Review Article

Thermoregulation in Sheep and Goats: A Review

Abstract

Thermoregulationis~~howmammals~~the ability of an animal to maintaintheircoreinternaltemperatureby~~returningthebodyto~~homeostasis. Small ruminants like ~~S~~sheepandgoatsareadaptabletodifferentenvironmentalchangesandoftenperformbetterduring heatstress~~additivity~~ comparedtootherruminants.~~animals.~~Adaptation ~~ing~~of small ruminants ~~sheepandgoats~~toextremeweatherconditionsoccursthrough behavioral, genetic,physiological~~,~~andmorphologicalmechanisms. ~~bases.~~Theycanminimizetheadverseeffectsofthermalstress through behavioralresponsessuchas increasedwater intake, ~~and~~seeking shade ~~seeking~~andothermorphological mechanisms suchashaircolorandfatstorage.Sheepandgoatsalsorespondtothermalchangesthroughphysiologicalmechanisms suchaschangesintherespirationrate,sweatingrate,metabolicrateand endocrinefunctions.From the genetics point of view, ~~Ingenetics,theauthorsreport~~ ~~that~~animalscould possibly ~~can~~inherittraitsthatfavortheirsurvivalinspecificenvironmentalconditions.Thesize and shape of the sheeporgoat~~'ssize~~ ~~andshape~~determinetherate of heatgainorloss~~rate~~andarecrucialinadjustingwaterlossandheatgaininscorching environments.Goatsandsheepexposedtohighambienttemperaturetendtohaveanelevatedrespiratoryrate,pulse rate~~,~~andincreasedrectaltemperature.~~Genetically,t~~Theadaptationofsheepandgoatstodifferentthermalenvironments ismediatedbyacomplexnetworkofgeneswithspecificgenome-wideDNAmarkersenhancingtolerancetoheat stress.

Keywords:Thermoregulation,SheepandGoats,Physiology,Behavior,Genetic,Heatstress

Introduction

Smallruminants~~, including~~likesheepandgoats,havebeenprimarilykeptinvariousenvironmentsandgrazingsystems, requiringmultipleadaptations,especiallyconcerningtemperaturechangesthroughthermoregulation.Froma biological perspective, thermoregulationcan bedefinedashow~~mammals~~animals maintaintheircore internal temperature~~by~~through the physiological process of ~~returning thebodyto~~homeostasis.The influenceofthethermal environment on animals isprimarilyexertedthrough energyexchangewhichinvolvesconvection,conduction,radiation~~,~~andevaporation.Many~~animal~~factors(e.g.,breed, genetics,healthstatus,bodycondition~~,~~andcoatcolor)determinemetabolicintensity,therateofthermalexchange, andthermalinsulation,whichcontributesignificantlytotheheatbalanceoftheanimal.Theoptimalinternal temperaturerangesfordifferentanimals ~~mammals~~andarebasedonvariousfactors,suchasthetemperatureofthe~~surrounding~~ambient environmentandenergyrequirements.Heatstressisoneoftheprimaryfactorsthatcanaffectthegrowthofsmall ruminantanimalslike ~~suchas~~sheepandgoatsindifferentpartsoftheworld.Asalimitingfactor,excessiveheatstresscan leadtoimpairedproduction,reproduction,compromisednaturalimmunity~~,~~andincreasedsusceptibilitytodiseases, in general the well-being of the animals. Heatstressaffectsruminants~~animal~~sthroughvariousenvironmentalfactors~~, including~~like highambienttemperature, excessivesolarradiation,relativehumidity,wind,rainfall,andnutrition.However,sheepandgoatsareadaptableto differentenvironmentalchangesandoftenperformbetterduring heatstress~~additivity~~comparedtootherruminants. ~~animals.~~ This ~~current~~review explains ~~explores~~theprocessofthermoregulationinsheepandgoats.Itdescribes~~the~~variousphysiological featuresofruminants~~animals~~thatenhancetheir abilitytoperform betterduringstress. ~~additivity.~~ Theadaptationofsheepand goatstoextremeweatherconditionsoccursthroughbehavioral,genetic,physiological,andmorphologicalmechanisms that~~bases.These mechanisms~~aredividedintothosethatmodulateheatproductionratesandtherateatwhichheatflowsin~~to~~andoutof theorganisms.Fromamorphologicalperspective,thecoatcolorofthesheeporgoatplaysavitalroleintheabsorption ofheat,with thelight-coloredcoatedanimalabsorbinglessheatthanthosewith darkercoats.

Genetically,scientificevidencehasshownthatdifferentgeneticfactorsenablesheepandgoatstothrive well ~~live~~inheat-stressed environments.Othergenesassociatedwithadaptabilitytotemperaturechangeshavebeenfoundinsheepandgoats, includingHSP70,whicharea set of heatshockprotein genesthatprotecttheanimalsfrom heat stress~~,~~andtheENOX2 gene, whichhasbeenfoundingoats susceptible to heat-stress. ~~susceptiblegoats.~~Otherpolymorphicgenes,includingMCIR,ASIP~~,~~andTYRP1, havebeenobservedindifferentsheepbreedsandareassociatedwithwoolcolor,whichcontrolstherateofheat absorption.~~Tothisextent,therefore,itcanbehypothesizedthat~~ It can be concluded thattheadaptationoftheruminantstodifferent environmentalconditionsisbasedontheirabilitytosurvive, growandreproduceunderextremelivingconditions.

