

Effects of water restriction on dairy goats under temperate or semi-arid environments

Lina Jaber

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Effets d'une restriction en eau chez des chèvres laitières en climat tempéré ou semi-aride

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Effets d'une restriction en eau chez des chèvres laitières en climat tempéré ou semi-aride

Mots clés : Déshydratation, climat semi-aride, climat tempéré, lactation

Effects of water restriction on dairy goats under temperate or semi-arid environments

Keywords: Dehydration, semi-arid environment, temperate environment, lactation

Lina Jaber

Travail réalisé

sous la responsabilité scientifique conjointe de

C. Duvaux-Ponter et S. Hamadeh et avec le co-encadrement de S. Giger-Reverdin

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PUBLICATIONS LIEES A LA THESE

Abstracts

1. **Jaber, L.S**., Barbour, E.K., Abi Said, M., Chedid, M., Giger-Reverdin, S., Duvaux-Ponter, C., Hamadeh, S.K.* 2012. Changes in blood and milk parameters in lactating shami goats subjected to intermittent watering. Book of abstracts of the XIth International Conference on Goats (ICG 2012), Gran Canaria, Spain, September 24-27, 2012, p. 96. (Poster)

2. **Jaber, L.S.**, Duvaux-Ponter, C., Hamadeh, S.K., Giger-Reverdin, S.* 2013. Responses to a heat stress episode in lactating Saanen and Alpine goats. Book of Abstracts of the 64th Annual Meeting of the EAAP, August 26-30, 2013, Nantes, France, p. 258. (oral presentation)

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3. Giger-Reverdin, S.*, **Jaber, L**., Tessier, J., Duvaux-Ponter, C. 2013. Effect of a heat stress episode on feed and water intake in dairy goats bred under temperate climate. 14th International Seminar of the the FAO-CIHEAM Network on Sheep and Goats: "Feeding and management strategies to improve livestock productivity, welfare and product quality under climate change", Hammamet, Tunisia, May 15-18, 2012. Options Mediterranéennes: Series A, No. 107: 271-275. (oral presentation)

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* Le présentateur de la recherche à la conférence

PUBLICATIONS PRECEDENTES EN LIEN AVEC LE SUJET

Abstract

1. Hamadeh, S.K., Hanna, N., Barbour, E.K., Abi Said, M., Rawda, N., Chedid, M., and **Jaber, L.S**. 2009. Changes in physiological and blood parameters in water stressed Awassi ewes supplemented with different levels of Vitamin C. Book of Abstracts of the 60th Annual Meeting of the European Federation of Animal Science, p. 284, Wageningen Academic Pub., Netherlands.

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2. Ghanem, A.M., **Jaber, L.S**., Abi Said, M., Barbour, E.K. and Hamadeh, S.K. 2005. The Effect of Vitamin C Supplementation on Some Physiological Indicators in Water-Stressed Awassi Ewes. Proceedings of the 6th International Sheep Veterinary Congress in Crete, Greece, 17-21 June, 2005. 182-183.

3. Hamadeh, S.K., Hanna, N., Barbour, E.K., Abi Said, M., Rawda, N., Chedid, M., and **Jaber, L.S**. 2009. Changes in physiological and blood parameters in water stressed Awassi ewes supplemented with different levels of Vitamin C. Proceedings of the EAAP Annual Meeting, Barcelona, Spain, August 24-28, 2009, published online. http://www.eaap.org/Previous_Annual_Meetings/2009Barcelona/Papers/26_Hamadeh.pdf

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INDEX DES ABRÉVIATIONS

Anglais		Français	
Abbreviation	Signification	Abréviation	Signification
ANOVA	Analysis of variance	ANOVA	Analyse de la variance
ASA	Acetyl Salicylic Acid		Acide Acétylsalicylique
BW	Body Weight	PV	Poids Vif
^{o}C	Degree Celcius	^{o}C	Degré Celsius
Ca^{++}	Calcium	Ca^{++}	Calcium
Cl^{-}	Chlorine	Cl^{-}	Chlore
CO_2	Carbon dioxide	CO_2	Dioxyde de carbone
CP	Crude Protein	MAT	Matières Azotées Totales
D	Day	J	Jour
Di-Cal	Di-Calcium Phosphate		Phosphate dicalcique
DIM	Days in milk		Jours après mise-bas
DM	Dry Matter	MS	Matière Sèche
DMI	Dry Matter Intake	MSI	Matière Sèche Ingérée
dS/m	Deci Siemen per meter		Deci Siemen par mètre
FFA	Free Fatty Acid	AGL	Acide Gras Libres
G	Gram	G	Gramme
GLM	Generalized Linear Model	GLM	Modèle Linéaire généralisé
h	Hour	h.	Heure
H_2O	Water	H_2O	Eau
Hb	Hemoglobin	Hb	Hémoglobine
HCO_3^{-}	Bicarbonate	HCO_3^{-}	Bicarbonate
K+	Potassium	K^{+}	Potassium
Kg	Kilogram	Kg	Kilogramme
mOsm	milliosmol		milliosmole
n	Number of samples	n	Nombre d’échantillons
N	Nitrogen	N	Azote
Na^{+}	Sodium	Na^{+}	Sodium
NEFA	Non Esterified Fatty Acids	AGNE	Acides Gras Non Estérifiés
NRC	National Research Council		
NS	Non Significant	NS	Non Significatif
P180DMI	Percentage of DMI during the		Pourcentage de MSI durant les

	first three hours after the afternoon feed allowance		3 heures suivant la distribution des aliments de l'après-midi
P180WD	percentage of water drunk during the first three hours after the afternoon feed allowance		Pourcentage d'eau bue durant les 3 heures suivant la distribution des aliments de l'après-midi
PC	Principal Component	CP	Composante principale
PCA	Principal Component Analysis	ACP	Analyse en Composantes Principales
pCO_2	Carbon dioxide partial pressure	pCO_2	Pression partielle du dioxyde du carbone
PCV	Packed Cell Volume		Hématocrite
pO_2	Oxygen partial pressure		Pression partielle d'oxygène
R^2	Coefficient of Determination	R^2	Coefficient de détermination
SEM	Standard error of the means		Erreur-type de la moyenne
SNF	Solid Non Fat	ESD	Extrait Sec Dégraissé
T3	Triiodothyronine	T3	Triiodothyronine
T4	Thyroxine	T4	Thyroxine
THI	Temperature-Humidity Index		Indice combiné de Température et d'Humidité relative
TMR	Total Mixed Ration		Ration complète
TP	Total blood protein		Protéinémie
	Milk fat content	TB	Taux butyreux (lait)
	Milk protein content	TP	Taux protéique (lait)
VitC	Vitamin C		Vitamine C
WD	Water Drunk		Eau Bue

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INTRODUCTION

L'accès à l'eau devient de plus en plus difficile, surtout dans les régions arides et semi arides de la Terre. Le problème touche aussi les régions tempérées qui ont récemment subi des épisodes de températures élevées dépassant les zones de confort thermique de la plupart des animaux indigènes. De plus, les animaux à haute performance des régions tempérées sont souvent exportés vers des pays au climat hostile et doivent donc faire face à un défi de survie et de production dans des conditions auxquelles ils ne sont pas adaptés.

Ce travail vise à traiter des effets du stress hydrique chez les chèvres. Le choix de ce sujet repose initialement sur l'expérience acquise sur le stress hydrique chez les moutons à travers des années de recherche précédentes, ce qui nous a montré l'intérêt d'explorer ce même sujet chez une espèce tout aussi importante qu'est la chèvre.

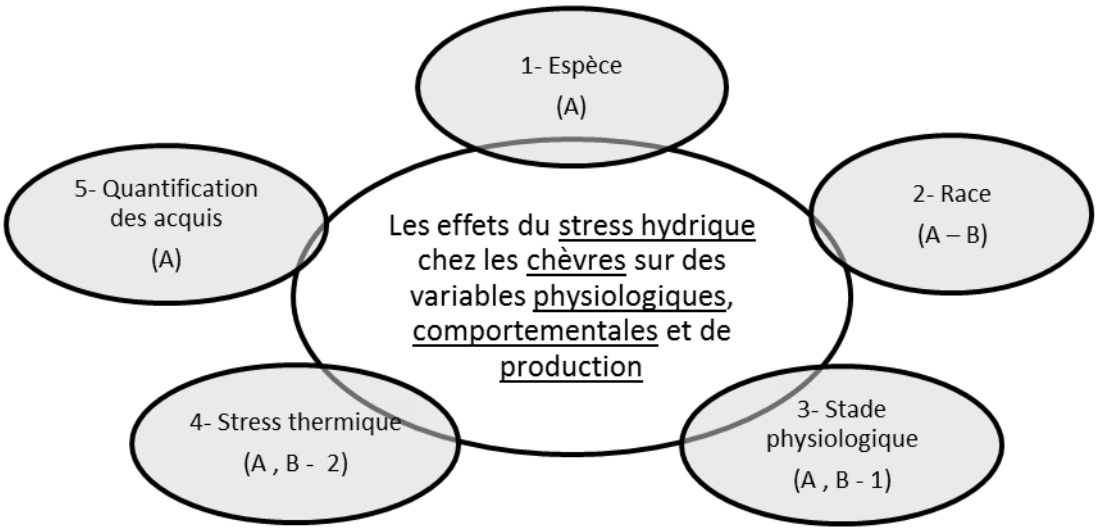
L'élevage des chèvres est une activité économiquement importante, surtout dans les régions arides et semi-arides. Ce type d'élevage est basé sur des races indigènes bien adaptées à l'austérité de l'environment et à la pénurie des ressources en tant que végétation et eau. Ces élevages sont souvent extensifs et mobiles, étant le seul moyen de transformer les maigres resources alimentaires disponibles en produits nutritionnellement riches et à valeur économique importante pour la communauté rurale et pauvre. De même, l'élevage des chèvres dans les milieux tempérés est plus intensif avec des animaux à forte productivité, mais tout aussi important sur le plan économique. Le choix de la chèvre comme sujet de cette recherche est basé sur son importance comme moyen d'existence d'une grande partie de la communauté rurale sous différents climats.

Ce travail tente d'explorer l'effet du stress hydrique sur différentes races de chèvres en milieux climatiques différents et à différents stades physiologiques. La première race, la shamie, est originaire de la Syrie et indigène aux pays du Moyen Orient au climat aride ou semi-aride. Elle est répandue dans les systèmes d'élevage extensifs mais s'adapte aussi bien aux systèmes semi-intensifs comme c'est le cas à Chypre. Normalement de pelage brun, avec une taille relativement grande, elle a de longues oreilles pendantes ; elle est considérée comme une race mixte : production de lait et de viande. La production laitière moyenne est de 450 kg/an, et peut être plus importante selon le système d'élevage et la nutrition. Normalement, les chevreaux sont allaités pendant les deux premiers mois *post-partum* et, par conséquent, la production laitière à but commercial ne commence qu'après le sevrage et s'étend sur cinq à sept mois ou même plus. Le lait a un taux butyreux compris entre 3.8 et 4.5%. La prolificité peut atteindre 1.8 chevreaux/chèvre (Güney et al., 2006 ; Mavrogenis et al., 2006 ; Khazaal, 2009).

Deux autres races laitières des pays tempérés ont été choisies, la Saanen et l'alpine. Ces deux races constituent plus que 95% du cheptel caprin en France ; le système de production est plutôt intensif avec presque la totalité de la production laitière destinée à l'industrie fromagère (Danchin-Burge et al., 2012). La production laitière moyenne est de 676 kg et de 648 kg par lactation pour les Saanen et alpines, respectivement. Mais des productions de 1000 kg sont souvent atteintes avec certains systèmes d'élevage alliant une alimentation adaptée et une bonne gestion du troupeau. Les taux butyreux et protéiques sont en moyenne de 3.2%, 3.0% et 3.5%, 3.1% respectivement, pour les Saanen et les alpines (Bélichon et al., 1998). Les hautes performances de la race Saanen l'ont rendue intéressante pour l'amélioration de la production caprine dans les pays arides et semi arides tels que le Soudan et le Liban (Khazaal,

2009 ; Ishag et al., 2012), mais ses bonnes performances sous ces nouvelles conditions environnementales restent à confirmer.

Les objectifs de la thèse sont présentés dans le schéma suivant, avec les différentes parties correspondantes de la thèse :



Parties de la thèse

A. Revue de la littérature
    1. Qualitative
    2. Quantitative
B. Expérimentale
    1. Expérimentation Liban (shamie) (lactation et gestation)
    2. Expérimentation France (Saanen et alpine en lactation) (stress hydrique et thermique)

Figure 1. Illustration des objectifs en relation avec les différentes parties de la thèse

Le thème central de la thèse est l'étude des effets du stress hydrique chez les chèvres sur des variables physiologiques, comportementales et de production. Ce thème est abordé sous différents angles et par des moyens de recherche variables. Une comparaison entre espèces, caprine et ovine, a été entamée à travers la revue de la littérature ; il en est de même pour la comparaison entre les différences races caprines. Ce dernier sujet a aussi été exploré dans la partie expérimentale, étant donné que le travail a porté, d'une part, sur des races tempérées et, d'autre part, sur une autre race indigène aux pays arides et semi- arides. L'effet du stade physiologique des chèvres en relation avec le stress hydrique a aussi été étudié à travers la littérature en plus des expérimentations sur les shamies qui ont permis d'explorer les différences dans les réponses entre les animaux en lactation et ceux en gestation. Le stress thermique, souvent co-présent avec le stress hydrique, est considéré dans la revue de la littérature, ainsi que dans les expérimentations sur les Saanen et les alpines. Finalement, vu l'importance du sujet, le dernier objectif de la thèse a visé à la quantification des données acquises dans la littérature à travers une méta-analyse qui permet de faire le point sur les

différents aspects du stress hydrique chez les petits ruminants et d'identifier des pistes de recherche pour le futur.

Le document est organisé autour des différentes étapes du travail, à commencer par une revue détaillée de la littérature sur les effets du stress hydrique chez les petits ruminants. Cette revue qualitative de la littérature est complétée par une méta-analyse. Ce dernier travail s'est étalé tout au long de ce projet de thèse et c'est ce qui a demandé le plus de temps pour la recherche bibliographique, l'entrée et la vérification des données, ainsi que pour l'analyse et l'interprétation des résultats.

Après la revue de la littérature, la présentation du travail expérimental commence par l'expérimentation sur l'effet de la restriction en eau chez les chèvres shamies. Une première expérience est présentée portant sur l'effet du stress hydrique chez les shamies en lactation, et une seconde expérience,chez les shamies en gestation. Ces deux expérimentations réalisées au Liban correspondent au chapitre 3 de la thèse. Par la suite, l'expérimentation sur les chèvres Saanen et alpines qui s'est déroulée en France est présentée en commençant par l'effet du stress hydrique et en finissant par l'effet d'un épisode de stress thermique. L'expérimentation réalisée en France correspond au chapitre 4 de la thèse.

Le document de thèse se termine, au chapitre 5, par une discussion générale et des recommandations suivies par une conclusion et la liste des références mentionnées dans les textes en français.

Chaque partie de la thèse qui a mené à une ou plusieurs publications en anglais est précédée d'un résumé en francais, les autres parties non encore publiées sont rédigées en francais.

CHAPITRE 1 : REVUE DE LA LITTERATURE

La revue de la littérature est destinée à faire le point sur le sujet du stress hydrique chez les petits ruminants. Elle comporte une partie qualitative, suivie par une partie quantitative sous forme de méta-analyse.

Les moteurs de recherche consultés pour retrouver les productions scientifiques pour la revue de la littérature étaient majoritairement Google Scholar, Agricola, Academic Search Premier et les CAB, ainsi que les archives personnelles accumulées au cours des années par les chercheurs concernés par ce projet. La base de données était agrémentée par d'autres articles qui ne traitaient pas nécessairement du stress hydrique, mais qui ont été jugés importants pour la revue qualitative du sujet. Pour cette dernière, le but était de traiter du sujet du stress hydrique et de ses effets sur les petits ruminants sous différents angles et, par conséquent, la bibliographie consultée a inclus des articles assez variés touchant à la physiologie comparée de plusieurs espèces, du stress thermique, de la lactation et de la gestation, des moyens d'atténuation du stress, de l'immunité, etc.

Pour la revue quantitative, la recherche des articles s'est concentrée sur ceux traitant du sujet des caprins et ovins soumis à une restriction ou à une privation d'eau. Parmi les 136 articles recueillis, 90 ont été retenus après élimination de ceux qui étaient hors-sujet, les revues, les articles non trouvés ou en langues non maîtrisées, ainsi que ceux qui faisaient doublons avec d'autres articles. Un fichier regroupant toutes les données sur les conditions expérimentales et les différentes variables mesurées dans ces articles a été construit. L'analyse statistique de ces données a été entamée afin d'avoir une appréciation globale des relations entre les différentes variables.

Les résultats de la revue de la littérature qualitative et de la littérature quantitative sont présentés ci-dessous.

1.1. Revue qualitative de la littérature

La revue de la bibliographie sur le sujet du stress hydrique chez les petits ruminants a donné lieu à deux travaux de synthèse qui ont été publiés. Le premier est un chapitre d'ouvrage dédié à explorer le stress hydrique en général ; l'autre publication est un article de synthèse sur le stress hydrique chez les moutons qui a été publié dans un journal international à comité de lecture. Etant donné que les deux ouvrages contiennent des points communs, ils ont été résumés dans la même section qui suit, afin de servir de synthèse bibliographique en français et de mise en contexte du sujet de recherche. Ce résumé garde globalement les mêmes titres des paragraphes que dans les textes en anglais pour faciliter au lecteur l'accès aux détails et aux références utilisées dans les publications en anglais. La liste des références.pour cette partie est détaillée dans les publications en anglais qui suivent.

a. <u>Résumé en français</u>

Introduction

Le secteur de production des petits ruminants est parmi les plus touchés par le stress environnemental, étant donné que ce secteur est surtout répandu dans les milieux ruraux des

régions arides ou semi-arides et duquel dépend la survie d'une grande communauté rurale. La déshydratation entraîne des effets physiologiques importants ainsi qu'une altération de l'efficacité de reproduction et de production des animaux. Cette revue a visé à présenter une synthèse des résultats des recherches effectuées sur ce sujet, en soulignant les domaines les moins étudiés et qui pourraient motiver des recherches futures.

Caractéristiques générales des petits ruminants en régions arides et semi-arides

Les effets du stress hydrique se manifestent à des niveaux différents chez les petits ruminants, selon les espèces et les races. Les races originaires des pays arides et semi-arides se caractérisent par des mécanismes d'adaptation particuliers leur permettant de mieux supporter cette condition. Ces mécanismes se présentent au niveau anatomique, morphologique, physiologique, comportemental, etc. Au niveau comportemental, certaines races montrent une préférence pour l'alimentation nocturne pour éviter les périodes de chaleur diurnes ; la période de reproduction est aussi ajustée de façon à synchroniser la mise-bas et la lactation avec des conditions climatiques favorables. De même, des adaptations morphologiques sont remarquées telles que la couleur et la nature du pelage, la densité de la laine, ainsi que la présence d'une queue grasse qui peut servir comme réserve d'énergie et permet de réduire l'isolation du corps par rapport à l'environnement pour faciliter la dissipation de la chaleur corporelle, chez les moutons. Finalement, au niveau physiologique, différentes races montrent une capacité variable à concentrer l'urine grâce à la présence d'une médullaire rénale plus au moins épaisse permettant une réabsorption de l'eau très efficace et la production d'une quantité d'urine très réduite, mais à forte osmolarité. De même, au niveau physiologique, on note un rôle important joué par le rumen et orchestré par un contrôle hypothalamique par lequel les animaux arrivent à se réhydrater en ingérant de grandes quantités d'eau en peu de temps sans risque d'intoxication par l'eau et avec un retour graduel à une composition sanguine normale.

