concept of resilience. A diversity of farming practices allows livestock keepers to cope with differences in local environments. The traits of inherent resilient and adptive capacity against heat stress are long legs, short hair coat, higher sweating rate, large surface area, body conformation, higher capacity for maintenance of heat balance,

Fig. 20.1 Different adaptive strategies to sustain sheep production in the changing climate scenario

lower metabolic rate, higher feed efficiency, higher tolerance to dehydration and adipose tissue depots, and capacity to alter the hormone and biochemical profiles to adapt to a particular environment.

20.7.1.3 Conservation of Local Genetic Resources

The survivability and adaptation of breeds to a new climatic condition are more risky when the rate of climate change is at a rapid pace compared to natural selection (Hoffmann 2008). Genetic factors in animals have a strong influence on the resistance capacity against heat stress, which is clearly evident from the lower body temperature in adapted breeds of the tropics compared to the non-adapted exotic breeds. The adapted breeds possess superior fertility because of the better capability of these animals to maintain thermoregulation during heat stress. Genetic selection for heat tolerance is also a possibility in non-adapted breeds. There are also specific genes that control cellular resistance to heat shock and confer increased thermoregulatory ability. Further, such genes can be efficiently utilized through conventional or transgenic breeding programmes for developing thermotolerant breeds with embryonic cells and oocytes possessing extreme tolerance to heat exposure. Little advantage will be offered in genetic selection of animals involving incorporation of major physiological responses such as reduced feed intake to decrease metabolic heat and enhanced vasodilation in an attempt to reduce the heat-stress impact. Physiologically, it does not seem tenable to select breeds that are both high producing and heat tolerant under the prevailing natural conditions. There is a lack of adequate studies for understanding the heritability of physiological traits such as efficiency of heat dissipation, respiratory and sweating rate, and rectal temperature. Likewise, information pertaining to the influence of genetic factors on production responses is inadequate.

20.7.2 Women Empowerment

The role of gender has become mainstream in the adaptation strategies to tackle climate change. Especially in a community early warning system, the role of women is central. They also help in securing livestock and properly maintaining the farm area. With the growing relevance of women in agriculture, their role in adaptation strategies has also become imperative. In a study carried out by the International Centre for Integrated Mountain Development in the Himalayan region to identify the relevance of gender in resource management of rangelands and on climate change adaptation strategies, it was shown that women possess excellent knowledge and skills for efficiently utilizing the natural resources in the mountain ecosystem as well as in farming activities (Leduc 2010). However, at both international and national level, the gender perspective has not been fully exploited in the development of strategies and framing climate policies. Women and men face different risks because of the unequal distribution and control over resources. It has been revealed that because of climate change and variability, there has been an increase in the workload of women and the dependence on feed relief by the pastoralists has also increased. There is an urgent need for vocational training and participatory research programmes for studying the relevance of women in uplifting of livestock and agricultural sectors.

20.7.3 Early Warning Systems

Early warning systems (EWSs) involve monitoring several indicators that would damage livelihood and providing effective information regarding the hazard at the proper time, allowing people at risk to take appropriate measures in avoiding or preventing the damage (Teshome 2012). Information should be made available in good time to plan and implement appropriate intervention ahead of time to prevent or curtail the impacts through proper planning. The five dimensions of EWSs are: (a) the capability to generate asessment that has been informed and mapping of emerging hazards and risks, (b) technical evaluation and forewarning service regarding the emerging regional threats and risks, (c) dissemination and communication of warnings that can be easily understood by those at risk, (d) knowledge and preparedness (skill, money, infrastucture) to act and respond and (e) implementation of the action (policy, governance, rights). Activities involved in this EWS include data collection, information development, dissemination methods and action-triggering mechanisms. During drought conditions, severe rainfall deficit results in feed scarcity over a large area. Livestock conditions deteriorate when the animals have to walk longer distances in search of feed. Production performance declines, disease occurrences rise, and mortality of vulnerable groups such as young and old animals increases. Sheep owners sell animals with weak reproductive performance to the market to buy feed. However, when the supply exceeds the demand in the market, livestock prices fall. During intensified drought conditions, more sheep become emaciated and face death. A successful drought management cycle is brought out by adequate actions for drought preparedness, managing the impacts and assisting recovery of affected sheep producers.

20.7.4 Disease Surveillance Measures

Higher temperatures lead to increased incidence of pests like lice and ringworm in sheep. The climatic conditions favouring the growth of pathogens in the major portion of the year due to the elevated temperature would enhance the disease spread during other seasons and also the disease spread area. The prevailing vector-borne diseases in sheep would be augmented due to the increasing temperature and changing precipitation patterns (Bhattacharya et al. 2006). Further, in sheep there would also be enhanced incidences of macro-parasites and development and circulation of new diseases. The changing climate would also alter the dispersal, reproduction, maturation and rate of survivability of vector species, which would ultimately bring out variations in the transmission of viral and bacterial diseases. In certain regions, it is likely that climate change would result in the generation of new transmission models. It has also been revealed that alterations in temperature and humidity could increase significantly the incidences of helminth and protozoan diseases such as trypanosomiasis and babesiasis. Certain diseases caused by viruses like rinderpest may also reappear affecting sheep. Warming climates likely allow pests and diseases to spread into new regions, which will affect sheep productivity. Variations in the range and pattern of helminth infections and other vector-borne diseases would result in increased heat-related morbidity and mortality. During drought crisis, tick and skin diseases in sheep are increasingly becoming common problems. The susceptibility of sheep to various diseases will increase during conditions of feed scarcity and when there are only few water-points around. Additionally, many animals would die when rain comes finally following a season of prolonged dry conditions. Primary health services such as de-worming, vaccination and other preventive measures should be encouraged. Growing appropriate fodder trees in and around animal sheds may be an effective measure for offering physical protection for the animals from the scorching sun. Promoting cooling mechanisms particularly for stimulating evaporative cooling for sheep may be highly beneficial. Ensuring appropriate bedding materials in the barn may be useful during hot environmental conditions. The cooling strategies must commence prior to animals showing signs of heat stress.

