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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).

Dr. John Gaughan, PhD is an associate professor in the School of Agriculture and Food Sciences at the University of Queensland, Gatton, Australia. He has authored or co-authored 11 book chapters, 34 refereed publications, 72 conference proceedings and 20 research reports. He is recognised as a leader in cattle heat stress research in Australia and internationally. He is part of an international team which has recently developed new thermal stress indices for livestock and a heat stress risk assessment model for feedlot cattle. John is the treasurer of the International Society of Biometeorology and is a member of the Editorial Advisory Board for the *International Journal of Biometeorology*.

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Dr. Rattan Lal, PhD is a distinguished university professor of soil science and director of the Carbon Management and Sequestration Center, the Ohio State University, and an adjunct professor of University of Iceland. He received BS from Punjab Agricultural University, Ludhiana; MS from IARI, New Delhi; and PhD from the Ohio State University. He served as senior research fellow with the University of Sydney, Australia (1968–1969); soil physicist at IITA, Ibadan, Nigeria (1970–1987); and professor of soil science at OSU (1987–present). He has authored/co-authored 834 refereed journal articles and 477 book chapters and has written 19 and edited/co-edited 66 books. He is also included in the Thomson Reuters 2014, 2015 and 2016 list of the most cited scientists.

Adapting Sheep Production to Climate Change

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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.

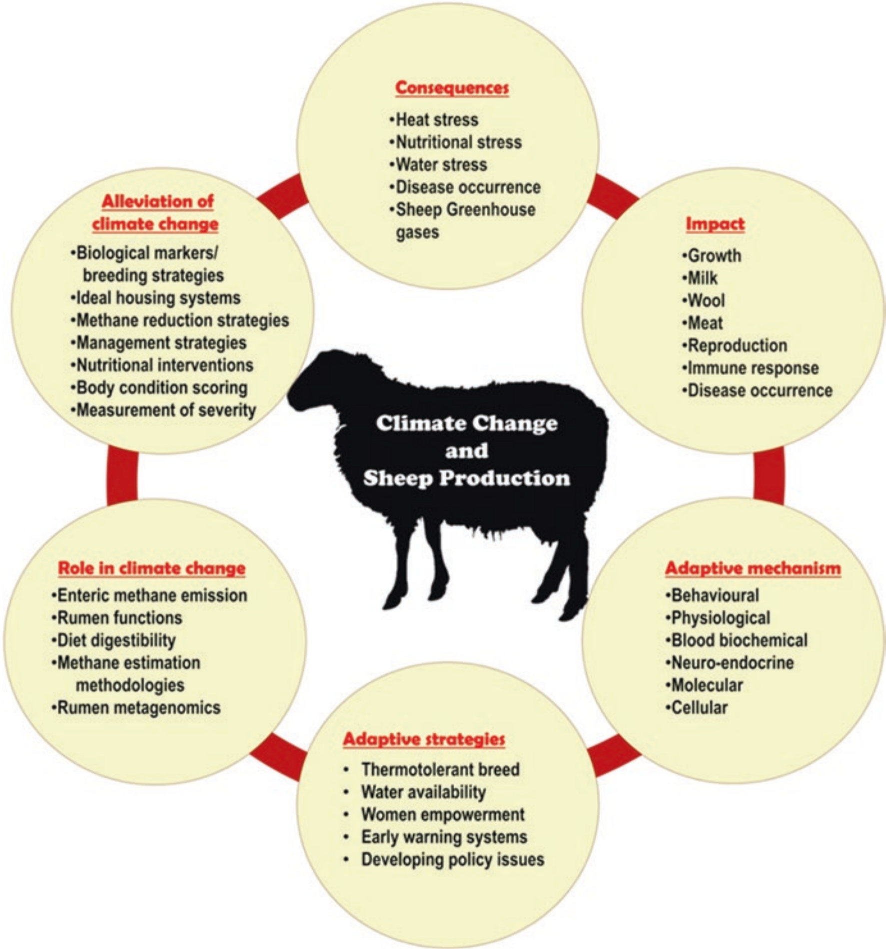

Fig. 1.1 Concepts associated with climate change and sheep production

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

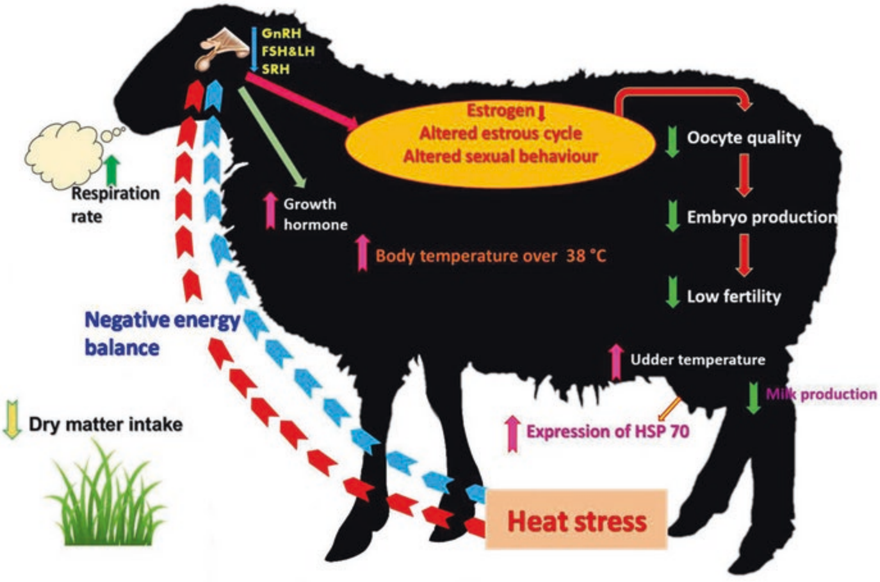

Fig. 1.2 Description of heat stress influencing various reproductive activities in sheep

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