Changements physiologiques sous l'effet du stress hydrique

Malgré ces différences anatomiques et physiologiques entre espèces et races, les effets physiologiques du stress hydrique semblent globalement similaires et cette revue a permis de mettre en évidence les effets les plus saillants et les plus communs au travers des espèces et des races. Les petits ruminants privés ou restreints en eau, baissent la quantité d'aliments ingérés. Cette baisse est d'autant plus marquée que la restriction en eau est sévère, que les animaux sont peu adaptés à ce stress et que la qualité du fourrage est mauvaise. De même, les animaux sous stress hydrique perdent du poids, principalement sous forme de perte d'eau corporelle qui peut être suivie par une perte de masse, si le stress hydrique se prolonge. Il en résulte que les animaux déshydratés développent un état de bilan énergétique négatif qui nécessite la mobilisation des réserves adipeuses. Cette mobilisation est orchestrée par un contrôle hormonal mettant en jeu une baisse des niveaux d'insuline et de leptine pour faciliter la lipolyse, mais aussi pour stimuler l'ingestion et prévenir une lipolyse excessive qui peut entraîner des effets toxiques par excès d'acides gras dans le sang. Les animaux déshydratés présentent aussi un état d'hémoconcentration qui se manifeste par une hausse des niveaux d'hémoglobine et de l'hématocrite, ainsi que du taux protéique sanguin. Toutefois, les meilleurs indicateurs sanguins de la déshydratation semblent être les taux d'albumine, d'urée, de sodium et l'osmolarité. La hausse observée au niveau de ces indicateurs est systématique au travers des espèces et des races. En effet, ces facteurs jouent un rôle important dans l'homéostasie du sang et la conservation de l'eau : l'albumine sert dans la régulation de l'osmolarité sanguine, alors que l'urée et le sodium jouent un rôle dans la rétention de l'eau

au niveau des reins et la répartition et la redistribution de l'eau dans les différents compartiments corporels, notamment le sang, le rumen, et les glandes salivaires, ce qui fait que, par la suite, l'osmolarité augmente en fonction de l'état de déshydratation. Le taux de cortisol ne change pas de façon systématique avec l'état de stress hydrique, ce qui indique que bien qu'il puisse jouer un rôle dans l'équilibre de l'eau et des électrolytes, le cortisol n'est pas un bon indicateur de ce genre de stress qui se présente souvent comme stress chronique sur une période assez prolongée. L'activité thyroïdienne fut aussi considérée, et il semble que le stress hydrique, surtout quand il coïncide avec un stress thermique, entraîne une baisse des niveaux des hormones thyroïdiennes probablement dans le but de minimiser l'activité métabolique et de diminuer ainsi la perte d'eau et la consommation calorique.

La réhydratation présente un défi physiologique opposé en raison de l'ingestion rapide d'une grande quantité d'eau qui risque d'entraîner une hémolyse sanguine. Cependant, ceci est empêché par l'activation bien orchestrée de mécanismes spécialisés qui permettent de séquestrer l'excès d'eau bue au niveau du rumen, pour préserver l'équilibre sanguin. Ceci est accompli par l'augmentation de la production salivaire, ainsi que par l'activation de l'appétit pour stimuler l'ingestion d'aliments et rétablir ainsi l'équilibre des électrolytes et de l'osmolarité. Finalement, la conservation de l'eau par les reins est maintenue suite à la réhydratation pour s'assurer de satisfaire tous les besoins corporels en vue d'une éventuelle restriction en eau dans un futur proche.

Changements en relation avec le stade physiologique : gestation et lactation

La revue a exploré l'effet du stade physiologique (animaux en gestation ou en lactation) sur les réponses au stress hydrique, sachant que les besoins en eau sont sensiblement plus importants chez ces animaux. Les chèvres et brebis gestantes ont montré des changements physiologiques similaires à ceux décrits plus haut. Par contre, leur capacité à concentrer l'urine semble être diminuée, probablement sous l'effet des prostaglandines qui, à leur tour, diminuent la sensibilité à l'arginine-vasopressine et donc à la capacité de concentration de l'urine au niveau des reins. L'effet du stress hydrique sur la progéniture n'est pas bien établi avec des conclusions divergentes ; des recherches plus poussées sur ce sujet semblent nécessaires. De même, les femelles en lactation ont présenté des réponses similaires au stress hydrique à celles des contrôles en notant une plus forte baisse de poids en raison de la perte en eau plus importante à travers le lait. Une étude a noté que le sang des brebis allaitantes soumises à une restriction en eau était plus alcalin que celui des brebis « sèches » soumises au même traitement. Ceci peut être attribué à la hausse du taux de Na^+ dans le sang accompagnée par une baisse en Ca^{++} et K^+ nécessaires pour la production du lait. Quant à la composition et la quantité du lait produit, il semble que certaines races adaptées pourraient maintenir leur production laitière quand elles sont soumises à une courte restriction en eau. Par contre, la plupart a tendance à diminuer leur production avec quelques changements dans la composition, telle que la hausse en osmolarité et en lactose, pour garder le lait isotonique avec le sang, mais une baisse en matière grasse.

La régulation thermique

La régulation thermique des moutons restreints en eau est d'une grande importance, vu que les mécanismes de refroidissement mènent à une perte en eau. Normalement, les moutons perdent 20% de leur chaleur corporelle par la voie respiratoire. Cette perte s'élève à 60% avec une température de 35°C. Les petits ruminants déshydratés semblent favoriser le refroidissement par voie respiratoire au lieu de la voie cutanée, bien que ceci puisse mener à une plus grande perte en eau. Par contre, l'avantage de ce mécanisme permet le

refroidissement sélectif du cerveau qui en dépend, et qui à son tour ralentit le halètement, et donc, la perte d'eau. De même, ce refroidissement sélectif permet de tolérer une certaine hausse de la température corporelle pendant le jour, puis à s'en débarrasser passivement durant la nuit quand la température ambiante baisse, et donc en minimisant la perte d'eau. Il est important de noter les variations observées entre les races dans la manifestation de ces mécanismes, ainsi que le rôle de la laine au niveau du refroidissement par évaporation cutanée. La littérature ne rapporte pas de résultats concluants vis-à-vis des changements dans la température rectale suite à la déshydratation ; alors que certains ont noté une hausse, d'autres n'ont remarqué aucun changement significatif. Outre l'effet de la race, la densité et la longueur de la laine ainsi que la température ambiante jouent un rôle important dans le contrôle de ce paramètre, de même que la sévérité et la durée de la déshydratation. Les hormones thyroïdiennes ont été évaluées aussi en relation avec la régulation thermique. La T3 et la T4 semblent baisser chez les moutons déshydratés. Cette baisse joue un rôle dans la conservation de l'eau suite à la baisse de l'activité métabolique générale. Cette réponse est plus accentuée en présence de stress thermique. La réponse thyroïdienne aux stress ambiants dépend aussi de l'acclimatation préalable des animaux à de tels stress. Chez les races adaptées, les variations thyroïdiennes semblent plus sensibles à l'état physiologique des animaux qu'à la chaleur ambiante. D'autres travaux ont aussi montré le rôle important de la prolactine dans la régulation thermique. Ce sujet reste peu étudié surtout dans le cas des animaux déshydratés.

La dépression immunitaire

Le stress hydrique, comme tout autre stress peut avoir un effet sur la santé générale des animaux. Pourtant, cette relation particulière entre l'état de déshydratation et l'immunité a été très peu étudiée. Certains chercheurs ont exploré l'effet du stress thermique sur l'immunité et ont noté une baisse de l'immunité démontrée par une baisse de la prolifération cellulaire, ainsi qu'une hausse des neutrophiles dans le lait et un nombre élevé de coliformes et autres micro-organismes indiquant une baisse de la qualité du lait. D'autres études ont comparé les réponses immunitaires des brebis Awassi déshydratées à celles des contrôles et ont aussi noté une baisse de l'immunité en tant que baisse de production d'anticorps. La littérature suggère plusieurs facteurs (internes et externes) capables de moduler la réponse immunitaire en cas de stress, en notant la complexité de cette relation.

Médicaments et suppléments modulateurs du stress

La dernière partie de cette revue traite de l'efficacité des suppléments et/ou médicaments à effet anti-stress, dans le cas du stress hydrique. Diminuer les effets du stress chez les animaux peut s'accomplir à plusieurs niveaux selon le genre et la durée du stress. Le stress hydrique, ainsi que le stress thermique, peuvent se présenter sur de longues durées, étant imposés par des conditions climatiques chaudes et arides. Les méthodes d'atténuation du stress sont diverses allant de la protection contre les radiations solaires, à la modification de l'alimentation, jusqu'à l'amélioration génétique des animaux pour une meilleure tolérance. De même, certains suppléments et médicaments furent testés dans ce but, notamment l'acide ascorbique (Vitamine C) et l'aspirine qui sont considérés dans cette revue. La vitamine C est normalement produite par les animaux et est donc rarement ajoutée à l'alimentation des animaux domestiques. Néanmoins, des études sur plusieurs races et espèces, surtout chez des animaux subissant un stress, ont montré un effet anti-stress exercé par la vitamine C. Dans le cas de la supplémentation en vitamine C sous stress hydrique, la littérature est rare et les résultats physiologiques ne permettent pas de conclure (taux protéique sanguin, mobilisation des matières grasses, osmolarité et électrolytes, cortisol et autres hormones, etc). Cependant,

il fut remarqué que la vitamine C, donnée quotidiennement, semble adoucir les effets du stress principalement sous forme d'une réduction de la perte de poids. Quant à l'aspirine, les données limitées disponibles dans la littérature semblent indiquer qu'elle n'est pas très efficace pour réduire les effets du stress hydrique chez les brebis. Il reste que ses effets en tant qu'anti-oxydant pourraient se révéler importants pour renforcer le système immunitaire des animaux sous stress hydrique.

Aperçu économique de l'effet du stresse hydrique

La revue rapporte aussi un petit aperçu sur l'impact économique du stress hydrique bien que la littérature à ce sujet soit peu abondante. En effet, les recherches portent principalement sur les effets du stress thermique en élevages bovins. Les pertes économiques à cause de la chaleur sont importantes et sont dues à la perte de production ainsi qu'au coût additionnel des interventions nécessaires pour atténuer le stress. De même, les quelques références sur les élevages de moutons ont montré l'importance des pertes au niveau de la production laitière ainsi qu'au niveau de la reproduction, du poids et de la croissance des agneaux exposés au stress thermique. L'importance des mesures d'atténuation, telles que la présence d'ombre et le contrôle de la longueur de la laine, ainsi qu'une approche globale pour gérer les élevages exposés à la chaleur est mentionnée.

Conclusion

La revue se termine par des conclusions indiquant principalement les différences entre les races pour s'adapter au stress hydrique. Le cas de la race de moutons Awassi est mis en relief avec ses mécanismes physiologiques propres, mis en action lors d'un stress hydrique. Des pistes pour les recherches futures sont suggérées, telles que l'exploration de nouvelles approches nutritionnelles et alimentaires pour atténuer le stress, ainsi que des études plus avancées sur les différentes races et les effets cumulatifs des stress hydriques, thermiques et de la sous-alimentation vu leur importance pour les élevages en milieux arides.

Ci-dessous un tableau récapitulatif des adaptations les plus générales et leur présence chez les chèvres et les moutons, selon la littérature. Etant donné la nature variée des articles et publications scientifiques consultées, ces observations ne sont pas nécessairement représentatives de l'espèce mais peuvent être basées sur une ou plusieurs races étudiées.

Tableau 1. Tableau comparatif des mécanismes d'adapatation les plus remarquables entre chèvres et moutons, d'après la revue de la littérature.

Adaptations	**Mouton**	**Chèvre**
Comportementales	Alimentation nocturne	
	Sélectivité alimentaire, plus marquée chez les chèvres	
	Grande buvée après déshydratation, plus marquée chez les	
	Reproduction saisonnière	
Morphologiques	Couleur et densité du pelage	
		Petite taille des races adaptées
	Distribution adipeuse/queue	

	Longues oreilles	
Physiologiques	Concentration de l'urine	
	Rétention d'eau	
	Hausse temporaire de la température corporelle	
	Adaptation à la réhydratation sans risque d'hémolyse	

b. <u>Texte en anglais du chapitre d'ouvrage sur le stress hydrique chez les petits ruminants : Water stress in small ruminants</u>

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1. Introduction

Small ruminants are an integral part of farming systems in the marginal arid regions of the world. These areas are characterized by water scarcity and fluctuating precipitation; under the effect of global warming and unpredictable weather, rainfall is becoming even more irregular and water availability more limited. Along with water accessibility, feed and other resources will be markedly affected by climate change. Livestock that are able, in open range, to select high quality forage to maintain a relatively similar basal diet quality from season to season, will have their intake significantly reduced in extremely dry seasons when forage biomass and its quality are low [1]. Hence, selection of adapted animal breeds is very valuable for sustaining animal production under an increasingly challenging environment [2].

Breeds of ruminants which are well adapted to arid environments demonstrate a greater capability than non-desert breeds to endure the stressful environmental effects [3]. Although small ruminants in hot arid and semi-arid regions may survive up to one week with little or even no water, water deficiency is proved to affect animals' physiological homeostasis leading to loss of body weight, low reproductive rates and a decreased resistance to diseases [4]. In addition, under natural conditions, water scarcity often occurs at times of high environmental temperature and low feed quality and availability. Therefore, the effects of these three constraints are often confounded.

In this review, the effects of various degrees and forms of dehydration on small ruminants are presented. The findings are based on previous literature on the subject as well as the results of original research by the authors on water restriction in Awassi sheep. The major changes in physiological indicators and blood parameters are presented, in addition to the interaction of dehydration with physiological status. Finally, a brief overview of new approaches for water stress alleviation, through drugs, is exposed.

2. General characteristics of small ruminants in arid and semi-arid regions

Small ruminants in the Middle East and North Africa region are mostly reared under extensive and traditional pastoral farming systems, centuries-old, relying on natural pastures and mobility to secure water and feed year round. Giger-Reverdin and Gihad (1991) [5] reported that the water requirement for maintenance of goats in temperate climates is 107ml/kg $BW^{0.75}$; they also indicated that the water requirements under different ambient

temperatures, based on previous work, range between 3.15 kg/kg DM (at 23°C) to 4.71 kg/kg DM (at 35°C). However, the effect of ambient temperature should be viewed in combination with the particular breed origin and adaptability, since wide differences in response to heat have been reported in different breeds [6].

Sheep breeds differ in their capacity to overcome water limitation; experiments show a variety of results: Yankasa sheep survived 5 days of water restriction but with several physiological changes [7, 8]. Jaber et al. (2004) [9] concluded that Awassi females can withstand more than one month of watering every 2 days without significant changes, while a regime of watering once every five days causes important physiological perturbations. The Australian Merinos sheep survived 10 days without water [10], and the desert bighorn sheep withstood water deprivation up to 15 days [11; 12], while the Barki sheep in Egypt did not endure 3 days without drinking [11].

Similarly, variations in water deprivation tolerance are observed in goat breeds. Ahmed and El Kheir (2001) [13] report that desert goats raised under traditional systems may be watered only once every 3-6 days, when water is scarce. The Black Bedouin and the Barmer goats are another example of adapted breeds that can live on a once every four days watering regime [14; 15].

Review papers are numerous on this subject, indicating differences between adapted and non-adapted sheep and goat breeds in tolerating water deprivation and the general arid conditions [6, 16].

Indigenous small ruminants are able to thrive despite extreme temperatures and limited water through their behavioral adaptations in combination with both morphological and physiological adaptations [17].

1. Behavioral adaptations

Feeding behavior is affected by environmental constraints. Nocturnal feeding has been documented in bighorn sheep [18] in order to avoid high temperatures during the day. Similar behavior is also reported in goats [16]. The author also indicated that feeding frequency is modified in some adapted goats which resort to more frequent and shorter meals in order to reduce heat production associated with rumen fermentation. Langhans et al. (1991) [19] further observed that feed intake is less affected by water deprivation in adapted breeds such as pygmy goats as compared to non-adapted breeds. Furthermore, Lechner-doll et al. (1995) [20] observed that adapted goats can select high quality feed during the dry season while sheep showed less selectivity to high quality feed. Drinking behavior is also affected by water restriction whereby water deprived sheep and goats tend to drink large volumes of water in one bout upon watering. This capacity is more pronounced in goats than in sheep [5].

Timing of reproduction is another adaptive feature of sheep living in semi-arid areas: parturition is timed to a favorable period of the year to ensure offspring survival [21]. Seasonality in small ruminants is commonly observed. Reproductive cycles are thought to be regulated by environmental cues, most importantly photoperiod. Research has demonstrated that nutrition and the general body score are also important factors for normal cyclicity. Under-nutrition (below 40-60% of maintenance requirement) is reported to cause an immediate retardation in follicular growth [22]. In addition, prolonged under-nutrition induces a delay in estrous behavior that lasts for a shorter period, as compared to normally fed animals. Similarly, fasting was reported to cause major changes in the concentrations of reproductive hormones and ovulation rate [23, 24]. Since water deprivation is often accompanied by feed intake reduction, the same effects on ruminant reproductive cycles can be expected. Indigenous sheep living in the tropical and sub-tropical regions tend to breed

throughout the year; however, their sexual activity may be limited, to a degree, during the summer season when the environmental temperature is elevated and feed is lacking [25]. In arid and semi-arid regions, where differences in daylight, as well as in food and water availability are well marked, the breeding season usually spans from June to November [26, 27]. Consequently, kidding and lambing mostly occur between February and April, when food and climate become more hospitable for the newborns.

2. Morphological Adaptations

Ruminants are usually classified as grazers, browsers or intermediate feeders. Sheep are usually classified as grazers feeding mainly on grasses while goats are intermediate feeders which can use grasses as well as shrubs [28]. These observed preferences in feed selection have been linked to underlying morphological and physiological digestive differences. These include larger rumen and long feed passage time for grazers to allow them to digest their high fiber diet, while browsers have simple and smaller digestive system with profuse saliva production to effectively process their feed high in cell solubles [28]. However, other scientists have argued that the observed differences in feed selection are related more to body size than to actual differences in the digestive anatomy and physiology [29]. Other morphological differences are also noted in relation to the mouth anatomy with goats having a mobile upper lip, while sheep are characterized by a cleft upper lip, features that allow them to best use the available vegetation. In addition, goats have the capacity to assume a bipedal position thus they are capable of browsing higher vegetation that is beyond the reach of sheep [30]. This area of research relating morphology, diet selection and utilization and response to changes in the available vegetation is still in need of further exploration [29, 31] as it is affected by the climatic changes and drought spells that put pressure on the vegetation cover and the animals that feed on it.

Morphological characteristics such as body shape and size help reducing heat loads and minimizing water losses; it is noted that goat breeds of arid and semi-arid regions are relatively smaller than their European counterparts [6]. Smaller animals benefit from a relatively larger surface area which allows them to better dissipate heat to the environment. Fleece is another feature that plays a major role in controlling body temperature, serving as a thermal barrier that reduces the effects of the ambient temperatures through the formation of a milder microclimate within the fleece [32]. In addition, fleece and hair color of small ruminants play a role in reflecting solar radiation with light colors absorbing less heat that the darker ones thus leaving the underneath skin relatively cooler [33]. Therefore, thermostability could be maintained without directly resorting to evaporative cooling (panting) which leads to high water loss [34]. Location of body fat also affects heat dissipation rates: arid-adapted sheep exhibit highly localized fat storage [35], such as in the fat-tail, as opposed to high subcutaneous fat in non-adapted breeds; this again facilitates heat conductance to the periphery for dissipation [34]. Moreover, fat-tails are important energy reserves that help in buffering long-term dietary shortfalls to maintain survival and productivity [36, 37]. The Awassi sheep, as a representative breed adapted to arid regions, presents a medium body size, with a large fat-tail and carpet type fleece. The carpet-type wool of the Awassi allows convective heat loss from the skin to the environment [34]. Their large ears are another anatomical adaptation that is thought to help in convective heat loss [34]. Finally, as mentioned above, the localization of the fat stores in the fat-tail facilitates body heat dissipation and serves as energy reservoir for times of scarcity.