Comment [GG1]: Cite reference

Comment [GG2]: Cite reference

~~Consideringthelackofcompleteinformationontheadaptationandsurvivaloftheseanimals,t~~Thecurrentreview providesanintegrativediscussiononthevariousadaptativemechanismsoftheruminantsinheat-stressed environments by assessing ~~.Itassessesthemultiple~~ the action of various genesthatareinvolvedinthermoregulation.

Comment [GG3]: There exists considerable information on the adaptation and survival of sheep and goats

~~LiteratureReview~~ Adaptation of animals to environmental stress

Differentenvironmentalconditions~~differently~~affecttheproductivityoflivestockwhilealsohavinganimpacton variousphysiologicalparameters.Temperaturesabovethethermoneutralzonetriggerachainofphysiological, anatomical~~,~~andbehavioral changesinthe body of ananimal~~'s body,~~suchasareduction of feedintake,adeclineinperformance (milkproduction,growth~~,~~andreproduction),adecreaseinactivity,anincreaseofrespiratoryrateandbody temperature,theadditionofperipheralbloodflowandsweatingandchangeinendocrinefunction(Fuquay,1981; Kadzereetal.,2002;Farooqetal.,2010;Renaudeauetal.,2012).Thermalstressaffectsthedynamiccharacteristics ofdigestionandneuroendocrinefactorsinfluencingmetabolism.Decliningfeedintakehasbeenidentifiedasa significant causeofreduced milkproductioninlivestockspecies(Farooqetal., 2010).~~Various~~Severalresearchstudieshave investigatedtherelationshipbetweenecologicalchangesandanimalresponse.~~However,quitelimitedextensive researchhasbeenconductedtodeterminehowsheepandgoatsrespondtotemperaturechangesthrough thermoregulatoryprocesses~~.AccordingtoaresearchstudybyLeiteetal.(2017),livestocktendstoshowreduced productivitylevelsinenvironmentswithhighlevelsofthermalradiationduetochangesintheirphysiological processes.Asexpected,animalsoftendevelopadaptivefeaturestocopewithenvironmentalchangestoguarantee survival.Intheir~~research~~study,Leiteetal.(2017)highlightedhaircharacteristicsasoneofthefeaturesdirectly associatedwithheatexchangeswiththeenvironment.Accordingtothe authors, ~~Leiteetal.(2017),~~thehairstructureservestwo primaryroles: protectingtheskinfromdirect solarradiation andpromotingtheprocesses ofconvectionandheat loss throughevaporation.Theefficiencyoftheperformanceoftheserolesisentirelydependentonthephysicalstructure ofthehaircoat.Therefore,theformofthehaircoatisconsideredaprominentphysicalthermoregulatoryfeatureof livestock,especiallyinsheepand goats.

Comment [GG4]: There are several studies to this effect

Berihulayetal.(2019)carried out ~~conducted~~areviewtoinvestigatetheadaptationofsmallruminants,specifically sheep andgoats,toenvironmentalheatstress.Accordingtothestudy,sheepandgoatsareamongthelivestockthatcan quicklyadapttochangesinenvironmentaltemperaturethroughacombinationofphysiology,morphology,andgenetic makeup. ~~(Berihulayetal.,2019).~~Thereviewrevealed ~~notes~~thatsheepandgoatscanminimizetheadverseeffectsofthermal stressthroughbehavioralresponsesuchasincreasedwaterintakeandshadeseekingaswellasothermorphological mechanismssuchashaircolorandtheamountoffattheykeep. ~~(Berihulayetal., 2019).~~ Otherphysiologicalchanges involvedthereductionofthebasalmetabolicrate,modificationsintheacid-basebalance,andhormonalbalance changes(Farooqetal.,2010;Renaudeauetal.,2012).Heatstresssignificantlyinducesthesecretionofhormones connectedwithmetabolism(thyroxine,somatotropin~~,~~andglucocorticoids)andwaterbalance(antidiuretichormone andaldosterone).Severaldaysafterheatstressbegins,thesecretionrateofthyroidhormonesisreduced.Growth hormonesecretionratesarereducedduringprolongedheatstressafteraninitialrise(Farooqetal.,2010).Adrenal corticoids,mainlycortisol,immediatephysiologicalchangesthatallowanimalstoundergostressfulconditions (Hansen,2004;Beattyetal.,2006;Renaudeauetal.,2012).Therefore,thermoregulationispartofahomeostatic mechanismtokeeptheorganismatanoptimumoperatingtemperaturewithincertainboundaries,evenwhenthe surroundingtemperatureisverydifferent(Ruben,1995;Griggetal.,2004).Intermsofphysiology,Berihulayetal. (2019)reportedthatsheepandgoatsrespondtothermalchangesthroughchangesintherespirationrate,sweatingrate, and metabolicrateendocrinefunctions.~~Regarding~~From the viewpoint ofgenetics,theauthorsopined ~~report~~thatanimalscaninherittraitsthatfavortheir survivalinspecificenvironmentalconditions(Berihulayetal.,2019).Theauthorsreported ~~note~~thatsheep andgoatsarerustic animalsthatcaneasilycopewithdifferentenvironmentsandarelesssusceptibletoheat-stressedenvironmentsthan otherruminants.