20.7.5 Water Resource Management

In addition to temperature elevation and deficient nutrition, shortage of water would be another important limiting factor for sheep during the summer season in semi-arid tropical environments under the changing climate scenario. The role of water as an essential nutrient is fundamental in all the metabolic activities of the body. A study has been carried out to examine the influence of restricted water consumption on growth, physiological functions and blood metabolites in Malpura sheep. The results indicate that despite significant effects of restricted water consumption on various physiological responses, blood biochemical responses and feed intake, Malpura ewes have the capacity to adapt and can tolerate up to 50% water restriction as well as alternate-day water restriction without this affecting their growth during the summer season under semi-arid tropical environmental conditions (NICRA 2014). In many regions, the majority of the water requirements are met from the rivers in the neighbouring areas. However, the pastoralists might find it difficult to access this water as usually some state farms, private investors or national parks occupy the land on the banks of such rivers. Measures should be taken for minimizing landslide, conserving forests and making arrangements for safe landing of running water during rainy periods. Water resource management should be given apt consideration and precision irrigation techniques such as sprinkler and drip irrigation are to be promoted, along with adequate rain water harvesting techniques such as rooftop and ground water harvesting (International Fund for Agricultural Development 2009).

20.7.6 Strengthening Meteorological Services

Any sort of change in the existing climatic condition should be adequately signalled by the meteorological services, which should be able to forecast and provide timely warnings. According to the assessment report by the IPCC, between 1906 and 2005 there was an increase in the earth's surface temperature of 0.74 °C, which is mainly attributed to the greenhouse gas emissions from anthropogenic activities. It has been projected that temperatures will increase by 1.8–4.0 °C by the end of 2100 (Aggarwal 2008). During 1901–2009, the annual mean temperature saw a 0.56 °C rise in the Indian region (Indian Meteorology Department (IMD) 2010). Based on different scenarios of development, the IPCC has predicted that temperatures will increase by 0.5–1.2 °C, 0.88–3.16 °C and 1.56–5.44 °C towards the end of 2020, 2050 and 2080 respectively. Further, frequent warm spells, heat waves and heavy precipitation will be increased with a 90% confidence level, and a 66% confidence level has been estimated for the increase in tropical cyclones, high tides and drought events. Based on the geographical location in India, the intensity of such events will also vary. The Indian Meteorology Department (IMD) and the Indian Institute of Tropical Meteorology, Pune, also reported a similar trend of varying magnitude of extreme events in different geographical zones. Further, there is also a report (MoEF, GOI) stating that annual mean surface air temperature would increase in the range of 1.7–2.0 °C by 2030 from the present climate base line (1960–1990), by focusing on four sensitive areas of India that are identified to be highly vulnerable to climate change (INCCA 2010). The end of the twenty-first century will see a rise of mean annual temperature of 3–6 °C in India (Aggarwal 2008).

20.7.7 Pasture Management

Pasture availability is severely reduced during extreme climatic conditions, particularly when there is severe drought in the summer season. This leads to severe nutritional deficiency in sheep. It is not only the quantity but also the quality of available pastures that is compromised during the summer season. This reduced pasture during summer months leads to additional environmental stress, i.e., walking stress for sheep as the grazing animals need to walk a long distance in search of these limited pastures (Sejian et al. 2012). The main systems of rearing by which sheep are raised are semi-extensive and extensive, wherein the animals rely on most of their nutrient requirement from the grazed pasture. Therefore, appropriate pasture management should be in place to meet the season-based feed requirement to sustain sheep production in the changing climatic scenario.

Promotion of drought-tolerant varieties may help to reduce vulnerability to climate change. The cropping pattern should be based on the rainfall pattern in a geographical location in order to ensure year-round fodder availability (Akinnagbe and Irohibe 2015). Further, mixed cropping should be a common practice in order to minimize the climate-induced reduction in fodder production during drought condition (Akinnagbe and Irohibe 2015). Efforts are also needed to develop feed and fodder banks at appropriate locations to store pastures to be used in scarcity periods. Biomass intensification specially targeting sheep should receive the highest priority. Much of the tree biomass for sheep can be enhanced easily with little effort and few resources.

20.7.8 Grazing Management

For grazing systems that produce sheep, there is a complex interaction between the grazing pressure and impact of climate change that will ultimately determine the limitations of the production system. Livestock stocking rate should be consistent with the grazing capacity of the pastures. A strategic and rotational grazing system should be followed. The pressure on fodder supplementation can be reduced by supplementing feed.