3. Physiological Adaptations

Physiologically, ruminant breeds of arid regions show many adapted mechanisms to conserve water in times of heat and drought. Adapted breeds resort to reduction of urine volume and fecal moisture. The production of more concentrated urine is related to the length of Henlé loops located in the medulla of the kidney [38]. The thickness of the medulla is relative to kidney size, and is frequently used as an index of kidney concentrating ability [38, 39]. For instance, the desert bighorn sheep exhibits a medulla nearly twice thicker than that of other domestic sheep and thus produces highly concentrated urine of 3900 mOsm/liter H_2O [40, 41]. The Awassi sheep demonstrated a similar ability to highly concentrate urine (up to 3244 mOsm/kg H_2O) under dehydration, and to drink large volumes upon rehydration without disrupting their homeostasis [42].

Urea renal retention is similarly increased under dehydration leading to increased urea concentration in the blood, on the other hand, urea recycling from the blood in to the gut is often observed under these conditions and is thought to contribute as a nitrogen source in times when the quality of the offered feed is low in protein [33]. The rumen is another organ that plays an important role in maintaining homeostasis under dehydration in adapted ruminants, particularly goats. Due to its relatively large volume, it acts as an important water reservoir providing most of the water lost during prolonged dehydration to maintain blood volume. It also allows the intake of large volumes of water upon rehydration which is temporarily sequestered in the rumen. Through efficient and well-coordinated mechanisms of saliva recycling and high water and Na^+ retention in the kidneys, slow rehydration is achieved without causing water toxicity and with minimal water losses. These processes are detailed in [15]. Small increases in body temperature are also observed during the hottest parts of the day, followed by body cooling at night through conduction and radiation. The capacity to tolerate this increase in temperature means that less water is needed for evaporative cooling [33].

3. Physiological changes in response to water stress

1. Effect on feed intake and body weight

Studies show a close relation between water intake and feed consumption [3, 43, 44]. Ruminant feeding behavior can be affected by the changes in osmolality of body fluids [45]. Feed intake causes hypovolemia and hyperosmolality due to the secretion of saliva and gastric juices. These mechanisms can urge ruminants, as well as other animals, to drink while eating, or alternatively not to eat when severely dehydrated [45]. Moreover, an adequate level of water intake is necessary for proper digestive functions [46]. On the other hand, Kay (1997) [33] states that drinking water is not needed for swallowing and moistening feed, since water can be circulated from the blood to maintain high salivation. However, water is needed to replace the inevitable water loss by excretion and evaporation. A possible explanation for the physiological mechanism behind the reduction in feed intake under water restriction, mainly through the reduction in meal size, may be attributed to the postprandial hyperosmolality of the ruminal fluid [19].

The co-occurrence of decrease in feed intake along with water restriction renders the differentiation between water versus feed shortage related effects difficult. Previous work has shown that Awassi sheep under 3-4 days intermittent watering regime reduced their voluntary

feed intake to approximately 60% of the control [9, 47]. Similar rates are reported in [48] in different domestic ruminants subjected to dehydration, especially when combined with heat stress. The drop in feed intake under dehydration is also dependent on the type of feed that is available to the animals. Water restricted goats reduced their feed intake by 18.8% when offered legume hay compared to 21.21% when offered grass hay with lower crude protein content [49]. Therefore the negative effect of water restriction is more pronounced on low versus high quality forage [16]. This reduction in feed intake is partially compensated for by a slower feed movement and longer retention time in the digestive tract [46, 50, 51]. This is thought to lead to an increase in digestibility and nutrient utilization, as longer time is available for the microflora in the digestive tract to act on the feed [49, 52]. However, this hypothesis needs further research as reports seem inconclusive. Further drop in feed intake was recorded with increasing the degree of water restriction in South African indigenous goats [52]; but an improved nutrient utilization was also reported by the same author. Concomitantly, Ahmed Muna and El Shafei Ammar (2001) [49] reported an improvement in digestibility of Lucerne hay under water restriction in desert goats, and similarly, higher organic matter digestibility was observed in water-restricted dairy cows [53]. These adaptations allow the exploitation of grazing areas which are distant from water sources, and prevent erosion especially in regions where water is scarce and grazing pressure is high. In contrast, others [46, 48, 54] found no changes in feed digestibility in water-restricted sheep and goats. It was suggested that the elevated digestibilities usually observed are rather the result of dry matter accumulation rather than "a real increase in fermentation or digestion" [50].

The drop in feed intake puts an additional burden on the water stressed animal. In fact, in order to survive such regimes, adapted ruminants are thought to resort to lowering their metabolic rate in order to reach a new body condition with lower maintenance requirements [55]. Consequently, the effects of this decrease in dietary intake should be considered along with the effects of dehydration. Feed restriction of 50% for only a 3-day period is enough to cause metabolic changes in lactating dairy Sarda ewes [56]. It has also been reported that the depleted body condition during periods of energy deficiency reduces heat tolerance [57], which in turn affects the reproductive potential of sheep [58, 59].

As reported in [9, 47, 60-64] the most obvious physiological consequence of water restriction with the concomitant reduction in feed intake is weight loss. Many trials on dry and lactating Awassi ewes recorded a drop in weight ranging between 0.84% and 26% (Table 1). Besides the effect of the water regimen, other factors contribute to body weight variation such as the physiological status of the animal (lactating or dry), its age, and the prevailing climatic conditions during the experiment (ambient temperature). It is clear in Table 1 that watering every two days did not cause a mentionable weight loss in Awassi ewes even if the temperature reached up to 32°C. The highest weight loss (26.2%) was recorded in young sheep (2-year-old ewes) and in lactating animals. Reported results lead to one conclusion that dry Awassi have a high adaptation to dehydration, and can tolerate 3-days water restriction regime, up to one month with losing only 16.8% of their body weight (Chedid et al., unpublished).

Table 1. Effect of water restriction on body weight of Awassi sheep.

Physiological status	Water restriction regime	Drop in weight (%)	Age	Ambient temp. (°C)	Reference
Non-lactating	2-day-restriction	0.84	mature	15-32	[9]

	3-day-restriction	9.98	mature	27-30	[62]
		16.8	mature	23-28	[63]
		16.7	mature	27-31	[47]
		26.2	2 years	30-31	[64]
		10.4	mature	18-21	
	4-day-restriction	3.32	mature	15-32	[9]
	1L on day 4 and 3L on day 8 of 12-day water restriction	22.13	mature	25-35	[61]
	1L on day 4 of 7-day water restriction	16.8	mature	23-33	Chedid et al. (unpublished)
Lactating	3-day-restriction	26.2	mature	27-31	[47]

Significant weight loss is documented in other breeds of sheep and goats subjected to feed and water stress [6, 65]. Part of this weight reduction is due to body water losses [9] while the other part is caused by the consequent mobilization of fat (and possibly muscle) used for energy metabolism to compensate the decrease in dietary intake [9, 66]. Furthermore it was observed that water restriction leads to more weight loss as compared to feed restriction alone [49, 62-63] although the difference was not always statistically significant.

The following table (Table 2) presents the effect of water and feed restriction on body weight of adult dry Awassi ewes [62, 63].

Table 2. Effect of water restriction versus feed restriction on body weight in Awassi ewes

	Treatment*		**Reference**
	Water restriction	**Feed restriction**	
Weight loss (%)	9.98	5.7	[62]
	17.9	8.2	[63]

*Water restricted animals received water every 3 days;
Feed restricted animals had free access to water but received 60% feed of the ad libitum intake.

Results in both studies are in compliance: water restricted animals lost more weight (approximately two fold) than those drinking every day but receiving less feed; however, large individual variations were recorded within each of the experimental groups (N=4). Therefore, further research is needed for conclusive results on the difference between water and feed restriction impact on weight loss.

2. Fat metabolism: fat cell diameter, cholesterol, glucose, fatty acids, leptin and insulin

The fat deposited during the periods of pasture abundance is mobilized and utilized for maintaining the body and sustaining production during periods of scarcity [67, 68]. The specialized fat depot represented in the fat-tail of many indigenous sheep, serves as a readily available source of energy to circumvent variation in dietary energy intake. This was well described in the Barbarine sheep subjected to long periods of undernutrition [37] as well as in the Awassi which showed a reduction in the fat-tail adipocyte diameter following an intermittent watering regime [64]. Ermias et al. (2002) [68] highlighted the importance of the

location of fat depots as adaptive features to periodic fluctuations in nutrition. They noted that the rump and fat-tail depots are the most responsive under such conditions. On the other hand, Atti et al. (2004) [37] noted that subcutaneous fat is the first energy depot to be mobilized when energy intake is deficient. This is true for the fat-tailed sheep such as the Barbarine on which they conducted their study, as well as other ruminants. However, the fat-tail provided an adaptive advantage by being slowly mobilized when undernutrion is extended over a long period thus allowing long-term survival by using up this important energy store.

Fat mobilization under water restriction is further denoted by high levels of cholesterol [69] and Free Fatty Acids (FFA) in the blood [61, 64]. The increase in plasma cholesterol following water scarcity is attributed to the decrease in energy intake, along with fat metabolism [70]. These results were recorded in different ruminant species submitted to water deprivation such as Awassi [9, 47] and Yankasa ewes [8]. Furthermore, the high level of FFA outlined in water restricted Awassi [61, 64] and the Sudanese desert sheep [71] reflects lipid mobilization within the adipocyte, thus permitting lipid stores to be used as fuel when feed intake is limited [72]. Similarly, FFA levels in the blood of lactating goats correlated positively with fat mobilization in times of under nutrition [73].

Reports about the changes in glucose levels in water restricted sheep are contradicting: while no significant change was recorded by some authors [8, 9, 61, 74], a decrease in plasma glucose level was observed in Merino sheep after 24 and 48 hours of fasting [75], and in intermittently watered Awassi, although the change was not significant [47]. Glucose metabolism decreases due to the decline of propionate (the major precursor for gluconeogenesis) production in the rumen caused by low feed intake [76]. Although ruminants derive most of their energy requirements from volatile fatty acids resulting from rumen fermentation of carbohydrates, they still have an absolute need for glucose, necessitating a good homeostatic control of this compound [77].

Fat mobilization seems to be coordinated by underlying changes in the levels of key hormones. In dry Awassi ewes, subjected to an intermittent watering once every four days, FFA were negatively correlated with insulin and leptin as highlighted in [64]. The decrease in plasma insulin is probably caused by the decline in feed intake, insulin secretion being accelerated by feeding [78]. Insulin levels are thought to remain low during fasting periods in order to facilitate lipolysis [79]. Similarly, the decrease in leptin levels in dehydrated and undernourished ruminants is well documented and explained by the decrease of the metabolic status which inhibits the adipose tissue from secreting leptin [80]. Moreover, a strong correlation between leptin concentration and fat-tail adipocyte diameter was noted in [64] highlighting the relation between the secretion of leptin by the adipose tissue and body fatness [81]. Chilliard et al. (2000) [36] proposed a model whereby insulin, cortisol and leptin interact in the process of adaptation to underfeeding and re-feeding in ruminants such as experienced also under intermittent watering. The drop in leptin following undernutrition leads to a chain of events that includes stimulation of re-feeding and decrease of energy expenditure and insulin-sensitivity, that serves to re-establish homeostasis by preventing excessive lipolysis that would yield toxic levels of fatty acids, and preserve body stores to prolong survival [36, 81].

3. Hematology: PCV and Hemoglobin

Dehydration in warm weather conditions reduces plasma volume as water is taken up by the tissue [82]. Although some authors reported and agreed that increased PCV and Hb concentration are good indicators of dehydration [42, 61, 71, 83, 84] results on these two parameters have been inconclusive. Even though levels of hematocrit were found to increase

in Awassi [42, 60] and Merinos [61] subjected to water stress in some experiments, no variation was remarked in Yankasa [7, 8] and Awassi [9] and Australian whether sheep [85] under similar watering conditions. Similar contradictory results were reported regarding hemoglobin: whilst an elevation of hemoglobin level was attributed to a decrease in plasma volume due to water loss [47, 61, 85] others did not report any variation [7-9]. These undetermined results may be an indication that adapted sheep can maintain plasma volume [86] and redistribute body water after a long water deprivation period [87].

4. Blood chemistry

4.1. Total protein, globulin and albumin

According to Caldeira et al. (2007a, b) [88, 89], serum total protein, globulin and particularly albumin are good indicators for predicting the animal's protein status. A drop in serum albumin concentration is observed in ruminants with low dietary protein intake [88, 90], followed by a decrease in globulin concentration when this dietary insufficiency is prolonged [88]. Many authors reported an increase in blood albumin and globulin in sheep under water restriction [9, 61, 74, 91, 92]. The high protein concentration is explained by the reduced plasma volume due to dehydration [93]. However, reduction in total protein and albumin was noticed after 3 days of water deprivation in Awassi [47] and in Barki sheep under water stress [94] suggesting that low feed intake is behind this reduction and that circulating proteins are being used in order to compensate for the dietary shortfall. Accordingly, maximum values of total serum protein were recorded on the 8^{th} day of water restriction in Awassi followed by a decline at the end of the experiment (12 days) [61]. Serum albumin is a major labile protein reservoir, but it is also very important in the maintenance of body osmoregulation. Consequently, some variations in serum albumin levels can occur, but the maintenance of normal levels has to be re-established as soon as amino acids from other sources like the skeletal muscle are available [95].

4.2. Creatinine and urea

Urea is mainly synthesized in the liver using NH_4^+, the end product of protein catabolism, and is released to the blood [96]. Urea is excreted by the kidneys to rid the body of the excess N intake that was not used for maintenance or production [90], or it is recycled through saliva or by reabsorption into the rumen to be utilized by rumen microflora [96, 97]. Creatinine is produced in the muscles and excreted by the kidneys in proportion to the muscle mass and the rate of proteolysis [88, 97]. The transfer function of the kidney is altered under water stress [98] with slower glomerular filtration and higher urea re-absorption [6, 8, 99].Water stress induces a decrease in urine output and the production of dry faeces under the action of vasopressin, and increased water reabsorption from the gastro-intestinal tract [100]. Urine volume dropped by 75% and fecal water output was 37% lower in desert sheep subjected to 5 days of water restriction [101]. Consequently, urea reabsorption by the kidney is also expected to increase as reflected by increased concentration in the blood [102], which was confirmed by several trials on Merinos [65], Yankasa [7, 8] and Awassi sheep [9, 42]. When Yankasa sheep were submitted to two consecutive periods of five-day water stress, an increase in urea and creatinine concentration was observed after the first period but only creatinine levels remained high after the second [8]. Thus the author suggested that urea is being re-circulated from the blood system into the digestive tract. This is consistent with the observations that urea conservation at the level of the kidneys and recycling into the gut is increased when dietary nitrogen intake is low [102].

On the other hand, creatinine levels in lambs were not affected by 48-hour water restriction [103], while others observed an increase of this parameter in water restricted animals [47, 91]. The creatinine concentration is influenced by the level of reliance on proteolysis and endogenous N sources [88, 98] as well as by higher kidney retention due to decreased glomerular filtration rate. In turn, these factors are related to the degree of protein/N intake deficiency that the animal is experiencing as well as the level of dehydration.

Figure 1, adapted from [47], illustrates the changes over repeated cycles of three days water restriction on major blood chemistry parameters of dry Awassi ewes. This figure shows that the response to the watering regime tends to decrease over time after it reaches a certain peak. This underlines the adaptation mechanisms that the animals activate in order to achieve homeostasis under the imposed treatment. The observed return to normal values in protein and albumin concentrations could indicate that these compounds are being used up from the blood in replacement of the deficient dietary intake, or this could also denote the mobilization of water from the extracellular fluid and the rumen into the blood stream [47]. Similarly, the decline in urea at the end of the treatment could be related to the above mentioned urea recycling mechanism, while creatinine concentrations remained relatively high as previously observed in [8]. The figure also illustrates that lactating and dry animals had similar responses to water restriction with no effect of lactation (2-3 months in lactation) on these blood parameters.

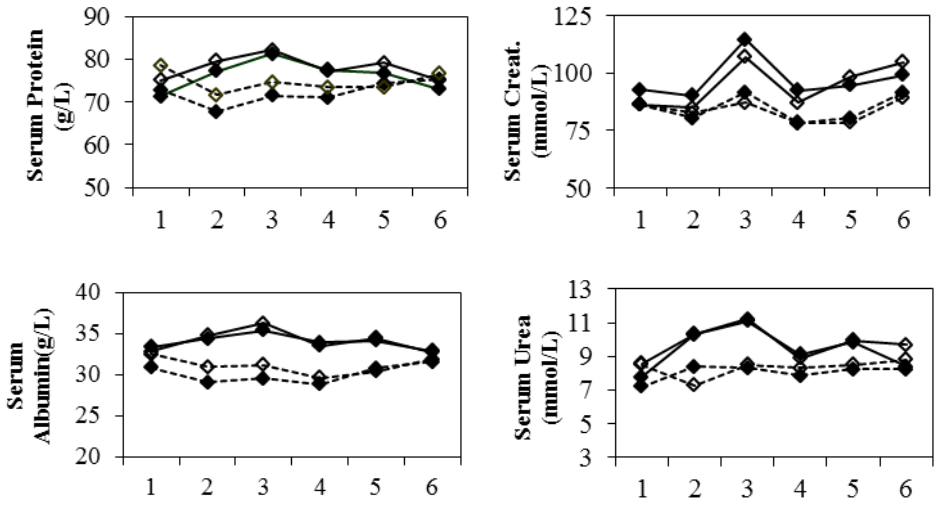


Figure 1. Changes in some serum chemistry indicators of dry (◊) and lactating (♦) Awassi ewes subjected to daily watering ( ) or to water restriction (- - - -). (Adapted from [47])

4.3. Electrolytes and osmolality

Analyzing osmolality is a good approach for monitoring the hydration status. It has been proved that osmolality and electrolytes levels are largely affected by water deprivation: the reduced plasma volume causes hyperosmolality inducing consequently an increase in electrolytes concentration [104] mainly sodium Na^+ and chloride Cl^- [60, 105, 106]. These results were reported in different breeds of sheep and goats [10, 63, 71, 91, 103, 107].

Increased renal retention of Na^+ is a physiological response to water restriction in different small ruminant breeds, which allows the maintenance of sodium balance in the body. Ashour and Benlemlih (2001) [87] attributed the increased renal retention to the influence of aldosterone, whereas McKinley et al. (2000) [107] added the effect of vasopressin secretion. Dehydration causes an increase in plasma vasopressin levels in both lactating goats [108-110] and non-lactating ones [108, 111]. According to Yesberg et al. (1970) [112] urinary

vasopressin excretion rate is directly related to urinary osmolality and inversely related to urine flow rate. This explains why dehydrated goats and sheep decrease their urine volume while the osmolality and vasopressin levels augment. Olsson (2005) [113] noted that thermoregulation and fluid balance, as regulated by thirst control, vasopressin secretion, sodium balance and other osmotic and cardiovascular signals, seem to be centrally regulated at the hypothalamic level, particularly the preoptic and anterior hypothalamic neurons. Silanikove (1994) [15] presents a detailed account of the dynamics of major electrolytes under dehydration in connection with water conservation and homeostatic mechanisms in ruminants. In addition to the increased renal retention of water and Na^+, saliva secretion is decreased in dehydrated animals but its osmolality is increased. In parallel, the ruminants resort to utilize the large volume of water present in the gut through active transport of Na^+ across the rumen wall. This transport necessitates the presence of a minimal amount of volatile fatty acids in the rumen, hence the importance of sustaining some feed intake during dehydration. The hyperosmotic fluid absorbed from the rumen needs to be desalted the salivary flow to the rumen has to be maintained in order to preserve homeostasis.

Rehydration is an equally challenging situation for ruminants that can lead to hemolysis in non-adapted or severely dehydrated animals. Many studies reported the slow return to normal levels of blood volume, osmolality and other blood components after the rehydration of ruminants, although the animals drank large amounts of water at once [42, 92, 114]. The mechanisms allowing the slow release of the ingested water from the rumen into the blood stream are not fully understood. The production of hypotonic saliva is dramatically increased following rehydration [15] thus allowing the recycling of absorbed water and Na^+ from the blood back into the rumen to prevent a sudden drop in blood osmolality. In parallel, the kidney sustains its water/Na^+ conservation activity to prevent the loss of the ingested water which is vitally needed in anticipation of a future dehydration cycle. Rehydration also activates appetite and thermoregulatory mechanisms that allow the final restoration of homeostasis and normal functioning in up to 24 hours after rehydration or more.