MorphologicalThermoregulationinSheepandGoats

Morphologicalthermoregulationinsheepandgoatsoccursthroughphysicalchangesthatenhancetheirfitness intheiroperationalenvironment.AccordingtoBerihulayetal.(2019),thecentralmorphologicaladaptationsofsheep andgoatstodifferencesinthermalconditionsincludebodysizeandshape,coatandskincolor,hairtypeandfat storage.Tobespecific,Leiteetal.(2017)reported ~~mention~~differentbreedsofsheepandgoatsthatuse~~s~~these~~mentioned~~ adaptationstosurviveinthermallystressedconditions.AccordingtoLeiteetal.(2017),theSudaneseSalehand EgyptianZaraibygoatshavelonglegsandearsasathermoregulatorymorphologicaladaptation,whileWestAfrican goats haveshortlegs.Theauthors reportthat theAwassi sheepof Israel haveloosecoarsewoolandadiposetissuereserves as athermoregulatorymorphologicaladaptationtoheatchangesintheir environment.

Comment [GG5]: Rephrase this sentence as meaning unclear

Incontrast,theDamarsheephavefattails.Ontheotherhand,Massese,Xalda,andSoaysheepusecoatcolorasthe thermoregulatorymorphologicaladaptivefeature,duringBarkisheepandgoatuseskinpigmentation.Therefore, Berihulayetal.(2019);Leiteetal.(2017)Berihulayetal.(2019)reportedthatsheepandgoatshavedifferentthermoregulatorymorphological adaptivefeaturessuch asbodysizeand shape, coatand skincolor,hairtype,andfatstorage. Ananimal'sThe body sizeandshapeof an animal isadominantmorphologicalfeaturethatinfluencesthethermoregulatorymechanismsofsheepand goatsinscorching environments.AccordingtoJoyetal.(2020),thesizeandshapeofthesheeporgoatdeterminethe heatgainorlossrateandcanbecrucialin adjustingwaterlossandheatgaininscorchingenvironments.

Comment [GG6]: Rephrase this sentence as meaning is unclear

Comment [GG7]: Repeated, hence delete

Biologically,any animalwith larger body sizeisexpectedto haveareduced metabolicrateandgain heatslower than smalleranimals(Berihulayetal.,2019).Assuch,sheepandgoatssmall ruminantsinscorchingenvironmentsareexpectedtohavea largerbodysizetoreducetherateofmetabolismandheatabsorption.Also,asreportedbyJoyetal.(2020),taller animalsareexpectedtoreleasemoreheatcomparedtoshortandsquat-bodiedanimals,whichexplainswhythe SudaneseSalehandEgyptianZaraibygoatshavelonglegsandearsasthermoregulatorymorphologicaladaptive featuresforevaporativeheatloss.Intermsoffatstorage,Berihulayetal.(2019)reportthatone-quarteroftheglobal sheeppopulationarefat-tailedbreedsandareextensivelythrive intropicalenvironmentalconditions,andcanaccumulate andmobilizethebodyfatfrom intheirinternalfatdepots.Itisimportanttonotethatsheepandgoatsusefattailsandfat rumpsasathermoregulatorymorphologicalfeaturebasedontheiroperationalenvironmentalcondition.Therefore, bodysize,shape,andfatstorageareimportantthermoregulatorymorphologicalfeaturesandmechanismsforsheep andgoats.Itisthoughtthattheevolutionofsubcutaneous(fattytissue)orsupercutaneous(hair)thermalinsulation affectsheatflowtoandfromtheorganismalongthethermalgradientfromtheorganismtotheenvironment(Schmidt -Nielsen,1997;Bligh,1998).Thisimpliesthatsheepfleecemorphologyaffectsheatdissipationfromtheirskinsurface throughthermoregulatorymechanisms.

Themorphology of external coat of sheep'scoatmorphologychangedsignificantlyduringdomestication.Thereareprimitivesheepbreedsthatstill possessadoublecoatofcoarseouterhairs(producedbyprimaryhairfollicles)andfineinnerhairs(derivedfrom secondaryhairfollicles),likeSoaysheep.Ratherthanhavingtwofollicles,modernwooledsheep(e.g.,Merino)have asinglecoatcontainingbothprimaryandsecondaryfollicles(SumnerandBigham,1993,Galbraith,2010).However, thereisawidevariationinskinandcoatmorphologyacrossdifferentbodyregions.Skinthicknessdecreasesfrom the dorsal side to the ventral dorsallyto ventrally on thetrunk andfrom proximally todistallyon thelimbs(Scott,1988).