Sheep rearing systems should comprise mixed farming systems so that animals can be grazed when the pastures are available in plenty, and they can be stall-fed during scarcity periods. This may ensure that the the energy requirement for maintenance is met, in addition to meeting the energy requirement for adaptation processes. Therefore, practising mixed farming systems would be advantageous, particularly in the tropical regions where pasture availability is at risk. Reducing the non-productive animals in the flock and maintaining the productivity of sheep farms through lower numbers of animals with high production capability may yield rich dividends in terms of effective utilization of existing limited pastures (Batima 2007). Introducing a silvipastoral system may also be an effective strategy for grazing management. This could offer multiple benefits for a sheep flock by meeting the fodder requirements as well as provision of shade for grazing animals. Rotational lopping of vegetative biomass of fodder, trees, shrubs, herbs and grasses to enhance forage production may also be practised to meet the year-round fodder requirement. Suitable range policy and establishment of authorities for managing the rangelands might ensure appropriate fodder supply during scarcity periods.

20.7.9 Shade and Cooling Management System

The most immediate and cost-effective approach for sustainable sheep production may be achieved through provision of low-cost shade, either through artificial or natural means. Physical protection against direct solar radiation by providing shaded structures may be of huge benefit to the heat-stressed sheep. In semi-arid and arid regions, a low-cost ‘Yangya’-type shed which facilitates heat dissipation and maintains relatively lower temperature at the ground level can be constructed for rest during grazing (NICRA 2014). Growing appropriate fodder trees in and around animal houses may be an appropriate strategy for providing natural shade to protect the animals against the sun. Cooling management is another important strategy for protecting the animals against heat stress, and promoting the evaporative cooling mechanisms may be very effective in promoting welfare in these animals. Provision of appropraite bedding materials in the barn may protect the animals from the adverse effects of heat stress. Cooling strategies may be practised before the animals shows signs of heat stress. Further, sprinkling should be practised in the morning hours rather than afternoon to have the beneficial impact in terms of providing comfort to the heat-stressed sheep. In areas where hot and humid conditions prevail, sprinkling the pen surface may be beneficial rather than sprinkling the animals as the latter may lead to humidity problems for the animals. In addition, handling of animals must be avoided during the hottest part of the day to ensure animal comfort.

20.7.10 Migration

Migration is commonly practised for sheep in tropical regions to meet the forage requirement during scarcity periods. In the changing climatic scenario, it is common for pastoralists to practise migration with their animals in search of feed and water resources during summer and drought conditions. Therefore, migration in terms of looking for better feed and water resources may be considered an important strategy to sustain sheep production during adverse environmental conditions. Judging the adaptive potential of the sheep breed is a prerequisite for deciding sheep migration as only the adapted breed might be able to cope with such migration patterns. There should be improvement in transport systems for sheep to winter and summer grazing areas. Movements of animals and people may be restricted because of increase in conflicts among the pastoral community. Effective management of conflicts that might arise among the pastoralists, farmers and state-owned livestock rearers for competition in sharing the geographical locations for water and pasture during migration must be strongly considered.

20.7.11 Capacity-Building Programme for Sheep Farmers

Imparting appropriate training for adopting different strategies for different stakeholders involved in climate change and sheep production is the need of the hour. Technologies pertaining to conservation of both feed and water resources must be promoted among the sheep rearers with hands-on training to implement such technologies. Capacity-building programmes must be included in the calendar of events to be followed. The capacity-building programme must address the following:

- Creating awareness about climate change and its consequences
- Signifying the value of local sheep breeds
- Training on implementing appropriate pasture management strategies
- Training to use unconventional feed resources
- Promoting technologies pertaining to improving soil fertility and water conservation
- Building knowledge on fodder production and conservation
- Strengthening flock health and reducing mortality

20.8 Impact of Cold Stress on Sheep

In sheep, cold stress increases the body's energy requirements, leading to mobilization of fat from adipose tissue and consequent fat oxidation and formation of non-esterified fatty acid (NEFA) as a by-product. The NEFA concentration in plasma is a reliable indicator of the nutritional status of the sheep body and the current level of response to cold stress in sheep (Hristov et al. 2012). Although the adrenal gland cortex is stimulated on hormone secretion in sheep exposed to cold and wet climate conditions and the number of eosinophils in the blood significantly decreases, the metabolic response to repeated cold exposure of sheep in the short term is progressively reduced.

20.9 Adaptation Strategies Against Cold Stress

20.9.1 Breeding Strategies

Sheep rearing is a feature of hilly areas of Western Himalayas. Particularly in the low hills, the sheep population has increased. Among the rare and endangered species inhabiting these rangelands is the Tibetan argali, a sub-species of rare Eurasian wild sheep which has successfully adapted to this harsh resource-limited environment (Singh 2008). In India, this sheep is mostly found in eastern Ladakh and north Sikkim (Fox and Johnsingh 1997).

20.9.2 Shade Management System

For sedentary sheep flocks, a house protected against direct wind-flow with thermo-cool-insulated roofing can also be a strategy to conserve day temperature to provide warmth at night during winter. For migratory sheep flocks, a dome-type easy-to-carry shed made of bamboo can be provided to protect the lambs from extremely low temperatures at night during winter (NICRA 2014). Care must be taken to provide appropriate bedding materials to protect the animals from the cold conditions.