Studies on different sheep breeds [115, 116] showed a negative correlation between Na^+ and K^+ in plasma. Concurrently, blood K^+ was reported to decrease in water-deprived sheep [9, 65] probably due to the intra-erythrocytic diffusion of K^+ or loss of these ions in urine in exchange of Na^+ re-absorption [8]. However, others observed an elevation in plasma K^+ under water restriction [7, 117], while [8, 47, 61] did not report a variation in K^+ levels in Yankasa and Awassi sheep, respectively. These inconclusive results about K^+ alteration under water restriction do not make of potassium a reliable indicator of the hydration status; on the contrary they warrant further studies about the role played by this blood parameter during dehydration.

Chloride Cl^- is the major anion in extra cellular fluids (ECF). It functions primarily in transport processes integral to cation and water balance and as a conjugate anion in acid-base metabolism. Several findings reported that dehydration leads to an increase in plasma chloride levels in parallel to sodium levels [8, 9, 47, 74] as Cl^- is passively distributed in relation to the electrical gradients established by active Na+ transport [118]. This increase may be attributed to many phenomena such as the hemoconcentration resulting from a lower blood water level [74], and the increase in aldosterone and vasopressin concentrations [87] leading to increased renal retention.

Calcium plays an important role in regulating ion gating and as a co-factor for intermediary metabolism reactions. However, studies did not report variation in Ca^{++} under water deprivation in the Awassi [9, 47] nor in Comisana sheep [74].

Finally, blood pH, a critical parameter for normal enzymatic and metabolic functions, seems to be well maintained in intermittently watered Awassi [9, 47, 61]. Increase in pH was

only recorded in highly restricted Awassi following a once in a five days intermittent watering regime [9], this could be related to a combination of the high dehydration state and environmental heat which leads to hyperventilation and consequently to respiratory alkalosis as observed in other heat stressed animals due to the increased elimination of CO_2 [119].

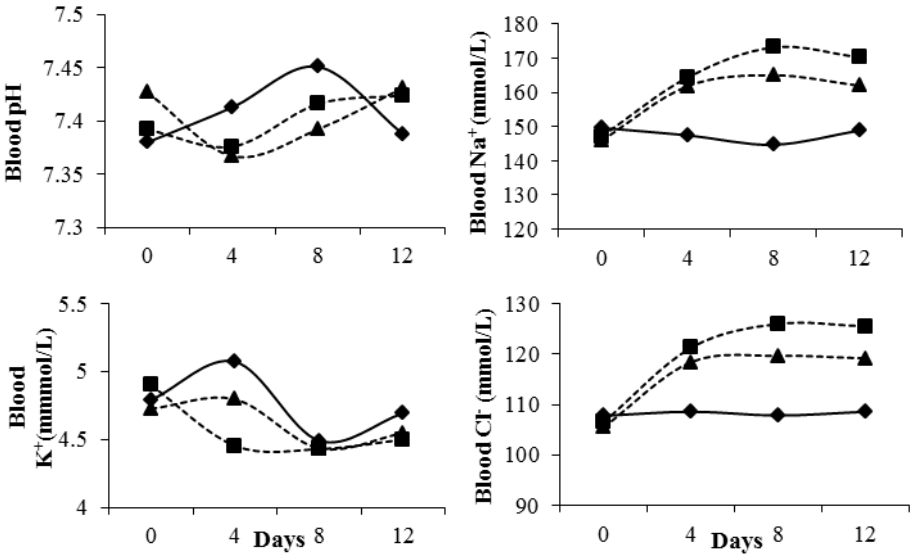


Figure 2. Effect of water restriction (- - -) on dry Awassi ewes with (▲) and without (■) vitamin C supplementation (Ghanem et al., 2008, unpublished data)

Figure 2 is an illustration of the effect of a 12 days water restriction episode on Awassi dry ewes. The animals were offered 1 liter of water on day 4 and 3 liters on day 8 only. In this trial, the treatment had no significant effect on blood pH and K^+ concentration, while Na^+ and Cl^- were significantly increased under the restriction regime. The trial also included a group of water restricted animals that received 2.5g/d of vitamin C, the effect of which is discussed below (vitamin C section). It is worth noting here that the levels of Na^+ and Cl^- seem to have reached a peak after which they started to show a slight decline. This observation reinforces the previously proposed idea of adaptation to the restriction regime to reach a new homeostasis by activating water mobilization and conservation mechanisms to restore the blood volume and composition.

5. Cortisol and other hormones

Cortisol is a hormone secreted in order to deal with stress. It is released due to the activation of the hypothalamo-pituitary-adrenal axis by stress. Although it plays a major role in maintaining the balance of water and electrolytes [120, 121], its mechanism is not very clear yet [122]. Dehydration had no effect on serum cortisol levels of Awassi [9, 61] and Clun forest sheep [123] which is consistent with the results obtained under laboratory conditions in sheep deprived of feed and water for 48h [124]. On the other hand, Kataria and Kataria (2004) [98] suggested that the increase in cortisol levels in dehydrated Marwari sheep (for 6 days) is a sign that the animals are under stress; they also reported that cortisol levels did not return to normal even after 72 hours of rehydration. Working on the same subject, Li et al. (2000) [85] reported plasma cortisol variation with fasting while water restriction had no additional effect on this parameter. A decline in serum cortisol was recorded in intermittently watered Awassi along the experimental period [47]. Concurring with [125], it is suggested that cortisol could

be a good parameter in assessing acute stress response in small ruminants but not chronic stress such as dehydration.

Thyroid hormones (Triiodothyronine T3 and Thyroxine T4) play a major role in many physiological events such as thermoregulation and metabolic homeostasis of energy and proteins [126-128]. T3 and T4 concentration is affected by many factors like reproductive status, climatic conditions [127, 129] nutrition, age and gender [130, 131]. Water restriction [64] and nutrient limitation [132] were found to lower the levels of T3 and T4 in dry Awassi ewes and pregnant Whiteface Western ewes, respectively. Similarly, Caldeira et al. (2007a) [88] noticed a decrease in these hormones with decreasing body score of ewes. They concluded that T3 is a good indicator of the metabolic state of the animal. On the other hand, variable T3 and T4 responses to seasonal variations and/or dehydration were reported in literature from various ruminants [133]. The concentrations of these two hormones were found to be strongly correlated (r^2=0.568; P=0.000) [64]. The authors suggested that this decline in T3 under water restriction reflected the declining metabolic state due to dehydration and decreased feed intake while the declining T4 concentration was probably a response to the thermal stress experienced by the animals in that experiment. Similarly, T4 concentrations were reported to vary with the season while T3 is affected by both the season and the physiological status of the sheep [134]. The reduction of thyroid hormone activity under dehydration is associated with the animal's attempt to minimize water losses by reducing general metabolism [135].

4. Changes in relation with physiological status

As seen above, small ruminants in arid and semi-arid regions face many constraints related to fluctuating temperatures as well as shortages in feed and water sources. Pregnancy and lactation increase the needs for adaptive mechanisms due to the greater need for food, water and electrolytes in order to meet the requirements of the fetus and the mammary glands [113]. Water requirements could increase up to 50% by late pregnancy (around 160 ml/kg $BW^{0.75}$) while the requirement for milk production is stated as 165 ml/kg BW0.75 for a milk production level of 148g milk/$kg^{0.75}$ [5]. Pregnant and lactating animals have 40-50% higher water turnover rates than dry animals [17]. However, Degen (1977) [35] recorded a small difference in water turnover between control and pregnant Awassi and Merinos sheep.

1. Pregnancy

The reported physiological changes vary according to the degree of water restriction and stage of pregnancy. Chokla pregnant ewes submitted to intermittent watering (every 72 and 96 hours) under semi-arid conditions showed significant hemocentration and reduction in extracellular fluid space as compared to pregnant Chokla receiving water daily [136]. Similarly, Olsson et al. (1982) [137] reported increases in plasma osmolality and Na^+ concentration in pregnant goats dehydrated for 30h accompanied by a decrease in glomerular filtration rate, while plasma protein and hematocrit did not change with dehydration. Interestingly, it was observed that pregnant goats [137] and sheep [138] have a lower capacity to concentrate urine in response to dehydration. Authors in both studies suggested that the apparent reason for this observation is a decreased sensitivity to Arginin-Vasopressin (AVP) which in turn, could be partially due to the effects of high prostaglandin concentrations which increase during late gestation. Research on the Matebele goat showed that a low nutrition level during late pregnancy had little effect on kid birth weight [139]. Similarly, a twice weekly watering regime imposed for a prolonged period had no effect on birth weight of

desert adapted Magra and Marwari sheep [140]. On the other hand, pregnant Chokla ewes watered every 4 days gave birth to lambs of lower weight compared to ewes that were watered daily or every three day; however, at 12 weeks of age, lambs' weight were similar between the differently watered groups [136]. Working on goats, Mellado et al. (2006) [141] highlighted the importance of goat birth weight and weight gain at 25 days of age on their future reproductive performance under intensive conditions in hot arid environments. On the other hand, in a recent study prenatal feed restriction in the last trimester resulted in lower male offspring weight in goats, but had no effects on later behavior and growth [142]. Further studies are needed to assess the long term consequences of dehydration and/or intermittent watering during gestation on the growth and later performance of the offspring.

2. Lactation

Significant weight loss was recorded in lactating water-stressed Awassi [47] and Comisana ewes [74] as compared to control animals. Weight loss during lactation is due to body water loss caused by less water and feed intake combined with energy deficit that drives lactating animals to strongly depend on their body reserves [143].

Physiologically, lactating animals show lower hemoglobin concentration than dry ones [47]. According to [120], the decrease in hemoglobin concentration in lactating ewes is explained by the high water content and plasma volumes due to increased water mobilization to the mammary glands. It was found in [47] that lactation did not affect levels of serum glucose or those of cholesterol in Awassi ewes in their second to third month of lactation. Concurrently, no significant changes were recorded in glucose level caused by lactation beyond the first month [144]. Moreover, lactation did not affect blood total protein, albumin and globulin concentration of Awassi ewes in their mid-lactation [47]; no change in albumin was also reported in [145], however an increase in the gammaglobulin fraction was noticed. El-Sherif and Assad (2001) [94] observed a return to normal total protein levels on the fourth week of lactation most probably caused by a fall in globulin concentrations. The same authors reported that lactation significantly increased plasma albumin, albumin to globulin ratio and blood creatinine in Barki ewes under semi-arid conditions. No alteration was caused by lactation on serum urea and creatinine levels in Awassi ewes [47] and Corriedal [138]. Working with lactating Comisana subjected to 60% water deprivation, Casamassima et al. (2008) [74] reported significant elevations in serum concentration of triglycerides, albumin, total proteins and cholesterol. Intermittently watered Ethiopian Somali goats, exhibited similar physiological responses to those described in other breeds, namely increased osmolality, AVP secretion and blood protein concentration [110] . The authors also noted a significant capacity to fluctuate rectal temperature in response to heat stress reaching 5^{o}C daily change in some animals; they also observed the activation of a water saving mechanism following the first cycle of water restriction, resulting in lower physiological changes in subsequent cycles. A similar trend was also noted in lactating Awassi ewes subjected to intermittent watering [47].

Concerning the effect of lactation on blood pH, Hamadeh et al. (2006) [47] reported significantly higher blood pH in water restricted lactating Awassi ewes as compared to dry ones. This increase in pH is correlated to the decrease in plasma Ca^{++} and K^{+} levels due to their need for milk production [47] and to the increase in plasma Na+ and Cl^{-} since Na^{+} is used for nutrient transport [146]. As for cortisol, lactating Awassi ewes tended to have high levels as compared to dry counterparts. However, more work is needed in order to elucidate the adaptive mechanisms of pregnant and lactating ewes to water restriction.

3. Milk production and composition

Water needs are reported to be the highest during lactation as compared to other physiological statuses [109]. Dehydration leads to a reduction in the blood flow to the mammary gland however, enough supply for milk production may still be achieved as supported by the sustained milk production in dehydrated goats [113] and sheep [74]. During dehydration, milk volume is generally decreased [109, 110, 147], although the Bedouin goats could maintain their milk production when watered every second day [108]. Dahlborn et al. (1997) [148] suggested that the drop in milk volume observed in some dehydrated animals was mainly the result of lack of water as such and not a reflection of the consequent decrease in feed intake; furthermore the authors suggested that this drop could be related to the alteration in casein production observed under dehydration. In fact, Silanikove (2000) [6] showed that stress leads to a chain of events including increased cortisol secretion leading the activation of the plasmin system resulting in the release of a proteose peptone with channel blocking activity (PPCB) from β-casein and interfering with lactose secretion into the lumen of the mammary gland and consequently causing a drop in production. Previous studies have indicated an increase in milk osmolality, lactose and density following water deprivation for 48 hours [109, 149, 150]. Milk osmolality is strictly controlled to keep it isotonic with plasma; the increase in lactose under water restriction, being the major osmotic component of milk, is probably a response to the increase in serum osmolality under water restriction [149]. Nonetheless, milk can be less concentrated in fat and non-fat solids and more rich in water. Alamer (2009) [150] noted a decrease in fat content of milk of 25% water restricted goats but not in those that were 50% restricted. The increase in water content [151, 152] is thought to be a form of adaptation allowing the offspring to receive the adequate quantity of water when water is not available.

5. Stress alleviation drugs

Domestic animals are routinely faced with different stressors. Most stressful conditions, including diseases [153] and farming practices such as milking [143], isolation [154], introduction to a new flock [155], road transportation [156, 157] last for only a short period ranging between hours to days. On the other hand, harsh environmental factors are probably the stressors with the longest lasting effect since they may prevail for months. For example, heat stress and elevated ambient temperature are considered major risks affecting sheep performance [85; 158]. The negative impact of heat is translated into increased body temperature, higher respiration and heart rates followed by a drop in feed intake, redistribution in blood flow and alteration in endocrine function [158]. Low temperatures or cold leads to an equally stressful situation which affects sheep performance by increasing the metabolic rate [85,160]. Furthermore, different environmental constraints often come together such as the situation in arid and semi-arid areas during the dry season when heat stress is combined with water scarcity and low pasture quality.

Animal producers and researchers have looked for ways to alleviate the negative effects of common stressors. Stress alleviation strategies are numerous, and their availability to producers depend on the access to water and energy, the price they are able to pay and the adopted farming system [153]. These strategies vary from simple on-farm practices such as modifying the feeding pattern, feed composition [160], water management, cooling systems and environmental modifications like shading [153, 161], protection from solar radiation [153], the use of micro-sprinklers, spray jets and ventilation [162] to more scientific procedures like genetic selection [161] and others.

In this quest for stress alleviation in domestic animals, researchers have tested special drugs and/or nutritional supplements. Trials showed that a pre-transportation administration of ascorbic acid to goats facilitates the transition from depression to excitation; it exhibited potential depression amelioration after road trips [163] and significantly decreased weight loss caused by transportation under unfavorable thermal conditions [164]. Ali et al. (2005) [156] reported that a single dose of the anti-stressor xylazine administered to sheep and goats before road transportation considerably ameliorated the effects induced by the stressful stimulus; whereas a pretreatment with sodium betaine (a test compound) had no significant effects. Electrolyte therapy was also found effective in reducing stress of transportation in market cattle allowing a better meat quality and a reduction in live weight loss [157].

In this review we will focus on two compounds that appear to have a good potential for stress remediation in domestic animals: Vitamin C which is tolerated at high doses without apparent side effects [165] and aspirin which showed some potential advantages warranting further investigation [166-168].

1. Vitamin C

Although ruminants biosynthesize ascorbic acid under normal conditions and do not need any additional supplementation [45], and even though vitamin C administration is not a common practice in adult livestock nutrition [169] scientists however, decided to study the effect of VitC administration to sheep under water-stress conditions [60, 61, 64, 92] and goats facing the stress of transportation [163, 164]. These trials were encouraged by promising results obtained on weaned pigs [170], Japanese quails [171], rabbits [172] and broilers [173] under stress.

Ascorbic acid is known for its function as an antioxidant mainly due to its redox properties; it acts as a free radical scavenger in numerous cellular oxidation processes [174] and has been demonstrated to be helpful for young ruminants in acclimatizing to cold stress [175]. Ascorbic acid plays an important role in modulating the immune response by enhancing neutrophil function and minimizing free radical damage [176] and by improving antibody response to antigen [177]. Concurrently, Minka and Ayo (2007) [164] reported that administering VitC to Red Sokoto goats before transportation reduced the post-journey effect to a minimum or eliminated it completely; however the impaired animals' homeostasis was rapidly recovered after the trip.

A daily dose of VitC was reported to decrease weight loss in adult female Awassi subjected to a water-restricted regime [61, 63] while this effect was not significant in other trials [63, 64, 92]. The alleviation of body weight loss can be explained by improved feed intake [92] and better feed conversion, also observed in other animals in stressful conditions and supplemented with vitamin C [164, 171, 178]. The ameliorated effect of ascorbic acid on weight loss during short-term transportation of goats in hot weather [164, 179] proves the advantage of VitC supplementation in order to maintain an adequate live body weight for slaughter.

VitC supplementation to sheep alleviated the effect of dehydration on PCV [61] but not on hemoglobin [61, 63]; while in goats submitted to transportation under unfavorable climate conditions, VitC significantly decreased levels of both PCV and Hb [164]. It was also found that supplementing VitC to deficient pigs increased hemoglobin levels probably due to increased iron absorption [180].

Lower serum protein concentrations were reported in VitC administered water-restricted Awassi as compared to non-supplemented counterparts [61], while others found no significant differences in total protein and globulin levels due to VitC [92]. The effect of vitamin C on

albumin levels is inconclusive as well: although some [61] noted lower concentrations in treated ewes, others [47] reported higher values of albumin in treated animals. The daily VitC dose also plays a considerable role on blood parameters: a daily dose of 5g significantly increased serum creatinine and urea concentrations as compared to 3g and to control [92]. This might be considered as an enhancement to the adaptive mechanisms of Awassi sheep to water restriction. However, in other experiments no effect of VitC was observed on creatinine levels [63] warranting further investigations on the role of VitC in urea and creatinine dynamics during dehydration.

In an experiment conducted in order to study the effect of VitC on fat mobilization under water stress, Jaber et al. (2011) [64] reported no significant effect of this drug administration on adipocyte diameter, fat mobility and weight loss in water deprived sheep. Authors speculated that a daily dose of VitC (3g or more) may be more helpful in increasing fat mobilization under water stress than single high dosages; they agreed that more work would be essential to confirm the observed trends.

A tendency for higher cholesterol levels was observed under VitC administration [60, 61, 63]. Vitamin C interferes in norepinephrine formation, an important hormone that increases fat mobilization [172], it is also essential in carnitine formation, which upon reacting with acetyl CoA forms acetylcarnitine that transports fatty acids into the mitochondria to be oxidized [60].

Reports on the effect of VitC on osmolality are scarce. However, Karnib (2009) [63] and Hanna (2006) [106] observed increased osmolality in water-stressed vitamin C supplemented Awassi ewes, but the mechanism of such phenomenon is still not well understood. Results obtained on the effect of VitC on blood electrolytes are not very clear and need more elaborated work. Ghanem et al. (2008) [60] reported that VitC administration alleviated the effect of water restriction as reflected in lower Na^+ and Cl^- (Figure 2). The authors attributed this observation to the role of vitamin C in norepinephrine formation, which affects the kidney function and therefore water and electrolytes dynamics. On the other hands, [72] reported an opposite result in one experiment while in a second experiment Na^+ and Cl^- were the same between supplemented and un-supplemented water restricted ewes.

Benefits of VitC in decreasing stress hormones was reported by several authors: some [181] observed that ascorbic acid intake resulted in a drop in adrenal and plasma corticosterone levels, others showed that vitamin C eliminated the secretion of cortisol in animals subjected to stress [182]. Still others did not observe any effect of VitC administration on cortisol concentrations in stressed animals [61, 122, 124]. Serum cortisol is a better marker for acute stress than for chronic stress [125]. While VitC and cortisol interact, the anti-cortisol role of VitC is still unclear and needs more research.