Thereisapositivecorrelationbetweenskinthickness,meanfiberdiameter~~,~~andstaplelength(Gregory,1982).Among sheep,thepinnae, ~~andthe~~axillary,inguinal~~,~~andperianalregionshavethethinnestskin,withanaveragethicknessof 2.6mminadults(LyneandHollis,1968).Theseareaswiththinnerskinandshorterhairactas"thermalwindows"for thedissipationofheat(Fowler,1994;Mauck etal.,2003).Infraredelectromagneticwavescanmeasuretheflowof thermalenergybetweentheskinandtheenvironment.Fordetectingthisinfraredradiationintheboundarylayerofan animal,infraredthermographyisan excellentnon-invasivetool(Gerken,2010;AL-Ramamnehetal.,2012).

Comment [GG8]: Some more details of this experiment can be cited

~~AccordingtoBerihulayetal.(2019),coatandskincolorarecriticalmorphologicalfeaturesusedforthermoregulation bydifferentanimals, includingsheepand goats.~~Thecharacteristicsofthecoatandskinofsheep andgoatsin tropical anddesertenvironmental conditionsareentirelydifferent fromthoseintemperateenvironments(Joyetal.,2020).The ability of the hair coat ~~A haircoat'sability~~toabsorbradiantheatdependsonitssurfacearea,pigmentation,structure,length~~,~~andcondition. Severalstudieshaveshownthatblack-pigmentedhairinbright ~~strong~~sunshinehasagreatersurfacetemperaturethanhair withothercolors,whetherinsheeporgoats.Thecoatcolorisanimportantfeaturethatdeterminestheradiantheat loadandtheamountofsolarradiationthatisreflectedandabsorbedbytheanimal.Thosewithlightcoatcoloring absorblessheatthanthosewithdarkcoatcoloring(Berihulayetal.,2019).AccordingtoLeiteetal.(2017),sheep withdarkpigmentsaremorepronetoareaswithheatstressthanthosewithlightpigmentation.Thecolorationof surfacesiscausedbydifferentialreflectionortransmissionofshortwaveradiation.Sensibleheatisgeneratedwhenever thesurface~~doesn't~~does notreflectortransmittheradiation(Walsberg,1983;Gerken,2010).Adarkercoatcolorabsorbssolar radiationmoreefficiently,providingmoreheatandemittingmoreenergy(GalvanandSolano,2016).

Consequently,animalsadaptedtohot climateshavebeenobservedtochangetheirhaircoatcolorstoaltertheirsolar absorption(Acharyaetal.,1995; Kadzereet al.,2002).Therefore,selectinganimals with alightcolorisessential for thewelfareandproductionefficiencyofthesheep.AccordingtothereviewbyBerihulayetal.(2019),theeffectsof coatcoloringthatarerelatedtoclimatic-stress-tolerancetraitsinthewestAfricandwarfsheepincludetherateof respiration,therectaltemperature,thepulseratepackedredcellvolume(PRCV),plasmasodium(Na^+),andpotassium (K^+).Ithasalsobeenreportedthatsheepwithcarpet-typewool,thinnerskin~~,~~andshorterhairsarewelladaptedtohot environmentsduetotheimprovedheatdissipationrate(Berihulayetal.,2019).Therefore,coatandskincolorare essentialthermoregulatorymorphologicalfeaturesusedbysheepandgoatstosurviveindifferentthermal environments.

BehavioralandPhysiologicalMechanismsofThermoregulation

Thebehavioraladaptationofsheepandgoatstodifferentenvironments isbasedontheirinstinctivereaction tochangesintheirexternalenvironmentbyperformingvariousactivitiestocontroltheirbodytemperature.According toBerihulayetal.(2019),thebehavioraladaptationofsmallruminantsismeanttoprotectthemselvesfromextreme environmentalfactorsthroughthesheddingofhair,waterrestriction,andcontroloffeedintake.Also,itisessentialto notethatruminantsareactiveduringthedayandrestduringthenighttocontroltheamountofheatandenergy requirementsbasedontheiroperationenvironment(Okoruwa,2014).Whensmallruminantslike sheepandgoatsare have exposedtoexcessivelyhigh-temperatureconditions,thereis shallbeareducedintakeoffeedasameansofadaptation to reduceheatproductionsincetheheat incrementoffeeding isacrucialsourceofheat production. AccordingtoJoy etal.(2020),goatsarebetteradaptedtoheatstressthanotherruminantsbecausetheyhaveadynamiceatingbehavior inhotenvironmentalconditions.Forexample,theSaanengoatsexposedtohighlysevereheatstresshavealargermeal sizebutareducednumberofmealscomparedtotheGermanImprovedFawn(GIF)goats(Berihulayetal.,2019). Goatsexposedtohighlystressfulconditionshaveareducedfeedintake,bodyweight,andgrowthratetomaintaintheir thermoregulatorymechanismsandaveragebodytemperature.