20.9.3 Migration

Sheep farming in high-altitude regions primarily rely on migration based on pasture availability. Migration is usually practised to move to highland pasture during summer and move towards lower hills and valleys during winter. The scarce agricultural land, adverse environmental conditions and seasonality in available feed resources are the reasons which determine the migration of sheep flocks. The traditional practices and the local knowledge gained generally determine the migration pattern (Uniyal et al. 2005). Since cultivated agriculture is not possible in the high rangelands, grazing by sheep enables pastoralists to convert plant biomass into animal products that are either used for consumption or sold for income. The pastoralists practise seasonal movements in search of better foraging or grazing conditions for their sheep. Therefore, practising pastoralism is an ideal means to ensure livelihood security for sheep farmers at high altitudes.

20.9.4 Management Strategies

During winter, the weather conditions need to be continuously monitored and frequency of feeding has to be increased in response to cold weather. The pregnant animals, in particular during the last trimester, must be supplemented with additional feed during winter when the environmental temperature falls below lower critical temperature. Ensuring protection against cold wind is another important management strategy as the cold wind may increase stress levels in the animals. Efforts are needed to introduce high-yielding nutritious forages at selective sites which may ensure appropriate fodder supply during winter to the sheep flock. Proper bedding material should be used in the barn to protect the animals from cold stress. Care should be taken to ensure appropriate cleanliness and dryness of the animals as wet coats make them susceptible to cold stress. Further, animals should have access to ample amounts of water to maintain feed intake to meet the maintenance energy requirement in sheep.

20.10 Constraints

The major constraints of sheep production that need to be addressed include climatic changes, feed and water scarcity, poor grazing, traditional system of flock management, poor genotype, and increased rate of morbidity and mortality. Failure in fodder production is a matter of growing concern, emerging mainly from the shortage of sufficient land for fodder cultivation and acute non-availability of good-quality seeds. Adaptation strategies face challenges mainly due to inadequate knowledge, data and skills on climate change-related issues. Capacity-building programmes for different stakeholders associated with climate change and sheep production is the need of the hour to find solutions to all the above-mentioned constraints. These efforts can help to develop specific institutional frameworks for climate change mitigation in sheep production and help to improve our capacities to cope with climate change.

20.11 Conclusions and Future Strategies

Climate change is considered to be a rapidly emerging factor which negatively influences sheep production. Therefore, developing appropriate adaptation strategies to sustain sheep production is the need of the hour to ensure food security. Development of new skills and infrastructures should be aimed at understanding in depth the multifaceted impacts of climate change on sheep production. The primary target that needs consideration to adapt sheep production in the changing climate scenario is the conservation of pasture and water resources. These conservative measures should take into account the ground reality involving the local knowledge. Special emphasis should be given to developing suitable disease surveillance measures to promote good health and welfare of sheep. Finally, appropriate extension services need to be in place to promote the uptake of the strategies by the poor farmers through the lab-to-land approach. The strategies that are easy to adopt, cost-effective, developed based on indigenous knowledge and meet the farmer's preference hold the best chance for implementation and bringing about the desired success.

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Adapting Sheep Production to Changing Climate: Conclusions and Researchable Priorities

21

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Abstract

This chapter summarizes the salient findings of various researchers in their field of specialization pertaining to climate change and sheep production. It also highlights the future perspectives that are essential to sustain sheep production in the changing climate scenario, and presents an insight into the impacts of climate change on various aspects of sheep production. It summarizes the salient findings pertaining to climate change impacts on adaptive capacity, immune response, and disease occurrences in sheep. The chapter synthesizes the knowledge about the contribution of sheep to climate change and the various mechanisms through which it adapts to the devastating effects of climate change. In addition, an attempt is made to summarize the different adaptation strategies to sustain sheep production in the changing climate scenario, and recapitulate the different ame-

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lioration strategies such as management strategies, nutritional intervention, and body condition scoring (BCS) application employed to improve sheep production during exposure to the hot tropical environment. The chapter also states the importance of refining the existing thermal indices to appropriately quantify the impact of heat stress on sheep. It proposes a new breeding strategy involving adaptation, production, and low methane (CH_4) emission traits to ensure optimum production in sheep farms. Further, it also emphasizes that the existing agroadvisory services must be strengthened to allow sufficient reaction time for the farmers. Proposed advanced biotechnological tools include nutrigenomics, metagenomics, transcriptomics, and epigenetics to study in detail the cellular and molecular mechanisms of sheep adaptation in an attempt to identify important biological markers for heat stress. The importance of developing appropriate vaccine against CH_4 producing microorganisms has been described. Finally, climate-smart sheep production is discussed, which involves breeding only the productive animals; improving diets; better flock, manure, health, water, and grassland management; appropriate housing; and insurance for sheep farmers.

Keywords

Biological markers • Breeding policy • Climate change • Heat stress • Immunization • Metagenomics • Nutrigenomics • Sheep

Contents

21.1 Conclusions

The concluding chapter summarizes the highlights of the information presented in the book. This particular volume highlights that sheep thrive well in harsh agroclimatic conditions and have tremendous potential for providing sustainable food and fiber to a large population of people in developing countries in particular. They are also a sole source of occupation and income to a majority of landless or marginal farmers. Sheep breeds can tolerate a wide range of climates and convert poor-quality forage into quality animal protein. These characters favor their rearing in extensive systems among poor rural people in harsh climates (especially arid and semiarid zones). Sheep rearing contributes to livelihood security of poor farmers in drought-affected regions and acts as an adaptation and coping instrument to reduce shocks and vulnerabilities. The present scenario of climate change may cause the shifting of sheep from one region to other, change in breed composition, change in livelihood and nutritional security of farmers, shifting sheep breeds from wool to mutton type, emergence, reemergence of new diseases, etc. In the present scenario of climate change, sheep husbandry is expected to undergo dramatic changes. Impact of climate change on sheep husbandry is visualized as changes in breed composition, population and distribution, feed and fodder scarcity, shrinkage of grazing land, spread of diseases, market trend for wool and meat, productive and reproductive disorders, poor performances, consumer demand, etc. Hence, while aiming for sustainable sheep production, it is imperative to focus on reducing the effects of climate change.