Concluding with VitC, it has been shown that the most important parameter in highlighting the role of VitC in counteracting the effect of water deprivation on sheep is the observed decrease in weight loss. Consequently, further work is warranted in order to elucidate the mechanisms of action of VitC, and to determine the best dose recommendations that would increase the adaptive capacities of shepherds and flock keepers to the changing weather and increasing global warming.

2. Aspirin

Acetyl-salicylic acid ASA or aspirin has been used for ages as an antipyretic and analgesic agent [183]. New studies have emphasized the role of aspirin in the treatment of some types of cancer [168] and cardio-vascular diseases [184] although data on the effect of aspirin in animal production is contradictory. On one hand, supplementation of 20ppm of ASA to layer

chicken under hot climates improved the number of eggs as well as their weight; it increased feed intake, improved fertility and hatchability [185]. On the other hand, chronic feeding of ASA had detrimental results to layer breeders with concerns for early hen livability and egg quality [186]. In mammals, aspirin reduced scouring and improved growth rate when supplemented to weanling pigs at a level of 125 or 250 ppm [166]. It also reduced plasma cholesterol levels in rats [167], and protected rats from colon cancer [168]. Recently, the role of aspirin in the protection from oxidative stress has been highlighted.

The role of aspirin in alleviating stress has been investigated in adult Awassi ewes subjected to water and feed restriction has been studied [62]. Treated animals with a daily dose of 100mg of ASA lost more weight than the untreated animals. However, the difference was not statistically considerable. Similar results had been reported in broilers [187] and weanling pigs [166].

Aspirin did not have any effect on rectal temperature; perhaps these results highlight the capacity of Awassi to remain thermostable even under dehydration [10, 35]. No changes were detected in PCV and hemoglobin levels [62] confirming that salicyclates do not usually alter these two parameters [188]. Moreover, results of the experiment revealed that aspirin has no effect on plasma concentrations of proteins, globulin and albumin. Similarly, no significant differences in the levels of urea, creatinine and osmolality were observed between treated and untreated animals. Furthermore, no significant effect of aspirin was observed on any fat mobilization indicator i.e. cholesterol, insulin, free fatty acids and leptin.

Other studies investigating the role of aspirin in water and feed stressed ruminants are not found. The available literature covers stress resulting from transportation and exposition to new environment [189] and physical pain caused by tail docking [190].

Further studies using different doses of aspirin could be done. Additional experiments might also help clarify the antioxidant property of aspirin and its effect on the ruminant immune system which might be compromised under stress.

6. Conclusion

This review helped in highlighting the adaptability of indigenous small ruminant breeds to water stress and the changes it induces under different physiological statuses. Most small ruminants respond to water stress by decreasing their feed intake, resulting in weight reduction due to water and body mass loss. The rumen plays an important role as water reservoir both in times of dehydration, to maintain blood volume, and upon rehydration to prevent hemolysis. Similarly, modulating saliva production and osmolality is an important mechanism for facing dehydration and rehydration cycles.

A ten-year research track on the Awassi demonstrated the key mechanisms that this breed activates in facing water stress. Strong water conservation is achieved at the level of the kidney, as reflected by a drop in urine output and increased blood Na^+, albumin and urea along with hyperosmolality. Furthermore, the Awassi seems to adapt to an intermittent watering regime after a couple of cycles by re-adjusting its blood volume and constituents to a new status tending toward control levels. Finally, the Awassi mobilizes its fat stores, including the fat-tail, to overcome the shortfall in dietary energy intake. This breed could be maintained, during the hot months and in times of severe water shortage, on short intermittent watering regimes. However, severe dehydration will ultimately result in detrimental effects on milk production, reproductive success, lambs' weight gain and disease resistance, particularly during gestation and peak lactation.

Stress alleviating supplements such as vitamin C show some promise in decreasing the effects of dehydration. Many tracks still need to be explored in future research such as feeding

and nutritional manipulations to alleviate water stress, with special attention to the long-term effects of such approaches on overall productivity and welfare. The identification of breeds that show high adaptability to arid and semi-arid regions with an acceptable level of productivity is also important.

7. References

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c. Texte en anglais de l'article de revue sur le stress hydrique chez les moutons élevés en milieux arides et semi-arides : Water stress in sheep raised under arid conditions: a review

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Running head: Water stress in sheep in arid regions

ABSTRACT: *Sheep breeds which are indigenous to arid and semi-arid regions are known for their ability to adapt to rustic environments, to climatic variations as well as to shortages in resources. Water scarcity, often combined with heat stress, is a common challenge facing these animals, causing physiological perturbations and affecting the animal's productivity. This review reports the effect of different forms of water stress on physiological indicators, blood parameters, thermoregulation and immunological status in sheep. Although the breed effect may be significant, the following are generally observed common responses: drop in feed intake and weight loss, increase in evaporative cooling through panting, production of a small volume of highly concentrated urine, haemoconcentration, high blood osmolality, and immunosuppression. Prolonged water shortage may affect lamb birth weight and survival, and leads to decrease in milk production, especially in non-adapted breeds which could lead to important economic losses as reported in heat stressed sheep husbandries. Novel stress alleviation approaches are also presented such as vitamin C supplementation.*

*(**Key words**: Arid regions, Dehydration, Immunosuppression, Physiology, Sheep, Thermoregulation)*

I. INTRODUCTION

Sheep production is a major economic activity in the arid and semi-arid regions of the globe. Sheep can make use of low quality biomass in times of scarcity and transform it into useful products such as milk, meat or wool. Native sheep breeds in arid and semi-arid areas demonstrate better performance under harsh environmental conditions than their non-native counterparts. Therefore, proper breed selection is a very valuable tool for sustaining animal production under an increasingly challenging environment (Silanikove 1992; Iñiguez 2005).

Water scarcity is a growing problem in arid and semi-arid regions with global warming and changing patterns of rainfall which limit water resources and affect feed quality and quantity in addition to increased 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).

The objective of this review is to highlight the physiological and immunological changes in sheep when faced with water restriction and in particular their responses during pregnancy and lactation. The additional burden of heat stress is also considered as well as the novel approach of vitamin C supplementation to alleviate water stress.

II. SHEEP BREEDS ADAPTED TO ARID AND SEMI-ARID REGIONS

Sheep breeds differ in their capacity to overcome water shortages; the desert Bighorn sheep (*Ovis canadensis nelsoni*) can withstand water deprivation for up to 15 days (Farid et al. 1979; Turner 1979), while the Barki sheep in Egypt could not withstand 3 days without drinking (Farid et al. 1979). Reports on other breeds like the Awassi (Jaber et al. 2004), Yankasa (Aganga et al. 1989), Merino (MacFarlane 1964) and Barbarine sheep (Ben Salem et al. 2011) lie between these two extremes.

Dehydration corresponds to a negative water balance, which means that the water inputs (water drunk + water in the feed + metabolic water linked to the oxidation of carbohydrates, protein and fat) are lower than water outputs (urinary water + faecal water + water lost by evaporation from both the skin and respiratory tract). In order to avoid dehydration, sheep resort to various forms of adaptation. At the behavioral level, nocturnal feeding has been documented in Bighorn sheep (Dwyer 2008): by foraging at night, sheep minimize their exposure to high thermal loads, reducing the need for evaporative cooling and thereby minimizing water loss. 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). Timing reproductive events may be affected by dehydration; water stressed animals often decrease feed intake which is reported to cause retardation of ovarian follicular growth (Blanc et al. 2004). In arid and semi-arid regions (in the northern hemisphere), where differences in daylight, as well as in food and water availability are well defined, the breeding season usually spans from June to November (Amoah et al. 1996; Hamadeh et al. 1996). Consequently, lambing mostly occurs between February and April, when food and climate become more favourable for newborn survival and for dam milk production.

Morphological adaptations are also observed in sheep adapted to arid and semi-arid regions. Fleece type (Eyal 1963) and color (Kay 1997) contribute to protection against heat and minimise water lost due to evaporative cooling. Indigenous breeds in arid and semi-arid 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 to 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). In comparison, hair-type sheep seem to be less thermoresistant under hot conditions when compared to their wool-bearing counterparts (Symington 1960). In contrast, under tropical conditions of high temperature and high humidity, McManus et al. (2009) concluded that hair-type sheep were better adapted than wool-type breeds. Moreover, a light colored fleece allows better reflection of solar radiation thus keeping the skin underneath relatively cooler compared to darker fleeces (Cain et al. 2005, McManus et al. 2009). Another anatomical characteristic of indigenous sheep breeds from arid and semi-arid regions 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 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, 1992), 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).

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/liter in the Bighorn desert sheep (Horst and Langworthy 1971; Turner, 1973) and 3244 mOsm/kg in the Awassi sheep (Laden et al. 1987) as compared to values around 769 mOsm/kg 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). The rumen plays an equally important role in water conservation in arid adapted animals whereby it can act as a water reservoir to replenish the lost volume in the blood. Rehydration of water-deprived adapted sheep activates a coordinated chain of events from the rumen, the kidneys and the salivary glands, under hypothalamic control, to preserve the water, restore homeostasis and appetite, and prevent water toxicity. These processes are described by Silanikove (1994).

Finally, arid adapted animals may allow small increases in body temperature during the hottest parts of the day, followed by body cooling at night through conduction and radiation. The capacity to tolerate this increase in body temperature means that less water is needed for evaporative cooling (Kay 1997).

III. PHYSIOLOGICAL CHANGES IN RESPONSE TO WATER STRESS

a. Feed intake and body weight

Feed consumption is highly related to water intake (Silanikove 1992). An adequate level of water intake is necessary for proper digestive function (Hadjigeorgiou et al. 2000). In contrast, Kay (1997) states that drinking water is not needed for swallowing and moistening feed, since water can be circulated from the blood to maintain high salivation; it is however needed to replace the inevitable water loss by excretion and evaporation. When Awassi sheep experienced a 3-4 day intermittent watering regimen voluntary feed intake was reduced to approximately 60% of controls (Jaber et al. 2004; Hamadeh et al. 2006). The effect of this reduction in feed intake caused by dehydration is dependent on the type of feed that is available for the animals. Van der Walt et al. (1999) observed that sheep kept on a low protein

diet and subjected to water restriction showed a smaller reduction in feed intake as opposed to those given a medium protein diet and they had better urea recycling through the digestive tract. However, the group on low protein had a slightly lower growth rate than the medium protein group. Similarly, water restricted desert goats fed low quality forage lost more weight than their well-fed counterparts (Ahmed Muna and El Shafei Ammar 2001). Therefore, the negative effect of water restriction is more pronounced when sheep are kept on low *versus* high quality forage (Morand-Fehr 2005). Because of this relation, it is often difficult to differentiate the effects of water restriction, *per se*, from those due to low feed intake. Pulina et al. (2007) suggested that feed restriction of 50% for a period of only 3 days is enough to cause metabolic changes in lactating dairy Sarda ewes. Prolonged reduction in feed intake may eventually affect the reproductive potential of sheep (Rhind and McNeilly 1986; Maurya et al. 2004), and consequently reduce production.

The direct consequence of water restriction and the associated decrease in dietary intake is a reduction in body weight (Jaber et al. 2004; Hamadeh et al. 2006; Jaber et al. 2011). Part of the reduction in weight is due to body water loss while the other part is caused by the consequent mobilization of fat (and possibly muscle) used for energy metabolism to compensate the decrease in dietary intake (Jaber et al. 2004) and rumen fill is also reduced due to the decrease in feed intake. Furthermore, it was observed that water restriction leads to more weight loss than feed restriction alone (Ahmed Muna and El Shafei Ammar, 2001; Chedid 2009; Karnib 2009). The decrease in body weight in the Awassi sheep is aggravated at peak lactation, high ambient temperature and in young animals (Hamadeh et al. 2006; Jaber et al. 2011). Moreover, dry mature Awassi ewes can tolerate a 3-day intermittent watering regimen for a month or more, although a weight loss of up to 17% would be expected (Karnib 2009).

b. Blood chemistry

Dehydration in warm weather leads to haemoconcentration as highlighted by increased haemoglobin and Packed Cell Volume (PCV) levels (Li et al. 2000; Ghanem, 2008), although some authors reported no variation in these parameters in water restricted sheep (Igbokwe 1993; Jaber et al. 2004). More consistently, serum protein and albumin are reported to increase (Jaber et al. 2004; Alamer 2005; Casamassina et al. 2008; Ghanem et al. 2008; Hamadeh et al. 2009;) due to the decreased blood volume (Cork and Halliwell, 2002). However, albumin and protein levels tend to decrease after prolonged water restriction (Hamadeh et al. 2006; Ghanem et al. 2008) which reflects dietary deficiency. Serum albumin serves as a labile protein reservoir providing a readily available source of amino acids until an alternative source is secured through diet or by mobilizing body sources such as skeletal muscle (Moorby et al. 2002). Albumin also plays an important role in osmoregulation and fluid movement control between different body compartments since it is a major contributor to blood colloid osmotic pressure; for this reason the rates of albumin breakdown and synthesis are regulated in response to dehydration to maintain normal colloid osmotic pressure and fluid distribution (Burton 1988).

Water stress causes a decrease in urine output and the production of dry faeces controlled respectively by vasopressin and increased water reabsorption from the gastro-intestinal tract (Olsson et al. 1997). Under these conditions, the transfer function of the kidney is altered (Kataria et al. 2007) with slower glomerular filtration and higher urea reabsorption (Silanikove 2000). Consequently, the levels of urea and creatinine in blood are increased (MacFarlane et al. 1964; Laden et al. 1987; Igbokwe 1993; Jaber et al. 2004). However, upon prolonged water restriction and reduced feed intake, urea levels may start to decline reflecting

an increase in urea recycling into the gut (Igbokwe et al. 1993; Marini et al. 2004), so it can be used as a nitrogen source by rumen microflora.

Another consequence of decreased blood volume and increased renal retention is hyperosmolality as well as an increase in electrolyte concentrations (Qinisa et al. 2011); mainly sodium Na^+ and chloride Cl^- (Rawda 2003; Ghanem 2005; Hanna 2006). The chain of events activated under dehydration, in order to preserve homeostasis, is described by Silanikove (1994): renal water and Na^+ retention is increased, while saliva production is reduced; to compensate for lost water, the animals mobilize the water from the rumen and the digestive tract; water movement is achieved through active transport of Na^+ across the rumen wall; this ruminal fluid is hyperosmotic therefore the excess Na^+ is reabsorbed by the kidneys and recycled through saliva, to preserve the blood Na^+ levels. Rehydration in water-deprived sheep is equally challenging since they can drink a large volume of water in one bout and therefore risking haemolysis. However, adapted animals respond by producing large volumes of hypotonic saliva (Dahlborn and Holtenius 1990; Silanikove 1994) that channels the excess water in the blood back to the rumen. At the same time it is important that the animal minimizes the loss of this water, since the next watering may be days away; therefore kidney water retention is maintained immediately after rehydration. Finally, in order to keep body fluids at the correct tonicity, appetite is activated to ensure that Na^+ and energy requirements are met to restore normal transport of water and electrolytes across different body compartments.

c. Fat mobilization

As previously mentioned, along with restricted water intake comes a reduction in feed consumption, leading to undernutrition. In order to compensate for the energy shortfall, sheep mobilise body reserves. 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, the 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). Results of different experiments describing the effect of intermittent watering supply on changes in fat mobilization parameters in Awassi ewes are summarized in Table1. These findings show the significant increase in cholesterol and FFA while glucose levels remained practically the same between water-restricted and control groups.

Interestingly, the variations in energy intake following water restriction do not appear to be consistently mirrored by changes in glucose levels. Most reports indicated no significant variation in glucose levels in water-restricted sheep (Igbokwe 1993; Jaber et al. 2004; Casamassima 2008; Ghanem et al. 2008). Moreover, Ahmed and Abdelatif (1994) observed a direct relationship between plasma glucose and dry matter intake in feed- and water-restricted sheep. In ruminants, diet derived volatile fatty acids are the main source of energy, however, glucose is needed for key processes in the body; hence the importance of maintaining blood glucose at a constant level (McDowell, 1983).

Additionally, insulin and leptin concentrations, key hormones in energy metabolism, tended to decrease in water-restricted Awassi ewes (Jaber et al. 2011). Low insulin levels are

thought to facilitate lipolysis (Vernon 1992) needed to compensate the dietary energy shortfall. Leptin levels are usually related to animal fatness; indeed, fat-tail adipocyte diameter is strongly correlated to leptin in water-restricted Awassi sheep (Jaber et al. 2011). According to Chilliard et al. (2000; 2005), the decrease in leptin activates a mechanism that will eventually control lipolysis to prevent FFA from reaching toxic levels; at the same time, this will ensure the preservation of fat stores for longer survival under conditions of fluctuating feed availability.

d. Thermoregulation

Thermoregulation under water restriction is of particular importance since in sheep, evaporation is the major route of heat dissipation, at a time when the animal is challenged to maximize water preservation. It is estimated that 60% of heat is lost by respiratory evaporation and 40% through cutaneous evaporation (Brockway et al. 1965; Jenkinson 1972). The thermoregulatory aptitude of sheep to react to different environmental conditions varies according to the breed and its capacity to tolerate heat or cold (Degen and Shkolnik 1978; Srikandakumar et al. 2003). Thermoregulation traits include respiration rate, rectal (core) temperature, thyroid activity and water and feed consumption (Bhattacharya and Hussain 1974), which will be discussed in the following sections.

Evaporative cooling.

Sheep in semi-arid regions need to adopt special physiological functions to sustain thermal equilibrium (Maurya et al. 2004). Under neutral environmental temperature (12°C), sheep lose about 20% of their total body heat through respiratory moisture; this rate increases to about 60% at an ambient temperature of 35°C (Thompson, 1985) which sometimes leads to respiratory alkalosis due to increased respiratory rate (Cain et al. 2006). Hales (1973) observed that sheep could maintain normal respiratory and cardiovascular functions when subjected to mild heat stress, while severe hyperthermia greatly affected the respiratory function although cardiovascular activity remained mildly altered.

When dehydrated, arid adapted sheep (and goats) tend to reduce their thermoregulatory evaporative cooling mechanisms (panting and sweating) in order to maintain their body water and prevent further dehydration (Baker 1989; McKinley et al. 2009). McKinley et al. (2009) reported that water-deprived sheep have a slow panting rate that increases two-fold after rehydration. Different breeds demonstrate different panting and sweating rates reflecting different adaptive potential to tolerate heat stress. Alamer and Al-hozab (2004) observed that the Awassi and Najdi sheep could tolerate water deprivation with the Awassi demonstrating a better capacity at water conservation under heat stress, through a lower sweating rate, than Najdi sheep. In a comparative study, Rai et al. (1979) found that breeds with denser fleece such as the Rambouillet, were less effective in heat dissipation through cutaneous evaporative cooling and had to rely more on respiratory cooling; furthermore, in this breed sweating started at lower environmental temperatures than in adapted breeds such as the Chokla, thus leading to higher water losses. Unlike the camel (Scmidt-Neilsen et al., 1956), dehydrated sheep and goats shift to preferential heat dissipation through the respiratory path rather than by sweating (Hales and Brown 1974; Baker 1989; Robertshaw 2006). It was suggested that this may be a way of obtaining evaporative cooling of the brain area while minimizing total water losses in dehydrated animals (Robertshaw and Dmi'el, 1983). In fact, Fuller et al. (2007) concluded that dehydration leads to selective brain cooling, which is usually followed by inhibition of evaporative heat loss thus preserving body water. Selective brain cooling is probably achieved by transferring heat from arterial blood in the carotid to the venous blood cooled by respiratory evaporation in the nasal passages

(Taylor and Lyman 1972; Cain et al. 2006; Fuller et al. 2007). Brain cooling maybe also responsible for the observed temporary hyperthermia that is often reported in dehydrated sheep, activated by the hyperosmolality observed in dehydrated animals (Fuller et al., 2007). This could allow for temporary heat storage at peak day temperatures, followed by passive body cooling at night when ambient temperatures drop (Alamer and Al-hozab 2004). This adaptive feature, allows the maintenance of homeothermy while minimizing water loss (Silanikove 1992) by increasing the core temperature threshold and delaying the time at which evaporative cooling mechanisms are activated (Cain et al. 2006).