~~Goatsandsheeppossessvariousphysiologicalthermoregulatorymechanismstoadapttodifferent environmentalconditions.~~Whenthephysiologicalmechanismsoftheanimalsfailtoaddresstheeffectofvariousheat changes,thebodytemperaturecanchangetoapointwhereitswell-beingiscompromised(Berihulayetal.,2019).The bodytemperatureofananimalisessentialingaugingitsheattoleranceasitrepresentsthenetamountofheatasa resultoftheheatgainandlossprocessesinthebody.Thecriticalphysiologicaladaptationmechanismsinsmall ruminants,~~includingsheepandgoats,~~includethechangeinheartrate,respirationrate,andrectaltemperature.The rectaltemperatureofsheepandgoatsisastandardtoolofmeasurementofthebodytemperature,evenifthereisa significantvariationin thetemperatureofotherbody partsatvarioustimesoftheday.Inareasofhigh heatstress,the respiratoryrateistheprimarythermoregulatorymechanismusedbysmall ruminants~~sheepandgoats~~tomaintainanaveragebody temperature.Anotherphysiologicalthermoregulatorymechanismsmall ruminants ~~sheepandgoats~~useispanting,resultingfroman increasedrespiratoryrate(Berihulayetal.,2019).Itisimportanttonotethatsheepandgoatsexperiencevarious complexphysiologicalchangesinresponsetovaryingchangesintemperature.Inmostcases,animalsexposedtohigh ambienttemperaturestendtohaveanelevatedrespiratoryrate,pulserate,andincreasedrectaltemperature.Therefore, physiologicalmechanismsarenecessaryforthethermoregulatoryadaptations ofsheepandgoatstodifferent environments.

~~Asaforementioned,~~Berihulayetal.(2019)reportedthat thephysiologicaladaptationofsheep andgoatsina heat-stressedenvironmentoccursthroughanincreasedrespiratoryrate,increasedsweatingrate,reducedmetabolic rate~~,~~andchangesinthefunctioningoftheendocrinesystem.Variousresearchstudies~~andliterature~~haveshownthat therespiratoryrateandtherectaltemperaturearegoodindicatorsofthermalstressandcaneffectivelyassessthe adversityoftheoperationalthermalenvironment. AccordingtoGuptaetal.(2013),an increaseintherectal temperatureofgoatsfrom38^0to39^0indicatesthattheanimalhasbeenkeptatahotambienttemperatureformorethan sixhours.Another~~research~~studybyAl-Dawood(2017)reportedthatanincreaseinrectaltemperatureabove44^0C indicatesthattheanimalhasbeenexposedtohighertemperatures.AccordingtoAl-Dawood(2017),therespiration rateofgoatsincreasessignificantlyatatemperatureabove40^0C~~,~~andewesalsoreportsignificantincreasesinthe respiratoryrateandrectaltemperaturewhensubjectedtowalkingstressofmorethan14kminadaywhichincreases theirbodytemperature~~s~~.Anincreaseinthetemperatureofsheepandgoatsabovethethermalcomfortleadstothe activation ofevaporativecooling mechanisms,andtherateofsensible heatloss gets reduced(Berihulayetal.,2019). Therefore,therespiratoryrateandrectaltemperaturecanbeconsideredcriticalphysiologicalindicatorsofthethermal conditionsoftheenvironment.

GeneticMechanismsofThermoregulation

Performancetraitsareantagonisticwithheattolerance. ~~and,therefore,~~theuseofheat-resistantindividualsingoat breedingprogramsshouldbeoneofthemainstrategiestoimproveboth animalwelfareandproductivityinhotclimates

Comment [GG9]: Indicate the measure (C)

Comment [GG10]: This needs to be deleted as adaptive features of animals have very low heritability. When heritability is low, one cannot undertake selection for that trait. Selection is carried out only when the trait shows moderate to high heritability.

Adaptationconcerninggeneticaspectsisassociatedwiththe~~in~~heritabletraitsofanimalcharacteristicsorfeaturesthat enhancetheirsurvivalortolerancetotheirexternalenvironment.Inmostcases,adaptivefeaturesarecharacterizedby ~~reduced~~lowheritabilityof ~~with~~thegeneticvariationwithinapopulation,providingtheflexibilityofadaptationtovarious environments,whichiscrucialforthelong-term survival of a population.~~population'slong-termsurvival.~~Researchstudies~~andliterature~~haveindicated thatthe role of genes ~~genes'role~~indeterminingthecapabilityofsheepandgoatstosurviveinaheat-stressenvironmentiscomplicated mainlybecausethemitochondrialgeneshaveahighassociationwithadaptabilitytotemperaturechangesasitplaysa centralroleinenergymetabolism.Mostorganellesinsmallruminantslikesheepandgoatshaveaspecificgenome withoneparticularmodifiedgeneticcode,withthemitochondrialD N A ~~genome~~beingacircularanddouble-stranded molecule.SomeoutstandingcharacteristicsofthemitochondrialDNAthatplayaroleinthermalregulationinclude therelativelyconservativegenecontentandorganization,thereducedsize~~,~~and~~the~~limitedrecombination.As Berihulay etal.(2019) reported,theadaptation ofsheep andgoatstodifferentthermalenvironmentsismediated by a complex network ofgeneswith specificgenome-wideDNA markersenhancing tolerancetoheatstress, asisthecase inthecaseofEgyptBarakidesertsheepandgoats.Somepossiblegenesthatplayaroleinheattoleranceinsheepand goatsincludeANXA6,GPX3,GPX7,andPTGS2.Therefore,genesplayacriticalroleinthermoregulationinsheep andgoats.