While measures to reduce the growth of greenhouse gas (GHG) emissions are an important response to the threat of climate change, adaptation to climate change will also form a necessary part of the response. In this context, adaptation refers to strategies that act to reduce the adverse impacts of climate change. Developing adaptation strategies is therefore an important part of ensuring that countries are well prepared to deal with any negative impacts that may occur as a result of climate change. Given limited resources, adaptation strategies must target those populations most vulnerable to global change and equip those unable to adapt—generally the poorest—with the tools and incentives that will enable them to do so. Adaptation to climate variability has been an ongoing necessity for the agricultural sector. Existing strategies to manage climate variability present opportunities for meeting the challenges of future climate change. Finally, the authors of this particular chapter also urge the need to develop appropriate capacity-building programs for different stakeholders involved in climate change and sheep production, and establish a proper coordination between these stakeholders by strengthening the existing extension system, which could help to sustain sheep production in the changing climate scenario. Table 21.1 summarizes the salient points from each chapter of this book.

21.2 Future Perspectives

Future strategies and researchable priorities for enhancing productivity and resilience of sheep are outlined in Fig. 21.1.

21.2.1 Refining the Existing Thermal Indices

Many indices are available to quantify thermal stress in sheep. However, efforts are still needed to develop a more appropriate index including all the cardinal weather parameters as well as representing other primary factors influencing energy exchanges between the animal and its surroundings. Moreover, the available indices possess species-specific and location-specific limitations, as the adaptive capabilities of the animals are not the same between species and they respond quiet differently in various geographical conditions. Additionally, the index should be readily adjustable across different animal age groups, since their adaptive potential varies between age groups.

Table 21.1 Salient observations of different chapters in the book

Chapter number	Salient observations
Section I	
Chapter 1	Provides an overview on adapting sheep production to climate change
Chapter 2	It states the importance of rearing sheep in the changing climate due to its higher resilience compared to large ruminants
	Describes the economic consequences of various impacts of climate change on sheep farms
	Salient the importance of genetic selection based on the productive and adaptive performance to identify the thermo-tolerant breed specific to an agroecological zone
Chapter 3	Describes the impact of both heat and nutritional stress impact on sheep reproduction
	Describes the compromised reproductive performance in both ewes and rams subjected to different environmental stressors
	Salient the significance of providing optimum nutrition to counter heat stress condition in sheep
Chapter 4	Sheep can augment pro-inflammatory responses, both by physiological and psychological stressors, by increasing in vivo plasma secretions of pro-inflammatory cytokines, such as interleukin-6 (IL-6) and IL-1β
	Sheep experience a reduction of both IL-4 and IL-13 during heat stress, thus supporting the hypothesis of reduction of Th2 responses under hot climate
	It establishes that heat shock proteins (HSPs) are potent activators of the innate immune system capable of inducing the production of pro-inflammatory cytokines
	Polyunsaturated fatty acids (PUFAs) supplementation using flaxseed in sheep can improve the cortisol-producing capacity to relieve heat stress
Chapter 5	The authors rationalize that sheep rearing is a major part of animal production particularly in arid and semiarid areas
	Sheep possess the inherent capacity to adapt to the environmental challenges; however, while doing so, their production potentials are compromised
	Among the various adaptive responses, cellular and molecular mechanisms of adaptation are very crucial as studying these responses can yield confirmatory biomarkers to quantify heat stress in sheep
Chapter 6	Deliberates the genetic diversity and breed differences in sheep to adaptation to climate change
	Emphasizes the significance of marker-assisted selection and breeding strategies to evolve thermo-tolerant sheep specific to an agroecological zone
	The author of this chapter denotes that identification of genomic regions that have been associated with selection for phenotypic adaptation traits, such as tail fat deposition, is a challenging area of research in sheep genetics
	The phenotypic differences for adaptation, including coat, tail length, heat tolerance, and disease resistance, among sheep breeds have been shown to be associated with specific genes and genomic regions, using both high-density genotyping and landscape genomics approaches

(continued)

Table 21.1 (continued)