As observed in desert adapted goats (Ahmed and El-Kheir, 2004), water lost through panting for evaporative cooling is compensated for by an increased capacity to conserve water through the production of small volumes of highly concentrated urine. To achieve this, sheep resort to high Na^+ and water retention in the kidneys. More and Sahni (1978) reported that dehydrated sheep maintained positive balances for cations, particularly K^+, based on the comparison of electrolytes input through feed and water and their output through faeces and urine. The highly positive K+ balance led them to conclude that it is being lost through sweating, since it cannot be stored in the body, in order to maintain osmotic pressure and acid-base balance within different body fluid compartments. Therefore, cutaneous evaporative cooling also plays a role in maintaining electrolyte and acid-base balance under arid conditions.

Rectal temperature.

Sheep are homeotherms (MacFarlane 1964; Degen 1977); they try to maintain their body temperature within a fixed range even under harsh climatic conditions. Normal rectal temperatures range between 38.3 and 39.9°C under thermo-neutral conditions; but when exposed to heat stress (33-38.5°C), the rectal temperature increases significantly and when surrounding temperatures exceed 42°C, it becomes life threatening to the sheep (Marai et al. 2007). A high variation (increase) in rectal temperature indicates lack of thermal equilibrium and increased water ingestion in order to replace evaporative losses (Mohamed and Johnson, 1985); it also involves a marked reduction in feed intake and will negatively influence reproductive function of the sheep (Eltawill and Narendran 1990).

Reports on the effect of water restriction on rectal temperature in sheep are not consistent. While some (Ghanem et al. 2005; 2008; Sevi et al. 2009) reported that dehydration was found to cause an increase in rectal temperature in sheep, others (MacFarlane 1964; Degen 1977; Jaber et al. 2004; Hamadeh et al. 2006; Chedid 2009) found that sheep, such as the Awassi, retain thermostability even under water suppression. On the other hand, Ahmed and Abdelatif (1994) pointed out that dehydration causes a slight decrease in rectal temperature, while reduced feed intake considerably reduces it, especially when combined with a reduction in water intake. When studying the effect of water deprivation on unshorn sheep, McKinley et al. (2009) found that the core temperature was maintained during the first day (24h) of dehydration, but a significant increase was noted on the second day without water.

Table 2 shows that Awassi sheep can maintain their core temperature under different water restriction regimens. However, when subjected to water limitation combined with high ambient temperatures, this breed displayed a significant increase in its rectal temperature supporting the hyperthermia hypothesis mentioned above.

Thyroid activity.

Thyroid hormones, T3 and T4, play a major role in thermoregulation and metabolic homeostasis of energy and proteins, as well as in the metabolic response of animals to

different nutritional and environmental conditions (Huszenicza et al. 2002; Latimer et al. 2003; Thrall 2004). Levels of T3 and T4 were found to decrease in water limited healthy Marwari, non-lactating Awassi ewes and Butana desert rams (Abdelatif and Ahmed 1994; Kataria and Kataria 2006 Jaber et al. 2011); this effect was reversed upon rehydration in Marwari sheep (Kataria and Kataria 2006). The reduction in thyroid hormone activity under dehydration is associated with the animal's attempt to minimize water losses by reducing general metabolism (Nazifi et al. 2003; Kataria and Kataria 2007). It also reflects the reduction in feed intake since T3 and T4 were reported to decrease in feed restricted pregnant Whiteface Western ewes (Ward et al. 2008), while T4 increased following the afternoon meal in water-restricted Butana rams (Abdelatif and Ahmed 1994). The decrease in thyroid activity is further reinforced under heat stress (Hamadeh et al. 1997; Khalifa et al. 2002). In arid adapted animals, changes in thyroid activity may be affected more by the physiological activity (pregnancy or lactation) of the animals than by seasonal changes in temperature as has been noted in Awassi and Finn x Texel x Awassi sheep (Hamadeh et al. 1997). Furthermore, the authors noted the importance of the production system under which the animals are raised, whereby extensively raised animals of both breeds were shown to be less sensitive to ambient heat than their intensively raised counterparts due to better adaptation to the environmental conditions. Bernabucci et al. (2010) further described the importance of metabolic and hormonal acclimation to heat stress in order to limit its negative consequences.

Many aspects of thermoregulation in situations of dehydration remain to be studied. In a recent review, Alamer (2011) noted that prolactin is a hormone that is found to be increased in blood in response to heat stress. In this review, the author summarizes the role of prolactin in thermoregulation including its possible effects on fluid balance and distribution in hydrated and dehydrated animals, modulation of sweat gland activity, regulation of seasonal pelage growth, etc. Research on this topic will be valuable in understanding how different sheep cope with the combined effects of heat and dehydration.

e. Immunosuppression

In general, immune response and stress are negatively correlated. Exposure to stressful environmental conditions can modify a host's resistance by affecting its immune system, mainly through the mediation of immunosuppressant hormones such as glucocorticoids (Ewing et al. 1999). Although it is obvious that, water stress, as any other form of stress would cause perturbations in the general health status and welfare of the animal, research dealing with the effect of dehydration and immunity is very limited. This might be due to the fact that sheep native to arid regions, where occasional water shortages are most common, are known to be well-adapted to dehydration, thus directing scientists' attention to other research topics.

The effect of heat stress on sheep immunity, milk production as well as udder health was reviewed by Sevi and Caroprese (2012): heat stress reduced cellular immunity by decreasing cellular proliferation. The mechanism of action is unclear and may involve Heat Shock Proteins, altered cytokines profiles as wells as changing cortisol levels. Sevi et al. (2009) reported a severe drop in immunity in ewes exposed to high ambient temperatures; this immuno-reduction was accompanied by a significant mineral imbalance and an increase in milk neutrophil levels, and higher counts of *Staphylococci*, coliforms and *Pseudomonas*, thus showing how heat stress can negatively influence both an animal's health and milk quality.

In 2004, Barbour et al. studied the effect of water restriction on the humoral antibody response of Awassi ewes to *Salmonella* Enteritidis; they found that immunity in the dehydrated animals was significantly lower than in Awassi receiving water 24h a day. Moreover, the study showed that the humoral antibody response to *Salmonella* Enteritidis

fimbriae and other polypeptides decreased by 38.5% in the water restricted sheep as compared to their daily watered counterparts. Marked immunosuppression was also observed in water deprived lactating Awassi ewes which showed a significant drop in their immunity to polypeptides >21KDa as compared to non-lactating ewes (Barbour et al. 2005).

Differential leukocyte counts are sometimes used as a combined indicator of the immune status and stress level of animals. Kannan et al. (2007) reported that a leukogram is a good indicator of prolonged stress in transported goats. Glucocorticoid levels have been linked to leukocyte profiles of the immune system where high ratios of heterophils or neutrophils to lymphocytes in blood samples indicate high concentrations of glucocorticoids and therefore high levels of stress (Dhabhar et al. 1995; Kannan et al. 2007; Davis et al. 2008). However, it was also observed that glucocorticoids may not always suppress leukocytes but rather induce a re-distribution of the immune cells to certain organs such as the skin, thought to be the first line of defense against pathogen entry (Dhabhar, 2006; Martin, 2009).

In a review about the mechanisms of stress-induced immunity modulation, Moynihan (2003) summarized the possible routes for immune suppression and even stimulation following stress. The author describes four main compounds that can modulate stress: corticotropin-releasing hormone, endogenous opioids, catecholamines and glucocorticoids, with glucocorticoids being the most widely studied. He further notes the complex relationship between stress and immunity highlighting differences in the response based on the nature, duration and severity of the stressor on one hand and on the immune function or organ that is being assessed on the other. To these factors, Salak-Johnson and McGlone (2006) add the effects of social status and genetics, which also play an important role in determining how an animal's immune system responds to a certain stressor.

The specific effects of water stress, particularly in sheep, are poorly understood. This line of research would be of great interest to determine the consequences of short-term and long-term water shortages on sheep defense systems during different critical production and reproductive periods.

IV. CHANGES IN RELATION TO PHYSIOLOGICAL STATUS

Pregnant and lactating animals have 40-50% higher water turnover rates than non-lactating animals (Cain et al. 2005) with a greater need for feed, water and electrolytes in order to meet the requirements of the foetus and the mammary gland (Olsson 2005).

a. Pregnancy

The reported changes in pregnant water-restricted sheep are usually similar to those observed in non-pregnant animals, including haemoconcentration (More and Sahni 1980) which denotes a reduction in the extracellular fluid space. However, in contrast to non-pregnant sheep, pregnancy seems to reduce the urine concentrating capacity of animals in response to dehydration, probably due to the high concentrations of circulating prostaglandins which cause a reduction in sensitivity to arginine-vasopressin (Benlamlih et al. 1985, Rodriguez et al. 1996).

The effect of water restriction during pregnancy on lamb weight and survival is an important aspect to consider since it affects productivity and sustainability of the farm operation. The desert adapted Magra and Marwari sheep could sustain a twice weekly watering regimen imposed for an extended period with no effects on lamb birth weight (Mittal and Gosh 1986). Furthermore, pregnant Chokla ewes watered once every 4 days gave birth to lambs of lower weight compared to ewes that were watered daily or once every three days;

however, after birth at 12 weeks of age, lamb weights were similar between the different groups (More and Sahni 1980). Further studies to assess the long term consequences of water restriction during gestation on the growth and later performance of offspring are necessary.

b. Lactation

Water restriction in lactating Awassi (Hamadeh et al. 2006) and Comisana ewes (Casamassima et al. 2008) led to a greater weight loss than in non-lactating animals since they have higher metabolic requirements necessitating greater mobilization of fat deposits (Sevi et al. 2002). Lactating sheep have a relatively higher blood volume due to the high water demand by the mammary gland (El-Nouty et al. 1991). Consequently, water restriction led to lower haemoglobin levels in lactating Awassi sheep when compared to their non-lactating counterparts (Hamadeh et al. 2006). Reports indicate that blood chemistry indicators such as glucose, cholesterol, protein, albumin and globulin, show little variation between lactating and non-lactating sheep beyond the first month of lactation (Hamadeh et al., 2006). When subjected to water restriction, the changes in blood indicators of lactating sheep were similar to those of non-lactating animals including significant increases in serum concentrations of triglycerides, albumin, total proteins and cholesterol, urea and creatinine (Rodriguez et al. 1996; Hamadeh et al. 2006; Casamassima et al. 2008). Lactation did not seem to modify the response to water restriction. Moreover, differences in pH and electrolyte levels were observed between water-restricted lactating and non-lactating Awassi ewes. An increase in pH was noted in water-restricted lactating Awassi sheep; it was related to a drop in Ca^{++} and K^{+} that were needed for milk production and a corresponding increase in Na^{+} and Cl^{-} needed for nutrient transport (Figure 1) (Hamadeh et al. 2006). Dehydration usually causes a decrease in milk production due to reduced blood flow to the mammary gland (Hossaini-Hilali et al. 1994; Dahlborn et al. 1997; Mengistu et al. 2007). In contrast, milk osmolality, density and lactose content appear to increase under water restriction (Dahlborn 1987; Hossaini-Hilali et al. 1994). Lactose is the major osmotic component of milk and its concentration in strictly controlled to keep milk isotonic with the blood (Dahlborn 1987).

V. ECONOMIC IMPACT OF HEAT STRESS ON SHEEP PRODUCTION

Loss in production due to water stress is similar to that observed under heat stress, especially since the two occur together under arid and semi-arid environments; heat stress leads to a decreases in milk production, reproduction and feed intake, causes infertility and increases the risks of lameness and culling (Alhidary et al., 2012; De Vries, 2012; Lucy, 2012). Heat stress in cattle causes loss in appetite and weight gain (Sackett et al., 2006), it negatively affects the estrus cycle and hence reduces reproduction (Monty and Wolf, 1974; Hansen et al., 2001) leading ultimately to economic losses.

Most of the found literature investigates the economic impact of heat stress on dairy and beef cattle production. According to Sackett et al. (2006) economic losses in feedlot beef cattle in Australia is estimated around 16.5 million AUD when 30% of the cattle is subjected to heat stress during summer, whereas losses in dairy and beef cattle in the United states is estimated to be 897-1500 million and 370 million dollars respectively (St-Pierre et al., 2003). While St-Pierre et al. (2003) attribute these losses to welfare expenses such as infrastructure and shading, others (Sackett et al., 2006; Lucy, 2012) suggest that heat stress problems can be solved by investing in heat reduction systems, modifying animals' genetics and intensifying the reproductive management in heat stress periods.

A decade ago, although heat was acknowledged as a source of stress in sheep, the economic impact of this stress was not well studied, perhaps because sheep are mainly raised

in extensive systems rather than in feedlots (that exhibit high rates of respiratory diseases under hot and humid climatic conditions) or because sheep are bred in a variety of environmental conditions and they are considered as rustic animals that can withstand high ambient temperatures (Silanikove, 2000). Literature on the economic impact of heat stress on sheep production is still scarce; nonetheless, recent works reported that thermal stress can lead to severe economic losses in sheep husbandry (Pluske et al., 2010; Wojtas et al., 2013). Kandemir et al., (2012) reported that lamb production is seriously affected when pregnant ewes are exposed to heat stress during mid and late gestation: the total of embryo cell number and the placentome size are significantly decreased; lamb birth weight, growth rate and the total body solids and daily solids gain are also reduced.

Economic losses caused by high temperatures could be reduced by protecting ewes from heat waves during the breeding season (Kandemir et al., 2012), and by the addition of shelters and the implementation of fleece length strategies in commercial feeding lots (Pluske et al., 2010). Moreover, the integration of a preventive health program, feed optimization and basic selection of the animals has proved efficacy in improving the economic sustainability of sheep production in semi-arid regions (Tami et al., 2005). The economic impact of water and/or heat stress on sheep production in arid and semi-arid regions warrants further research especially since it reflects on the livelihoods of the majority of the rural population in these areas.

VI. VITAMIN C: STRESS ALLEVIATOR

Vitamin C administration is not a common practice in adult livestock nutrition (McDowell 2000) since it is normally biosynthesized in ruminants (NRC 2007). It is an important antioxidant that helps in the scavenging of free radicals (Jariwalla and Harakech 1996). It also plays a role in modulating the immune response by enhancing neutrophil function and in minimizing free radical damage (Politis et al. 1995) and by improving antibody response to antigens (Cummins and Brunner 1990).

Administration of vitamin C to stressed animals such as weaned pigs (de Rodas et al. 1998), heat stressed Japanese quails (Avci et al. 2005), aluminum intoxicated rabbits (Yousef 2004) and heat stressed broilers subjected to feed restriction (McKee et al. 1997) yielded positive results such as improving performance under stressful conditions, enhancing feed intake, protecting from toxicity and improving body energy storage. Similarly, stress alleviation was reported in vitamin C supplemented goats in hot and dry conditions (Minka and Ayo 2007).

Several studies were performed to assess the effect of vitamin C supplementation on water stressed Awassi sheep: supplementation tended to decrease weight loss (Ghanem et al. 2008; Karnib 2009) and was linked to improved feed intake (Hamadeh et al. 2009). Similar results were obtained in goats during stressful transportation conditions accompanied by dehydration (Kannan et al. 2000; Minka and Ayo 2007). The effect of vitamin C on weight reduction after water restriction is shown in Table 3. It is clearly seen that vitamin C administration reduces weight loss regardless of the dose given and the water limitation regimen. The reduction in weight loss could have economic significance in large farming operations, warranting further studies.

When assessing haematological effects, PCV levels were reported to decrease in vitamin C supplemented dehydrated Awassi sheep (Ghanem et al. 2008) and transported Red Sokoto goats (Minka and Ayo 2007). In contrast, conflicting observations were reported regarding the haemoglobin concentrations: in transport-stressed goats vitamin C

administration decreased haemoglobin (Minka and Ayo 2007), while in water-stressed Awassi sheep there was no effect (Ghanem et al. 2008).

The effects of vitamin C administration on serum protein, globulin and albumin in water-stressed Awassi sheep are not consistent (Ghanem et al. 2008; Hamadeh et al. 2006; 2009). It is worth noting that the water restriction regimen and the amount of vitamin C used in these experiments were not identical. This may explain the variable results. Additionally, it was observed that daily supplementation of water-restricted Awassi sheep with 5g of vitamin C led to an increase in serum creatinine and urea, while lower levels had no effect (Hamadeh et al. 2009; Karnib 2009)

Vitamin C has an indirect impact on fat mobilization through its role in norepinephrine and carnitine formation which helps fat mobilization and fatty acid transport, respectively (Ghanem et al. 2005). However, vitamin C administration to water-restricted Awassi sheep did not lead to significant changes in adipocyte diameter and other fat mobilization indicators (Jaber et al. 2011), while cholesterol levels tended to be higher in other experiments (Ghanem et al. 2005; 2008; Karnib 2009).

Blood osmolality and electrolytes are greatly affected by water restriction. However, their response to Vitamin C supplementation in water-stressed Awassi ewes is not consistent (Hanna 2006; Ghanem et al. 2008; Hamadeh et al. 2009; Karnib 2009). Cortisol levels, used as indicators of water stress, did not show any differences between vitamin C supplemented and non-supplemented animals (Parrot et al. 1996; Parker et al. 2003; Ghanem et al. 2008), although others demonstrated that vitamin C played a role in decreasing cortisol secretion (Civen et al. 1980; Sivakumar et al. 2010).

In conclusion, more research is needed to fully explore the role of vitamin C in stress alleviation and determine the correct level to be supplied to sheep in various stress situations, particularly since supplemented animals lost less weight.

VII. CONCLUSION

This review highlights the adaptive mechanisms observed during dehydration of sheep reared mainly in arid and semi-arid regions. Regardless of their physiological statuses, sheep subjected to water stress decreased their feed intake which consequently resulted in a reduction in weight caused by water and body mass loss. Changes are also observed in blood parameters, thermoregulatory mechanisms and immunity.

Adapted breeds under water restriction during hot and dry seasons, mobilize their fat stores in order to overcome dietary deficiency. This is clearly seen in the high levels of FFA and cholesterol in blood. Moreover, water conservation is mirrored by water retention by the kidneys as reflected by small volumes of urine and high blood Na^+, urea and osmolality. Non-lactating ewes of highly adapted breeds, are able to survive severe water shortages on short intermittent watering regimens without displaying serious physiological damage, thus enabling pastoralists to roam during the hot summer months with their flock when water resources are scarce. However, young, lactating and gestating animals are affected by dehydration which may reduce milk production (during peak production), reproduction, lamb weight and resistance to disease. The Awassi sheep is presented as an example of adapted indigenous breeds.

This review also highlights the promising use of vitamin C, an antioxidant nutrient supplement, in attenuating the negative effect of water stress.

Determining the adaptability of sheep to water restriction is crucial in order to take the proper measures to sustain the extensive production systems in arid regions where water scarcity is becoming more common. Future research is needed to study the overlapping

effects of water stress, feed limitation and high ambient temperatures. Testing new management approaches and drugs for stress alleviation is also important while giving special attention to animal welfare and the practical use of these procedures in the field.

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Table1: Effect of different water restriction regimens on fat mobilization in non-lactating Awassi ewes.

Water regimen	Age of animals	Fat mobilization parameters			Reference
		FFA	Cholesterol	Glucose	
2-day restriction	Mature	-	No change	No change	Jaber et al., 2004
3-day restriction	Mature	-	Increase*	No change	Hamadeh et al., 2006
	1-2 years	-	Increase*	Increase*	Karnib, 2009
	Mature	-	Increase*	-	Karnib, 2009[z]
	Mature	Increase*	Increase*	-	Chedid, 2009[z]
	2 years	Increase*	No change	-	Jaber et al., 2011
	Mature	No change	No change	-	Jaber et al., 2011
4-day restriction	Mature	-	Increase*	No change	Jaber et al., 2004
1L on day 4 and 3L on day 8 of 12-day water restriction	Mature	Increase*	Increase*	No change	Ghanem et al., 2008

*Indicates significant differences at $P<0.05$

[z] Comparisons were made between the initial values of day 0 before the initiation of the experiment (Control) and the means of values obtained under water restriction (water restricted). For all other experiments, the comparison was between separate water restricted and control groups that were included in the experiment.