Comment [GG11]: Cite reference

EndocrineandMetabolicThermoregulatoryAdaptation

Heat stress generallyaffects livestockproductivity,but very littleinformationis availableregardingtheirresponseto heatatacellularlevel.Stressaffectsbothinnateandadaptiveimmuneresponsesinanimals.Theimmunesystemdoes notresponddirectlytostressbutactsviatheneuroendocrinesystem.Thestress-relatedhormonesactontheimmune cellreceptorstomodulatetheimmuneresponse.Theinnateimmuneresponse~~isoneoftheprimaryimmuneresponses that help~~primarilytackle thepathogensthatenterthehost animals.According toRoachetal.(2005),most vertebrategenomes containonegeneforeachofthesixmajorTLRfamilies(TLR1,TLR3,TLR4,TLR5,TLR7,andTLR11).Theheat shockresponseconferstransientthermaltolerance,partlyduetotheexpressionofheatshockproteins(HSPs).HSP70 playsthemostdominantroleamongalltheHSPsinprotectingcellsfromdamagecausedbyacutethermalstress (Dangi et al., 2014).Several reports~~kinds oftheliteratureshowed~~reveal that heatshockproteins (HSPs)arerapidlysynthesizedin tissuessubjectedtothermalstressors.

Inlivingtissues,HSPmaintainstheintegrityofstructuralproteins,preventsproteinaggregation,andaidsthefolding–refoldingofdamagedproteins(Morimoto,1998b,2008).The gene Hsp90isnecessaryfortheviabilityofeukaryotes.Ithasbeen provedthatHsp90directsfolding,structuralintegrity~~,~~andproperregulationofasubsetofcytosolicproteins(Carveret al.,1994;Matsumiyaetal.,2009;Nguyenetal.,2009;Teetal.,2007).Besides,adecreaseinintracellularHsp90 concentrationhasbeenreportedtoincreasethemortalityofmammaliancellsathightemperatures(Barnesetal., 2001).The gene Hsp60isbelievedtoprotectthestructureandfunctionofnativemacromolecules,particularlyastheytraffic acrossmembranes(Guptaetal., 2010).

Theplasmacortisolconcentrationinthebblooddeterminestheendocrineadaptationofsheepandgoatstodifferent thermalenvironments.AccordingtoArchanaetal.(2018),theSalemBlackgoatsin India havereducedplasmacortisol concentrations,whichindicatestheirsuperiorityinadaptabilitytostressfulconditionscomparedtotheOsmanabadi goats,witharelativelyhighconcentrationofplasmacortisolintheirbloodduringthesummer.TheplasmaT3/T4 concentrationsalsodeterminethevariationsinthebreedsofsheepandgoatswiththeirresponsetodifferentheat conditions.AccordingtoJoyetal.(2020),thecross-bredChoklasheephavehighplasmaT3concentrationsduringthe summercomparedtootherpurebreeds,whichindicatesaberrantthyroidglandactivityandpoorthermoregulationin heat-stressedenvironments.The author Joyetal.(2020)furtherreportedthatsheepbreedswithlowplasmathyroidhormone concentrationsaremore adapted toheat-stressed environmentsasa resultof thereductionintherateof production of metabolicheat.Ithas been isfurtherreportedthatheatstresssignificantlyincreasedtheconcentrationsofplasmagrowth hormonesinvariousgoatbreeds,includingOsmanabadi,SalemBlack,andMalabari.TheOsmanabadigoatshave higherplasmaconcentrationsassociatedwithincreasedthermotolerancetoexcessivelyheat-stressedenvironments. Therefore,theendocrinesystemplaysacrucialrolein thermoregulationinsheepandgoats.