Chapter number	Salient observations
Chapter 7	Describes the climate change impact on water resources in terms of quantity, quality, variability, timing, form, and intensity of precipitation
	Water-stress-adapted sheep have thicker medulla in kidney that helps to produce concentrated urine as a water management strategy
	Sheep adopt reduced urination and defecation frequencies during heat stress condition in an effort to conserve body water
	The authors of this chapter establish significant increase in both cortisol and aldosterone level and reduced triiodothyronine (T_3), thyroxin (T_4) and prolactin in water-restricted sheep, and they attribute these mechanisms to conserve body water content.
Chapter 8	Emphasizes the importance of developing appropriate strategies involving management of rangelands, disease surveillance, and genetic selection of sheep for greater heat tolerance
Chapter 9	Sheep diseases caused by various microorganisms were found to have a strong seasonal influence which establishes the role of weather events in disease epidemics
	The authors of this chapter further opine that the climate change phenomena significantly influence disease epidemics by affecting the essential components of infectious cycle, namely, the host, pathogens, and mode of transmission
	Disease management in sheep herd involving farm-level biosecurity, quarantining of sick animals, and regular use of vaccines against frequently occurring diseases is essential to maintain a healthy herd
Section II	
Chapter 10	Sheep raised on intensive feeding regime were established to produce less CH_4 than their counterparts reared on extensive system or on pasture because of the availability of more fibrous feed to the animals
	Enteric CH_4 emission in semi-intensive type of feeding management could be lower than extensive system as supplemental concentrate may aid in better synchronization of energy and protein with optimum fermentation
Chapter 11	The authors of this chapter opine that *Prevotella* ssp. are the dominant bacterial community that utilize pectin in the sheep's rumen
	Heat stress reduces microbial protein synthesis since higher temperature diminishes the carbon and energy supply through the microbial fermentation
	Emphasizes the future research attempts to establish the interrelationship between rumen microbes to attempt enteric CH_4 reduction targeting rumen microbial pathway
Chapter 12	The authors of this particular chapter opine that although many factors influence the choice of methodology for CH_4 estimation, the in vivo techniques such as greenfeed, SF_6 technique, respiration chambers may provide the precise estimation which could be useful for determining the national CH_4 emission
Chapter 13	Propionate enhancers, alternate hydrogen sink, and antimethanogenic agents are the three primary pathways by which enteric CH_4 reduction is targeted in sheep
	Appropriate grazing management, feed additives supplementation, and immunization against methanogens can contribute enormously in reducing enteric CH_4 emission

(continued)

Table 21.1 (continued)

Chapter number	Salient observations
Section III	
Chapter 14	Provides an overview of various thermal indices that are available to quantify the severity of heat stress in sheep
	This chapter also salient that Temperature Humidity Index (THI) cannot be the full proof index to quantify stress condition in sheep as these do not take into account wind speed and solar radiation
	The potential applications of the black-globe temperature-humidity index (BGTHI) and heat load index (HLI) have been discussed elaborately in this chapter to be used as a full proof index for measuring the severity of heat stress in sheep
Chapter 15	Salient the significance of developing genetic markers to quantify heat stress in sheep
	Identifies that the genes upregulated in stressed cells in the first few hours were predominantly associated with cellular and protein repair
	Genomic selection technologies allow the identification of chromosomal regions (QTLs) through Genome-Wide Association Studies (GWAS) to identify genes or markers associated with traits of interest
Chapter 16	Provides an insight into the various types of sheep sheds such as open sheds, semiopen sheds, and enclosed sheds with their respective advantages and disadvantages
	Explains the ideal house requirements for sheep shed particularly in hot arid climates to reduce the negative effects of heat stress
Chapter 17	States the importance of providing appropriate shade, air movement, and water applications to ensure optimum sheep production in the changing climate scenario
	The development of heat-tolerant breeds, combined with improved nutritional management, can be considered as a fundamental strategy to improve sheep performance and well-being during heat stress
Chapter 18	Provides research evidence for supplementing antioxidants like uric acid, glutathione, vitamins E and C, and polyphenols to alleviate oxidation stress (OS) induced by heat stress in sheep
	Identifies certain plant-derived antioxidants and suggests feeding high-quality forages to sheep during heat stress
Chapter 19	States the importance of developing BCS to optimize the productive and reproductive efficiency of sheep
	Recommends appropriate BCS to be maintained for different productive phases in sheep
	Sheep kept under the conditions of a hot, semiarid environment should be maintained at moderate (3.0–3.5) BCS to ensure an optimum return from these animals
Chapter 20	Primarily focuses on developing an appropriate breeding program to develop a thermo-tolerant breed that can withstand the adverse environmental conditions
	Emphasizes on conserving the local indigenous breeds to identify biological markers which could be used to develop the agroecological zone-specific breed through marker-assisted selection
	The authors of this chapter also urge the need to develop appropriate capacity-building programs for different stakeholders involved in climate change and sheep production
Chapter 21	Discusses the future strategies and researchable priorities for enhancing productivity and resilience in sheep