Table 2: Effect of water restriction on rectal temperature of Awassi sheep.

Water restriction regime	Average rectal temp. (°C)		Age	Ambient temp. (°C)	Reference
	Water restricted	Control			
2-day-restriction	39.4 ±0.06	39.4 ±0.06	mature	15-32	Jaber et al., 2004
3-day-restriction	39.4 ±0.14	39.2 ±0.14	mature	27-30	Chedid, 2009 [z]
	38.6 ±0.15	38.6 ±0.15	mature	23-28	Karnib, 2009 [z]
	39.5* ±0.05	39.4 ±0.05	mature	27-31	Hamadeh et al., 2006
4-day-restriction	39.5 ±0.06	39.4 ±0.06	mature	15-32	Jaber et al., 2004
1L on day 4 and 3L on day 8 of 12-day water restriction	40.0* ±0.25	39.4 ±0.10	mature	25-35	Ghanem, 2005
1L on day 4 of 7-day water restriction	39.8* ±0.10	39.5 ±0.10	mature	23-33	Chedid et al. (unpublished)

*Means within a same experiment with ([z]) are significantly different $P<0.05$

[z] Comparisons were made between the initial values of day 0 before the initiation of the experiment (Control) and the means of values obtained under water restriction (water restricted). For all other experiments, the comparison was between separate water restricted and control groups that were included in the experiment.

Table3: Effect of different regimes of water restriction (WR) and vitamin C (VitC) administration on % weight change in dry Awassi ewes.

Water regimen	Average ambient temperature	Age of animals	Vit C administration	Control	WR	WR + Vit C	Reference
3-day restriction	28.5 °C	2 years	3g Vit C/ewe/day	$+3.1^{a}$ ±9.85	-26.2^{b} ±3.77	-22.5^{b} ±1.85	Jaber et al., 2011
3-day restriction	28.5 °C	2 years	5g Vit C/ewe/day	$+3.1^{a}$ ±9.85	-26.2^{b} ±3.77	-23.0^{b} ±1.00	Jaber et al., 2011
3-day restriction	17.5 °C	3 years	3g Vit C/ewe/day	$+6.2^{a}$ ±3.16	-10.4^{b} ±1.6	-7.7^{b} ±0.74	Jaber et al., 2011
3-day restriction	17.5 °C	3 years	10g Vit C/ewe at the beginning and in the middle of the experiment	$+6.2^{a}$ ±3.16	-10.4^{b} ±1.6	-7.8^{b} ±3.15	Jaber et al., 2011
3-day restriction	25 °C	2-3 years	3g Vit C/ewe/day	-	-16.8^{a} ±1.14	-12.7^{b} ±1.27	Karnib, 2009
1L on day 4 and 3L on day 8 of 12-day water restriction	30°C	2-3 years	2.5g Vit C/ewe/day	$+0.7^{a}$ ±2.00	-13.7^{b} ±2.00	-6.0^{b} ±2.00	Ghanem et al., 2005
1L on day 4 and 3L on day 8 of 12-day water restriction	30°C	2-3 years	2.5g Vit C/ewe/day	$+1.2^{a}$	-22.1^{c}	-6.9^{b}	Ghanem et al., 2008

Control animals were watered daily.
All animals were weighed at day zero before the initiation of the experiment and at the end of the experiment
[a-c] Different subscript letters in the same row indicate significant differences ($P<0.05$)

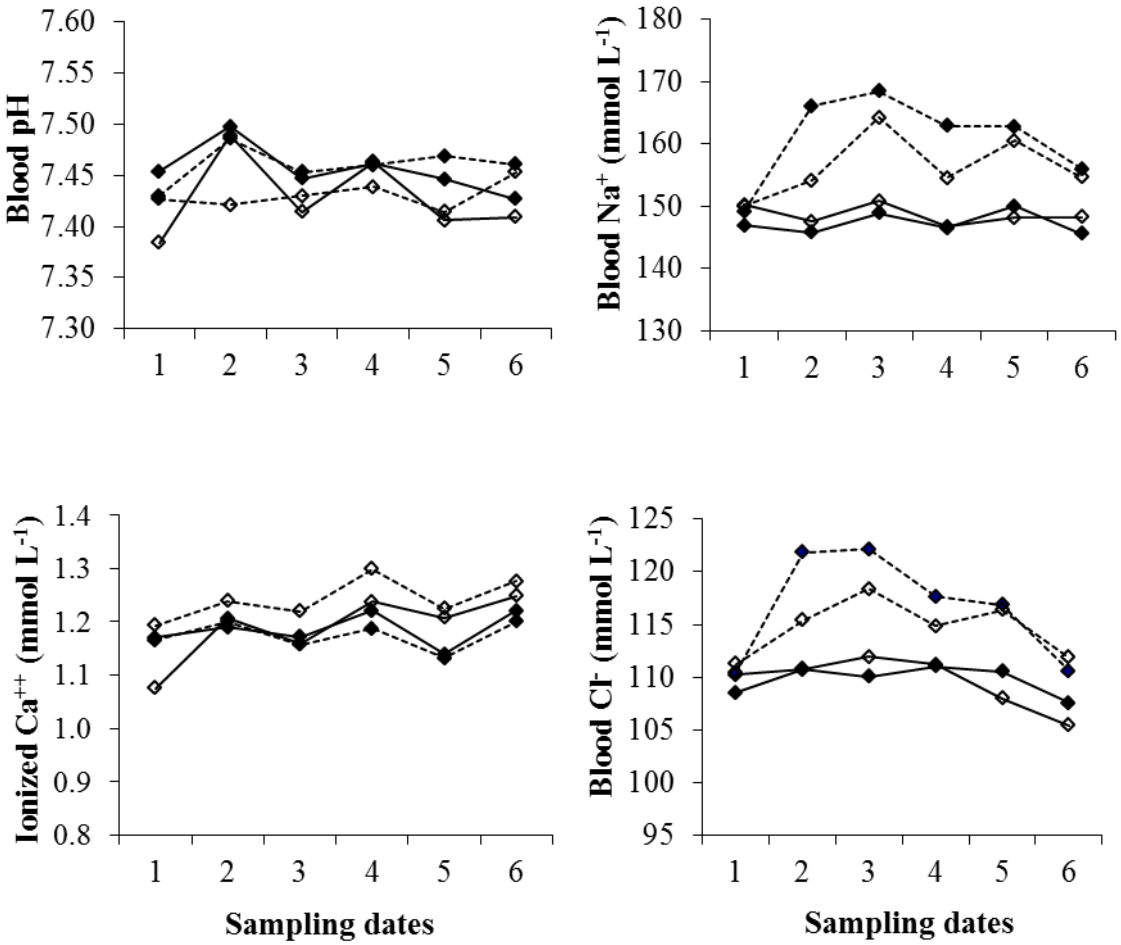


Figure 1: Changes in electrolytes of non-lactating (◊) and lactating (♦) Awassi ewes watered daily (-) or subjected to a 3-day-restriction regimen (---) (Hamadeh et al. 2006).

1.2. Revue quantitative de la littérature : Méta-Analyse

La Méta-analyse a visé à revoir les observations de la revue de la littérature d'un point de vue quantitatif. Etant donné le grand nombre d'articles inclus et de données enregistrées, ce travail présente une analyse préliminaire des résultats, sachant qu'une étude plus approfondie fera l'objet d'un projet futur pour faire ressortir les principales relations entre les paramètres consécutives à une restriction en eau chez les petits ruminants.

Le tableau ci-dessous résume les résultats de cette étape.

Tableau 2. Productions scientifiques considérées pour la méta-analyse

Type de productions scientifiques	**Nombre**
Productions scientifiques obtenues par les moteurs de recherche	136
Productions non retenues :	
Articles juges hors-sujet	11
Articles non trouvés dans les bibliothèques accessibles	13
Articles en langue non maîtrisée par les chercheurs	3
Articles de type revue, non retenus pour la Méta-analyse	10
Articles faisant doublons (données regroupées ensemble dans la méta-analyse)	4
Articles avec faible nombre d'animaux (1-2) et donc non retenus	5
Productions scientifiques retenues pour la méta-analyse	90

Le fichier de données est composé de 165 colonnes et 788 lignes, a partir de ces 90 productions retenues pour la méta-analyse. Chaque ligne représente un groupe expérimental tel que décrit dans les articles et les colonnes représentent toutes les données recueillies sur le groupe en tant que conditions expérimentales, traitements, relevés physiologiques, sanguins, hormonaux, de production, reproduction, etc.

Les analyses ci-dessous prennent majoritairement en considération la restriction en eau en tant qu'un seul traitement. Il faut cependant noter que les modalités de restriction étaient assez variées. En premier abord, on peut noter deux grands sous-groupes de restriction : le premier sous-groupe où le traitement consistait en une restriction totale d'eau pendant une certaine période (variant de quelques heures à plusieurs jours d'affilée) (N articles = 64) ; le deuxième sous-groupe où la restriction consistait à offrir aux animaux une proportion de la quantité d'eau normalement bue (N articles = 26). La distinction entre ces deux familles est considérée pour quelques paramètres sanguins clés dans le « paragraphe 1.2.g » ci-dessous.

A part cette importante source de variation au niveau de la restriction en eau, une autre source de variation est liée à l'espèce et à la race. Les données portent en effet sur des chèvres (N article = 43) et des moutons (N articles = 50) qui diffèrent au niveau de l'adaptation à la restriction en eau, sachant que cinq articlesconcernaient les deux espèces simultanément et sont donc comptés deux fois. Une comparaison entre les deux espèces a été effectuée par rapport au changement de poids sous restriction en eau (paragraphe 1.2.b ci-dessous) pour

montrer le potentiel du fichier à faciliter cette analyse comparative entre les chèvres et les moutons, une approche qui n'a jamais été menée de façon quantitative dans la littérature..

D'autres sources de variation sont à noter : les conditions climatiques, le stade physiologique et l'âge, le régime alimentaire, etc.

Bien que ces sources de variation soient identifiées, certaines relations générales étaient quand même apparentes et sont présentées plus loin. Un autre aspect important de cette analyse était de pouvoir identifier les paramètres les moins étudiés et qui pourraient être d'intérêt pour des recherches futures.

L'analyse statistique et la production des graphiques sont effectuées sur Minitab 16 (Minitab Inc., EU). Comme première approche globale à l'ensemble des données, toutes les analyses prennent en considération l'effet de l'article pour réduire l'effet de ce facteur sur les résultats. Par conséquent, les valeurs présentées dans les graphiques sont celles qui ont été ajustées après analyse selon un Modèle Linéaire Généralisé. Lorsqu'elles sont présentées, les moyennes entre les différents groupes (déshydratés, contrôles et réhydratés) ont été comparées par une analyse de variance simple (ANOVA).

N.B. Dans la légende des graphiques ci-dessous « Dehy » fait référence aux groupes d'animaux en fonction de l'abreuvement : « -1 » = Animaux restreints/privés d'eau ; « 0 » = abreuvement normal, contrôle ; « 1 » = réhydratation

a. Effets de la restriction en eau sur la MSI

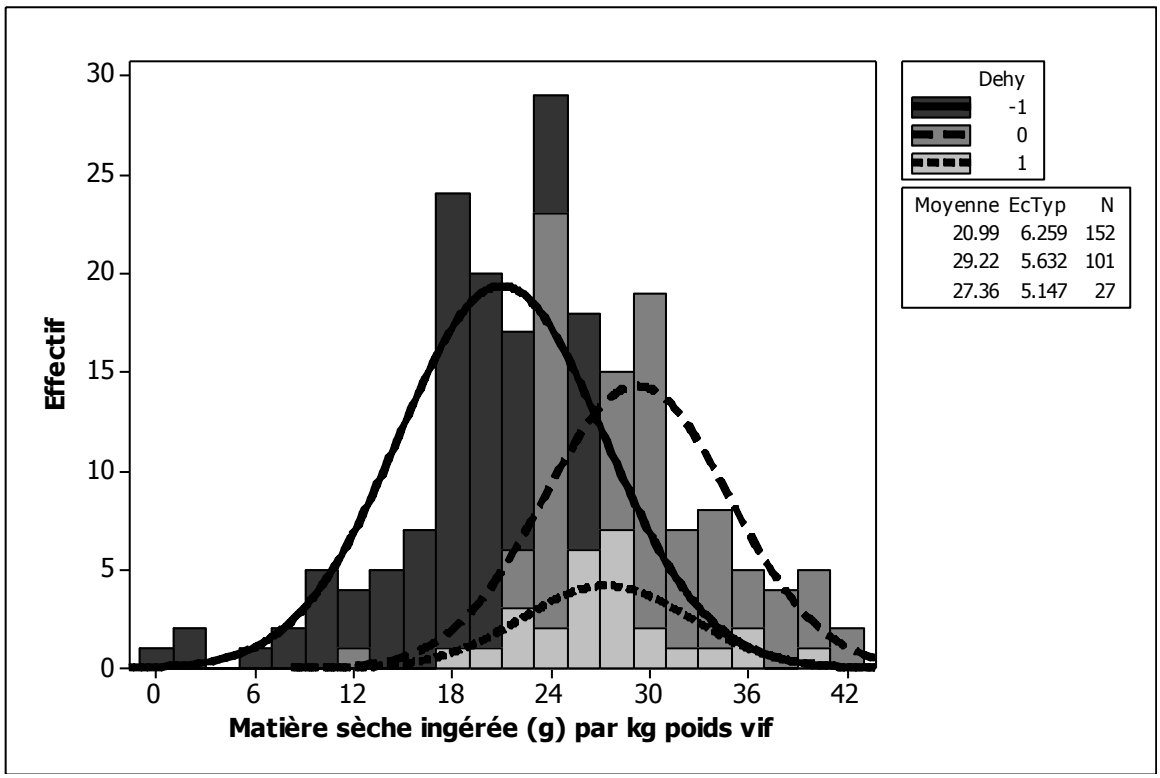


Figure 2. Histogramme de la quantité de matière sèche ingérée chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et les réhydratés (Dehy = 1)

La réduction de MSI lors d'une restriction en eau est une des premières réponses rapportées dans la littérature (Morand-Fehr, 2005 ; Hamadeh et al., 2006). La figure 2 confirme cette observation sur un assez grand nombre de groupes d'animaux restreints par rapport à d'autres

abreuvés normalement, alors que la prise alimentaire retourne vite à un niveau proche de la normale suite à la réhydratation.

En effet, la comparaison des moyennes des groupes déshydratés, contrôles et réhydratés aboutit au tableau 3 ci-dessous, montrant que l'ingestion de matière sèche par kg de poids vif est plus faible sous restriction en eau, et ceci malgrè la diversité des traitements, espèces et races.

Tableau 3. Comparaison entre les moyennes de matiere sèche ingérée (g) par kg de poids vif des groupes déshydratés, contrôles et réhydratés.

Groupe	Matière sèche ingérée (g) par Kg poids vif		
	Moyenne*	Ecart Type	N
Déshydraté	20.99[b]	6.259	152
Contrôle	29.22[a]	5.632	101
Réhydraté	27.36[a]	5.147	27

*Les moyennes suivies des lettres différentes sont significativement différentes (P<0.05)

b. <u>Effet de la restriction en eau sur le poids vif</u>

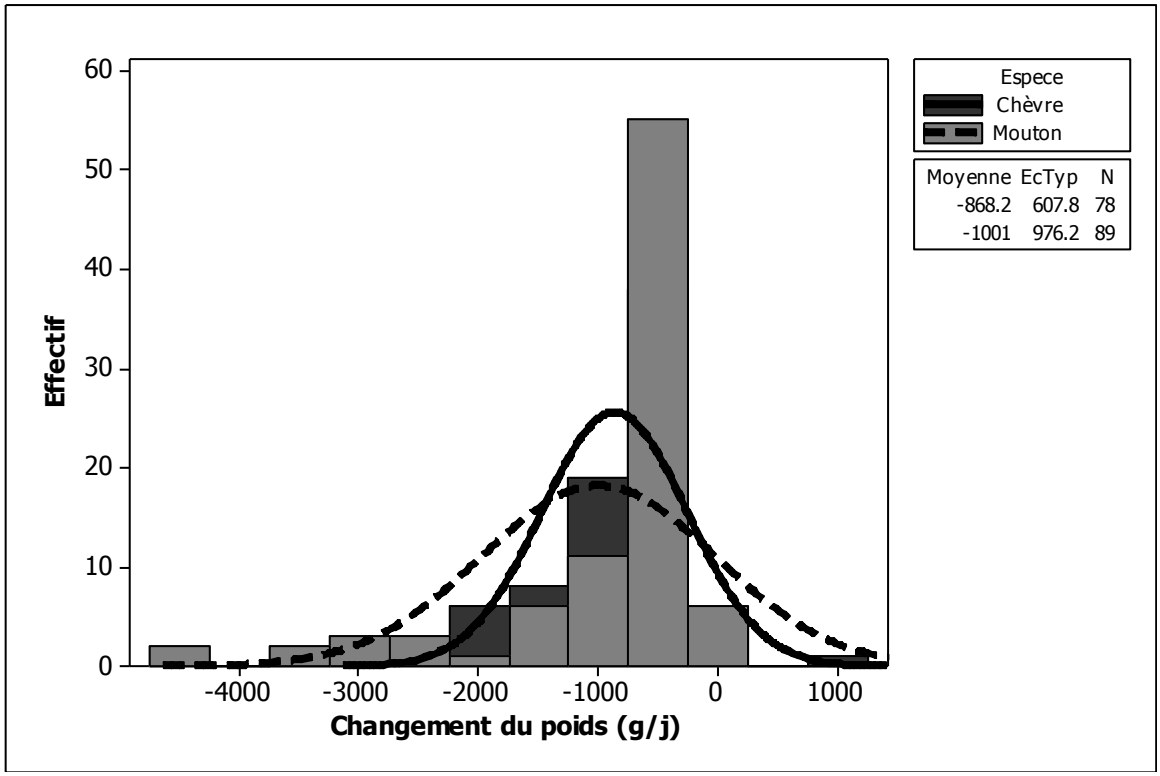


Figure 3. Histogramme du changement de poids chez les chèvres et les moutons lors d'une restriction en eau

La figure 3 montre la perte de poids moyenne recueillie des données de la littérature pour les chèvres et les moutons lors d'une restriction en eau ; Cette observation est en effet largement rapportée dans la littérature (Silanikove, 2000 ; Jaber et al., 2011). Les résultats montrent que

la perte de poids est une réponse commune aux deux espèces. La variation des réponses observée n'est pas statistiquement significative (P>0.05) ; elle est probablement due aux autres facteurs expérimentaux mentionnés ci-dessus, tels que le niveau et la durée de la restriction, la température ambiante, le stade physiologique, l'alimentation, etc.

c. Effet de la restriction en eau sur la température rectale

La thermo-stabilité des animaux est essentielle pour leur bien-être et pour préserver leurs fonctions physiologiques. La figure 4 et le tableau 4 montrent que les petits ruminants soumis à une restriction en eau ont une température rectale plus élevée que ceux normalement abreuvés. Pourtant, cette interprétation reste à confirmer en prenant en considération les autres facteurs pouvant influencer la température rectale, notamment la température ambiante.