Regardingmetabolism,thesizeofsheepandgoatsoftendeterminesthenaturalselectionforthegenotypesof adaptabilitytodifferentenvironments.AccordingtoJoyetal.(2020),metabolismisacrucialdeterminantof thermoregulationwhichdeterminesthenettemperatureoftheanimal.Sheepandgoatswithrelativelysmallsizeshave reducedmetabolicrequirementsandreducedheatproduction,whichhelpsthemtosurviveinheat-stressed environments.Thereducedsizeofsheepandgoatsoftenconfersanadvantagetothetropicalbreeds,ensuringtheir survival insuchenvironmental conditions.Also, anotherimportant determinantoftheamount ofheatinruminantsis thevolatilefattyacidsprofilesintherumen,whichareimportantdeterminantsofenergysupplyintheanimals.The fattyacidsdeterminetheamountofheatgainedorlostwhichdeterminesthenet temperature of the animal'snettemperature(Joyetal.,2020). AccordingtoPragnaetal.(2018),theSalemgoatbreedshaveahigherpropionateproductionthantheOsmanabadi andMalabari breeds,leadingtoreducedmethanesynthesis.Also,thedifferencesintheconcentrationoftheproportionof volatile fattyacidsdeterminethedigestibilityofdiets andthepopulationofrumenmicrobesingoatsexposedtoheat stresschallenges(Pragnaetal.,2018).Therefore,metabolicactivitiesinsheepandgoatsareimportantdeterminants ofthetemperatureoftheanimalsandtheir responseto differentthermalenvironments.

Conclusions

The current review explored the processes of thermoregulation in sheep and goats and describesd the variousphysiologicalfeaturesoftheruminantsanimalsthatenhancetheir ability to perform betterduring stress.additivity. Numerous studies have investigated the relationship between environmental changes and animal response. However,quite limited extensive research has been conducted to determine how sheep and goats respond to temperaturechanges through thermoregulatory processes. According to the review, hHeat stress is one of the primary factors thatcan affect the growth of small ruminantsanimals such as sheep and goats and can lead to impaired production,reproduction,compromisednaturalimmunity,andincreasedsusceptibilitytodiseases.Thearticlefurtherreports that the adaptation of sheep and goats to different thermal conditions occurs through behavioral, genetic,physiological, and morphological bases. Morphologically, the coat color of the sheep or goat plays an essential rolein the absorption of heat, with the light-colored coated animal absorbing less heat as compared to those with darkercoats. The behavioral adaptation of sheep and goats to different environments is based on their instinctive reaction tochanges in their external environment by performing various activities to control their body temperature. Sheep andgoats use fat tails and fat rumps as a thermoregulatory morphological features based on their operationalenvironmental conditions. Also, these small ruminants sheep and goats exposed to high ambient temperature tend to have an elevatedrespiratory rate, pulse rate, and increased rectal temperature. Therefore, thermoregulation in small ruminants sheep and goats occursthrough behavioral,genetic,physiological,and morphological bases mechanisms.

References

1. AbhijithA,SejianV,RubanW,MadiajaganB,KrishnanG,Joy A,etal.Comparativeassessmentofheatstress induced changes in carcass traits, plasma leptin profile and skeletal muscle myostatin and HSP70 geneexpressionpatternsbetweenindigenousOsmanabadiand Salem Black goatbreeds.MeatScience.2018;141.

2. AcharyaRM, GuptaUD,SehgalJP,Singh M.Coatcharacteristicsofgoatsin relation toheattoleranceinthehottropics. Small RuminantResearch. 1995;18:245-8.

3. Al-Dawood A. Towards Heat Stress Management in Small Ruminants – A Review. Annals of AnimalScience.2017;17(1):59-88.

4. Al-RamamnehD,RiekA,GerkenM.EffectofwaterrestrictionondrinkingbehaviourandwaterintakeinGerman black-headmuttonsheepand Boergoats. Animal.2012;6(1):173-8.

5. BeattyDT,BarnesA,TaylorE,PethickD,McCarthyM,MaloneySK.PhysiologicalresponsesofBostaurusan d Bosindicuscattleto prolonged,continuousheatand humidity.JAnim Sci.2006;84(4):972-85.

6. BerihulayH,AbiedA,HeX,JiangL,MaY.AdaptationMechanismsofSmallRuminantstoEnviron mentalHeatStress. Animals. 2019;9(3):75.

7. BlighJ.MAMMALIANHOMEOTHERMY:ANINTEGRATIVETHESIS.JournalofThermalBiology. 1998;23:143-258.

8. CarverLA,JackiwV,BradfieldCA.The90-kDaheatshockproteinisessentialforAhreceptorsignalingin a yeastexpressionsystem. JBiolChem. 1994;269(48):30109-12.

9. Dangi SS, Gupta M, Nagar V, Yadav VP, Dangi SK, Shankar O, et al. Impact of short-term heat stress onphysiological responses and expression profile of HSPs in Barbari goats. International Journal of Biometeorology.2014;58:2085-93.

10. FarooqU,SamadHA,ShehzadF,QayyumA.PhysiologicalResponsesofCattleto HeatStress.Worldapplied sciencesjournal.2010;8:38-43.

11. FowlerME.Hyperthermiainllamasand alpacas.VetClinNorthAm Food AnimPract.1994;10(2):309-17.

12. FuquayJW.Heatstressasitaffectsanimalproduction.JAnimSci.1981;52(1):164-74.

13. GalbraithH.Fundamentalhairfolliclebiologyandfinefibreproductionin animals.Animal. 2010;4(9):1490-509.

14. GalvánI,SolanoF.BirdIntegumentaryMelanins:Biosynthesis,Forms,FunctionandEvolution.IntJMol

Sci.2016;17(4):520.