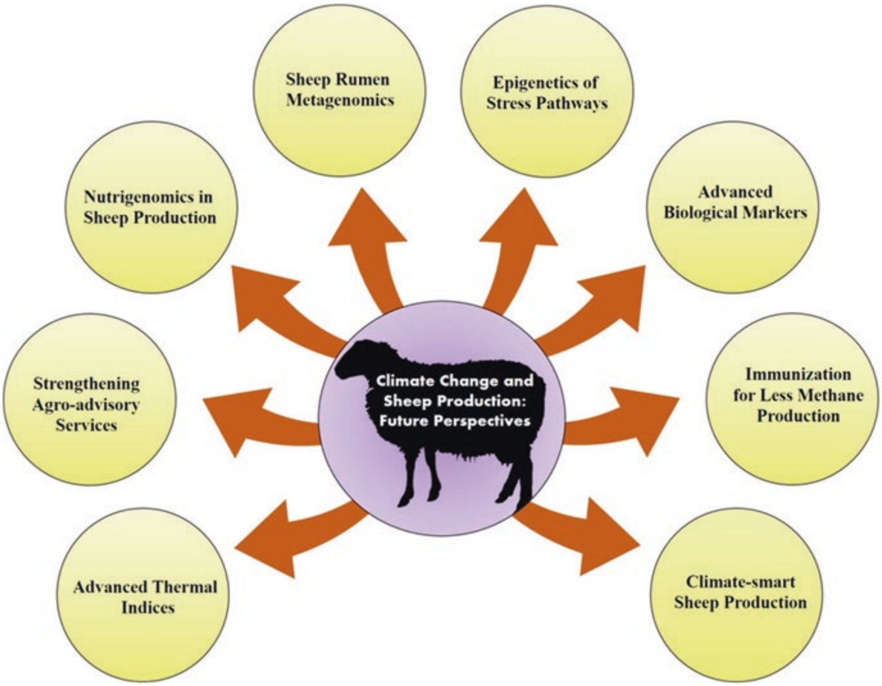
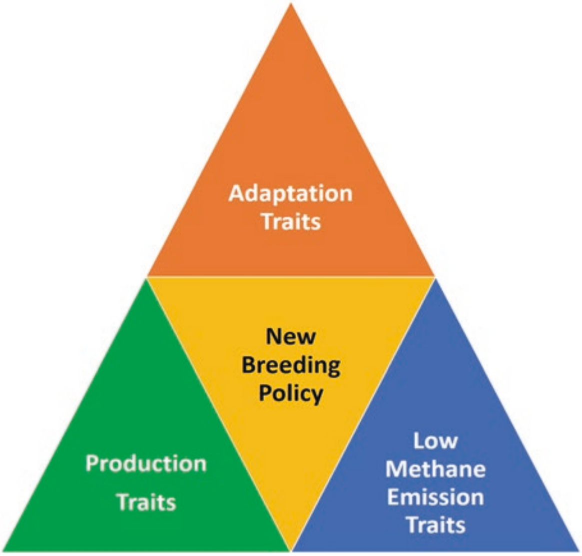


Fig. 21.1 Different future strategies to augment sheep production in the changing climate scenario

21.2.2 New Breeding Strategies: Adaptation vs. Production vs. Low Methane Emission

In the changing climate scenario, efforts are needed to develop appropriate breeding strategy to sustain sheep production. Although there is sufficient research pertaining to developing thermo-tolerant breeds using the germplasms of locally adapted breeds, still this may not serve the purpose as mostly the adaptive traits are taken into consideration and not the other important aspects such as production and CH_4 emission. Regardless of the superior adaptive/thermo-tolerant capacity, the selected breeds also should possess high production traits to improve the profitability of the sheep farmers, which is the ultimate aim of any strategy to improve food production. Further, enteric CH_4 emission causes severe economic burden to the farmers through dietary energy loss. Therefore, the breeding strategies developed should also incorporate traits pertaining to low CH_4 emission. Therefore, the existing breeding policies need to be refined by incorporating traits covering adaptation, production, and low CH_4 emission in sheep. This will ensure developing the most suitable breed, specific to an agroecological zone, which can ultimately ensure the livelihood securities for the sheep farmers. Furthermore, for the conservation of genetic resources throughout the world, practices like the compilation of complete

Fig. 21.2 New breeding policy to develop agroecological zone-specific sheep breed



breed inventories, higher support to the developing countries for managing genetic resources of animals and getting access to genetic resources in a broader way and correlated knowledge can be adopted. All these efforts may help to develop an agro-ecological zone-specific breed which can help to optimize the economic returns for sheep farmers. Figure 21.2 describes the new breeding policy involving adaptation, production, and CH_4 mitigation traits in sheep.

21.2.3 Strengthening the Agroadvisory Services

Weather and climate information of a particular location is crucial in controlling the biological functions of the animals, and if provided in advance, can be supportive to the farmers for organizing and planning their own resources to obtain maximum benefits. Nowadays, it becomes more and more important to provide climatic information along with medium forecasts (3–10 days) to adapt to the highly fluctuating weather patterns. In addition, the supply of agroadvisories based on medium weather forecasts enables the farmers to take timely actions for diminishing the adverse impacts on sheep production. The information from the agroadvisory services should cover detailed weather data of the particular region with appropriate forecasts, animal information, and proper management options to exploit or tackle the prevailing weather conditions. Such information will assist the farmers in taking appropriate decisions as well as provide sufficient time regarding the management practices and thereby reducing the weather risk on livestock production. Moreover, proper surveillance information and empirical data of disease response to climatic variables are essential to develop robust predictions and build GIS (Geographic information system) risk maps for parasitic diseases in sheep. Further, developing the satellite imagery could also contribute to these efforts by monitoring through infrared imaging for drought, pasture availability, and disease outbreaks. Further, these efforts may also strengthen the existing early warning systems in providing the most accurate weather predictions to the farmers to take timely preventive actions.

21.2.4 Applications of Nutrigenomics for Sheep Production

The effect of nutrition on different gene expression patterns is covered in nutrigenomics. This science can help the researchers to understand the mechanisms by which nutritional management can be applied to address disease occurrences, and productive and reproductive limitations in livestock species including sheep. The limitations of productive and reproductive performance can be elucidated at a molecular level using gene expression studies, and these studies are expected to revolutionize the existing methodologies and help define nutritional strategies for addressing them. Therefore, research efforts are needed with respect to nutrigenomics as it might serve as an important tool to improve sheep production by developing appropriate nutritional strategies for higher income and growth.

21.2.5 Significance of Studying Sheep Rumen Metagenomics

Metagenomics offers a huge scope in analyzing the collective microbial genomes using functional and sequence-based analysis in an environmental sample. Metagenomics provides a powerful tool for studying the rumen microbiome using next-generation sequencing and helps to create a reference database. There are two types of approaches: sequence-based metagenomics, which investigates the structural and functional biodiversity, and the second is the functional metagenomics, which screens enzymes from the microbial consortia. Rumen environment, being difficult to study using conventional culture techniques, can be understood through metagenomics analysis, which obviates the need for culturing the community members to understand their function. This technique will also be helpful in understanding the methanogenesis process and assessment of effects of CH_4 reducing agents on the overall composition and functions of the rumen microbial community in sheep. Although substantial progress has been made in establishing the application of metagenomics in understanding the rumen microbiology, further refinement of the technology is warranted to explore the possibility of metagenomics approach for enteric CH_4 reduction in sheep.

21.2.6 Studying Epigenetics of Stress Pathways

Thermal imprinting of genome and epigenetic regulation of gene expression could be applied to improve thermal tolerance in sheep. Although application of this technology is still in the state of infancy, this technology also offers huge scope for elucidating the stress-mediated pathways in sheep. Organized studies in this line might help to establish the DNA methylation patterns of liver and skeletal muscle associated with heat stress in sheep. Pathway and network analysis of these differentially methylated genes may reveal a number of candidate genes that might affect adaptation, muscle development, and meat quality. Such research efforts may therefore provide new clues for deciphering the epigenetic mechanisms of adaptation and skeletal muscle growth and development, and may likely contribute to the improvement of meat quality in sheep.

21.2.7 Cataloging Other Biological Markers for Heat Stress in Sheep

Although substantial information is available pertaining to the effects of heat stress on physiological aspects, the cellular and molecular mechanisms of stress response still remain unrevealed. Till date, most of the researchers have only attempted to establish the role of different heat shock proteins during heat stress condition in sheep. The whole transcriptome analysis helps to identify the superior thermo-tolerant genes by cataloging genes that are up- and downregulated during heat stress condition. These efforts might pave way for the creation of therapeutic drugs and treatments for the target genes. The genes responsible for regulating the adaptive mechanisms in sheep are very complex and therefore identifying those genes and characterizing them would be a tough task for the breeders. However, the development of advanced molecular biotechnological tools characterizing those complex traits of thermo-tolerance could be a possibility in near future. This might pave way for identification of crucial cellular pathways associated with heat stress response in sheep. These approaches may yield appropriate biological markers reflecting adaptation, production, immunological and meat qualities during heat stress in sheep. Cataloging these genes using an inventory can be of huge support for policymakers to use them up during marker-assisted selection program. With these advanced tools, it is possible to breed for thermo-tolerance involving the identified genetic markers in sheep with distinct accuracy. The identification, through genetic selection possibly using such systemic biomarkers, of such tolerant animals could be used as a strategy to counteract the detrimental effects of heat stress, culminating in improving the production and health of sheep in the changing climatic scenario.

21.2.8 Immunization for Less Methane Production

Development of vaccine against methanogens is considered a significant breakthrough in approaches of reducing the enteric methane emission. Further, there are few research reports which indicated the possibility of immunizing sheep against their own methanogens to reduce enteric methane emission. Although the preliminary research reports clearly suggest the possibility of developing a vaccine against CH_4 producing microbes, still they could not be commercialized. This warrants further research and refinement in the process of developing such vaccines to find solution to enteric CH_4 emission through immunological approaches in sheep. Development of universal vaccines has the potential to reduce CH_4 emission cost-effectively and enhance sheep production by preventing the dietary energy loss.

21.2.9 Climate-Resilient Sheep Production

Climate-resilient sheep production is the need of the hour. This requires a multidisciplinary research approach involving (1) breeding more productive animals; (2) improving diets so that animals produce more protein with less feed and lower emissions; (3) better manure management (e.g. composting); (4) better flock management to improve output, including better flock health management; (5) cost-effective sheep housing with indigenous knowledge; (6) less reliance on antibiotics; (7) better management of grassland; (8) developing appropriate water conservation measures; and (9) insurance for unexpected losses incurred during natural calamities for sheep farmers. These consorted efforts might pave way for effectively managing the sheep flocks in the changing climatic condition and may provide the ideal platform for the normal growth and reproduction in sheep which in turn can optimize the economic return from these flocks.

21.3 The Way Ahead

Sustaining sheep production in the changing climatic condition requires a paradigm shift in the rearing pattern and management practices. As we move forward, research efforts are needed in identifying the genes responsible for adaptation in local sheep breeds. Such studies must take into account the multiple environmental stresses influencing sheep production rather than heat stress alone. Therefore, research efforts are needed to assess the simultaneous impact of climate-change-related heat, nutritional, water, and walking stress particularly in the extensive system of rearing. This will help to identify the most suitable breed for a particular agroecological zone. Continued research evaluating the genomic and proteomic approaches to improve reproductive performance and nutritional status of heat-stressed animals is also warranted. While attempts are being taken to improve the genetic merit of the breeds to survive the multiple environmental stresses, efforts are equally needed to look for solution in reducing sheep-related GHG emission with the help of advanced metagenomic tool and immunization approaches. Scientific community must help the sheep enterprises by developing a new breeding policy involving marker-assisted selection to evolve a sheep breed which can adapt, produce, and emit low methane in the future. These are all the efforts that are needed in the future to sustain sheep production in the projected climate change scenario.