15. GerkenM.RelationshipsbetweenintegumentalcharacteristicsandthermoregulationinSouthAmericancamelids.Animal. 2010;4(9):1451-9.

16. Gregory I. Genetic studies of South Australian Merino sheep. 4. Genetic, phenotypic and environmentalcorrelationsbetweenvariouswoolandbody traits.Australian Journalof AgriculturalResearch.1982;33(2):363-73.

17. GriggGC,Beard LA,AugeeML.Theevolutionofendothermy anditsdiversityinmammalsandbirds. PhysiolBiochem Zool.2004;77(6):982-97.

18. HansenPJ.Physiologicalandcellularadaptationsofzebucattletothermalstress.AnimReprodSci. 2004;82-83:349-60.

19. JoyA,DunsheaFR,LeuryBJ,ClarkeIJ,DiGiacomoK,ChauhanSS.ResilienceofSmallRuminantstoClimateChangeandIncreased Environmental Temperature:A Review. Animals.2020;10(5):867.

20. KS-N.Animalphysiology:adaptation andenvironment.5thed.CambridgeUniversityPress:Cam.Uni. Press,Cambridge,UK.;1997.607 p.

21. Kadzere CT, Murphy MR, Silanikove N, Maltz E. Heat stress in lactating dairy cows: a review. LivestockProduction Science.2002;77(1):59-91.

22. LeiteJHGM,FaçanhaDAE,CostaWP,ChavesDF,GuilherminoMM,SilvaWST, etal.Thermoregulatoryresponses related to coat traits of Brazilian native ewes: an adaptive approach. Journal of Applied Animal Research.2018;46(1):353-9.

23. LyneAG, HollisDE.Theskinofthesheep:acomparison ofbodyregions.AustJBiolSci. 1968;21(3):499-527.

24. Matsumiya T, Imaizumi T, Yoshida H, Satoh K, Topham MK, Stafforini DM. The levels of retinoic acid-induciblegene Iare regulatedbyheatshockprotein 90-alpha.JImmunol. 2009;182(5):2717-25.

25. Mauck Br, Bilgmann K, Jones DD, Eysel U, Dehnhardt G. Thermal windows on the trunk of hauled-outseals:hotspotsforthermoregulatory evaporation?JournalofExperimentalBiology.2003;206(10):1727-38.

26. MorimotoRI.Proteotoxicstressandinduciblechaperonenetworksinneurodegenerativediseaseandaging. GenesDev.2008;22(11):1427-38.

27. Morimoto RI, Santoro MG. Stress–inducible responses and heat shock proteins: New pharmacologictargetsfor cytoprotection. Nature Biotechnology.1998;16(9):833-8.

28. Nguyen N, Francoeur N, Chartrand V, Klarskov K, Guillemette G, Boulay G. Insulin promotes theassociationofheatshockprotein90 withtheinositol1,4,5-trisphosphatereceptortodampenitsCa2+releaseactivity.Endocrinology.2009;150(5):2190-6.

29. OkoruwaMI.EFFECTOFHEATSTRESSONTHERMOREGULATORY,LIVEBODYWEIGHTANDPHYSIOLOGICAL RESPONSES OF DWARF GOATS IN SOUTHERN NIGERIA. European Scientific Journal,ESJ.2014;10(27).

30. PragnaP,SejianV,SorenNM,BagathM,KrishnanG,BeenaV,etal.Summerseasoninducedrhythmicalterations in metabolic activities to adapt to heat stress in three indigenous (Osmanabadi, Malabari and SalemBlack) goat breeds. Biological RhythmResearch. 2018;49(4):551-65.

31. RenaudeauD,CollinA,YahavS,deBasilio V,GourdineJL,CollierRJ.Adaptationtohotclimateandstrategiestoalleviate heatstressinlivestock production. Animal.2012;6(5):707-28.

32. Roach JC, Glusman G, Rowen L, Kaur A, Purcell MK, Smith KD, et al. The evolution of vertebrate Toll-likereceptors. ProcNatl AcadSciU SA.2005;102(27):9577-82.

33. Ruben J. The Evolution of Endothermy in Mammals and Birds: From Physiology to Fossils. AnnualReviewof Physiology.1995;57(1):69-95.

34. **ScottDW**.LargeAnimalDermatology.W.B.Saunders.JournalofVeterinaryMedicine,SeriesB. 1988;35(1-10):716-.

35. Sumner RMW, Bigham ML. Biology of fibre growth and possible genetic and non-genetic means ofinfluencingfibregrowthin sheep andgoats—areview. Livestock ProductionScience.1993;33(1):1-29.

36. TeJ,JiaL,RogersJ,MillerA,HartsonSD.Novelsubunitsofthemammalian Hsp90signaltransductionchaperone. JProteome Res. 2007;6(5):1963-73.

37. WalsbergGE.CoatColorandSolar HeatGain in Animals.BioScience.1983;33:88-91.