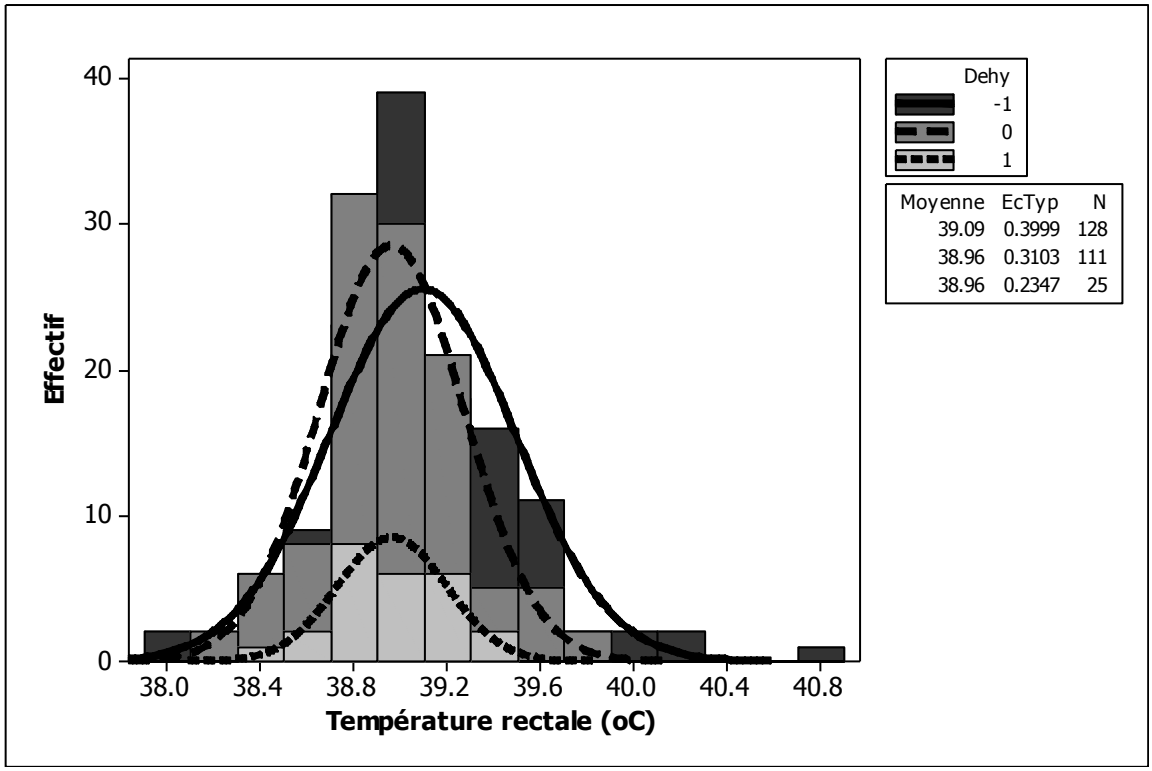


Figure 4. Histogramme de la température rectale chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et les réhydratés (Dehy = 1)

Tableau 4. Comparaison entre les moyennes de la température rectale (^{o}C) des groupes déshydratés, contrôles et réhydratés.

Groupe	Température rectale (^{o}C)		
	Moyenne*	Ecart Type	N
Déshydraté	39.09^{a}	0.3999	128
Contrôle	38.96^{b}	0.3103	111
Réhydraté	38.96^{ab}	0.2347	25

*Les moyennes suivies des lettres différentes sont significativement différentes (P<0.05)

La figure 4 semble indiquer que la température rectale des petits ruminants est en relation quadratique positive avec la température ambiante. Les détails de la régression sont les suivants :

Température rectale = 36.26 + (0.16008*TA) – (0.002116*TA^2)
(TA = Température ambiante ^oC)

N observations = 252 ; N articles = 26 ; R^2 = 0.65, Ecart type residuel. = 0.351

Fuller et al. (2007) ont observé qu'une hyperthermie temporaire chez les petits ruminants déshydratés pourrait être une adaptation pour minimiser la perte d'eau par les mécanismes de rafraichissement liés à l'évaporation. A partir de la figure 5, la température rectale semble augmenter en fonction de la température ambiante, quel que soit le niveau d'abreuvement, jusqu'au point maximal calculé de la courbe à 37.8^{o}C de température ambiante.

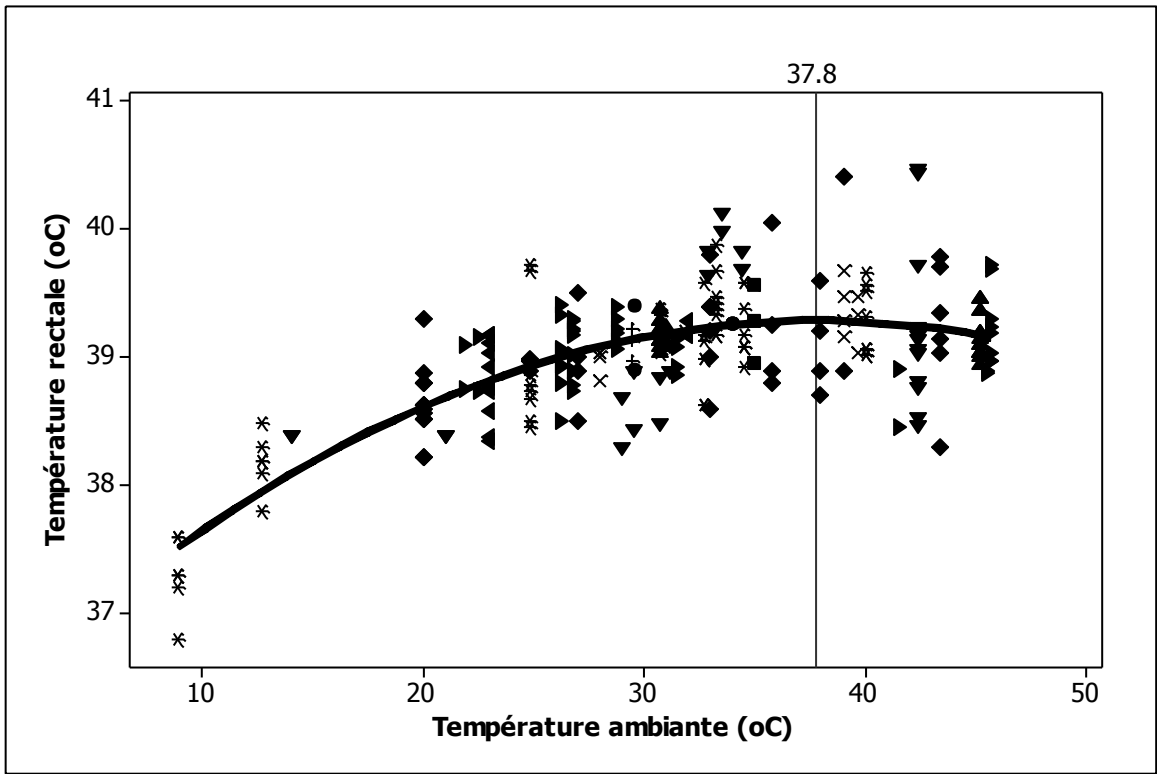


Figure 5. Nuage de points de la température rectale (^{o}C) en fonction de la température ambiante chez les petits ruminants restreints en eau, avec l'article comme facteur de goupement.

d. Effet de la restriction en eau sur les différents compartiments d'eau corporels

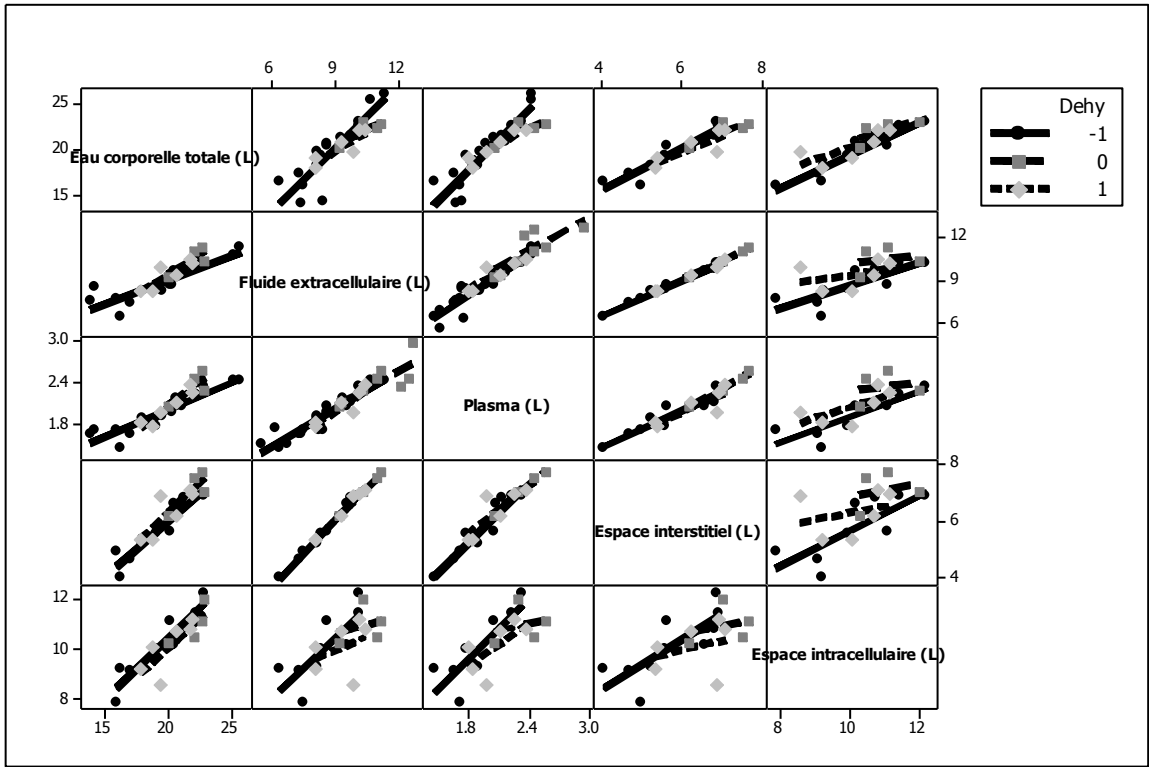


Figure 6. Graphique matriciel diagonal du volume d'eau corporelle total, volume du fluide extracellulaire, volume du plasma, volume de l'espace interstitiel, et volume de l'espace intracellulaire, exprimés en litres, chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et ceux réhydratés (Dehy=1).

La figure 6 montre que les différents compartiments d'eau semblent être intimement liés, quel que soit le niveau d'abreuvement, avec une relation positive entre les différents compartiments pris deux à deux.

Un compartiment important qui reste à explorer est celui du fluide ruminal. Les données sur ce paramètre sont rares et ne permettent pas de l'inclure dans l'analyse. Pourtant, la littérature indique que le rumen joue un rôle important dans la préservation de l'eau lors d'une restriction ainsi qu'au moment de la réhydratation, pour prévenir une hémolyse sanguine (Silanikove, 1994).

e. Effet de la restriction en eau sur la composition sanguine

La figure 7 montre que les relations générales entre les principaux paramètres souvent rapportés comme étant plus élevés lors d'une restriction en eau sont conservées. L'effet de la restriction en eau ne semble pas être assez clair, mais par contre, tous les paramètres sont corrélés positivement quel que soit le niveau d'abreuvement, à l'exception de la globuline et de l'albumine qui sont corrélés négativement. En effet, la plupart des méthodes d'analyse estiment la globuline comme la différence entre les taux protéique et l'albumine (Cork and Halliwell, 2002). Ces paramètres sont liés au changement du volume sanguin en relation avec le niveau d'abreuvement (Igbokwe, 1993), ce qui justifie la corrélation positive entre eux, deux à deux.

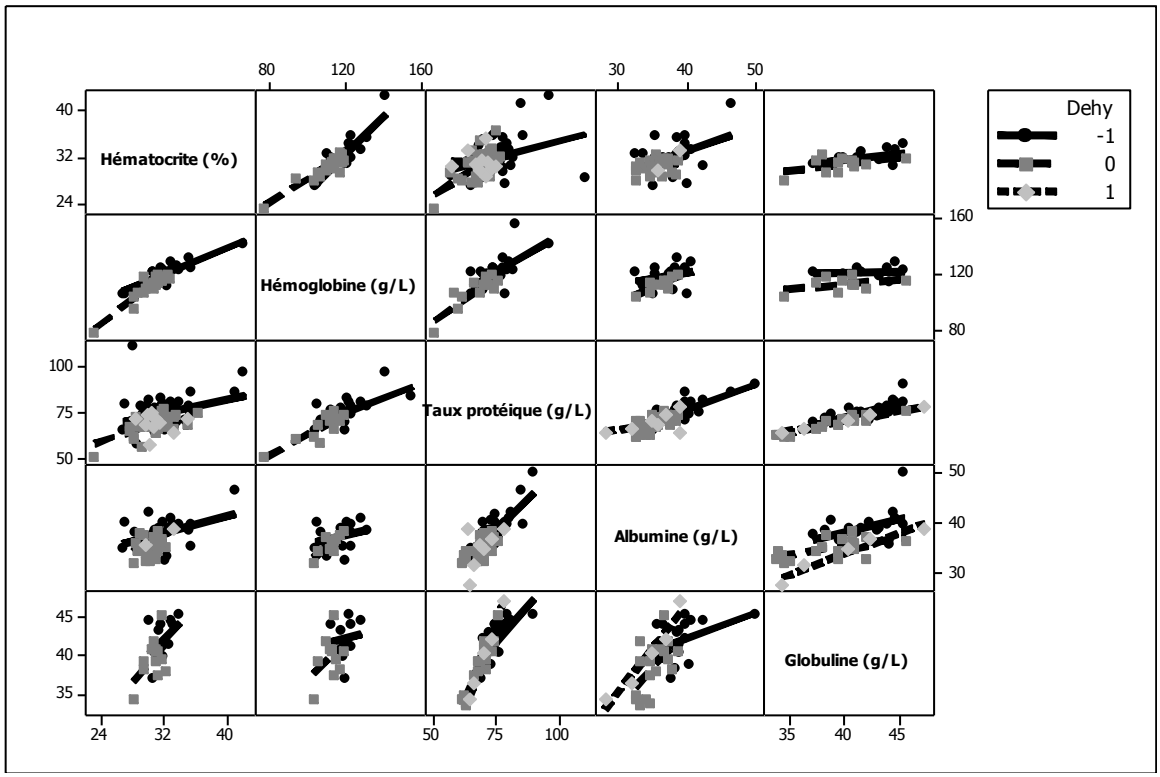


Figure 7. Graphique matriciel diagonal du taux protéique sanguin, l'hématocrite, l'hémoglobine et la globuline chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et ceux réhydratés (Dehy=1)

La figure 7 et le tableau 5 montrent que l'osmolarité s'élève en cas de restriction en eau en raison de l'élévation des solutés et de la baisse du volume sanguin. L'urée et le sodium s'élèvent à leur tour à cause du mécanisme mis en action au niveau des reins pour la conservation de l'eau chez les animaux déshydratés (Silanikove, 1994 ; Qinisa et al., 2011).

Tableau 5. Comparaison entre les moyennes de l'osmolarité (mOsm/L), l'urée (mmol/L) et du Na (mmol/L) des groupes déshydratés, contrôles et réhydratés.

Groupe	Osmolarité (mOsm/L)			Urée (mmol/L)			Na (mmol/L)		
	Moyenne*	Ecart Type	N	Moyenne*	Ecart Type	N	Moyenne*	Ecart Type	N
Déshydraté	308.7[a]	14.47	182	8.28[a]	2.087	82	151.5[a]	6.32	108
Contrôle	299.4[b]	9.99	155	6.14[b]	1.831	59	144.8[b]	5.51	78
Réhydraté	300.3[b]	10.87	57	6.82[b]	0.774	13	146.1[b]	3.97	53

*Les moyennes suivies des lettres différentes sont significativement différentes (P<0.05)

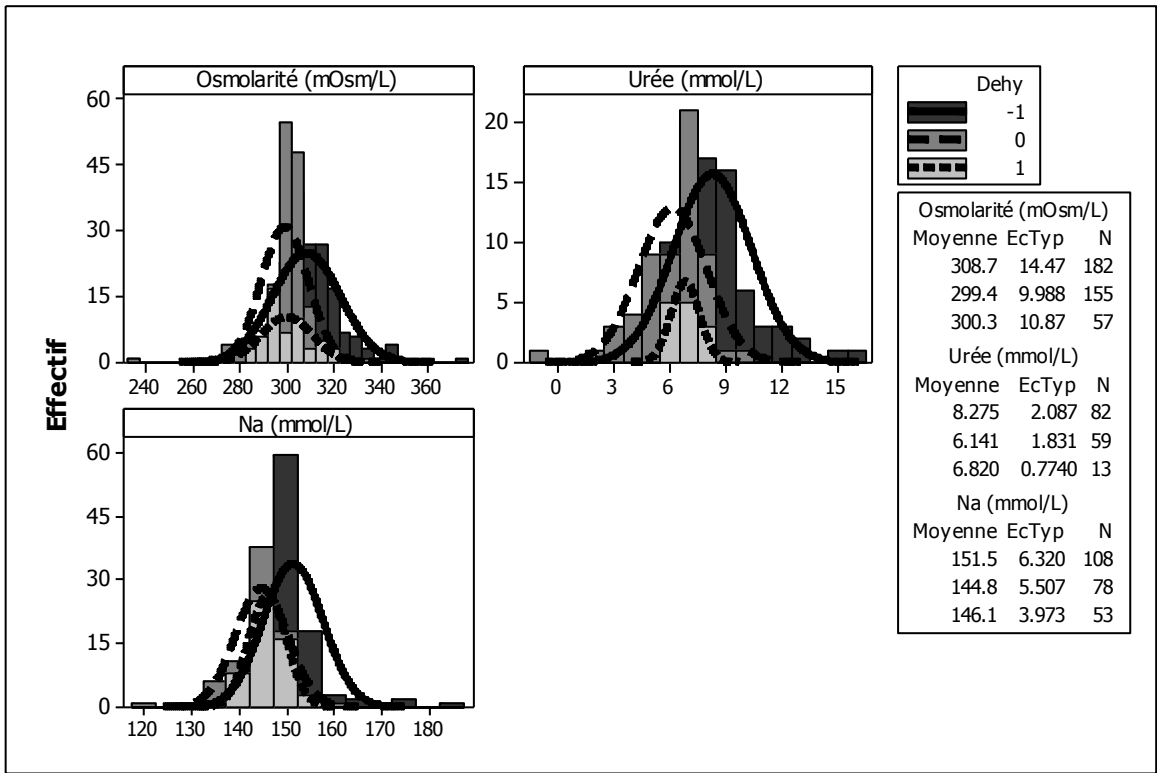


Figure 8. Histogramme de l'osmolarité, l'urée et le sodium chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et ceux réhydratés (Dehy=1)

La baisse de la prise alimentaire lors d'une restriction en eau a été déjà montrée plus haut, par conséquent il est prévisible que les petits ruminants restreints pourraient souffrir d'un bilan énergétique négatif. La figure 8 et le tableau 6 montrent qu'en effet les taux de cholestérol et des AGNE sont plus élevés chez les animaux restreints alors que la glycémie semble être moins sensible à ce traitement. Ces données quantitatives s'accordent avec les observations de la revue qualitative qui indiquent que les effets de la restriction en eau sur le glucose sont assez variables, alors que le bilan énergétique négatif est mieux traduit par l'élévation du cholestérol et des AGNE qui montre la mobilisation des réserves adipeuses (Voir « Water stress in sheep raised under arid condition : A review »).

Tableau 6. Comparaison entre les moyennes du glucose (mmol/L), du cholestérol (mmol/L) et des AGNE (mmol/L) des groupes déshydratés, contrôles et réhydratés.

Groupe	Glucose (mmol/L)			Cholestérol (mmol/L)			AGNE (mmol/L)		
	Moyenne*	Ecart Type	N	Moyenne*	Ecart Type	N	Moyenne*	Ecart Type	N
Déshydraté	3.366[a]	0.3293	35	1.951[a]	0.2232	20	0.3890[a]	0.1205	13
Contrôle	3.292[a]	0.4526	36	1.611[b]	0.1767	17	0.2084[b]	0.1583	13
Réhydraté	3.126[a]	0.2097	11	1.719[ab]	0.1816	5			

* Les moyennes suivies des lettres différentes sont significativement différentes (P<0.05)

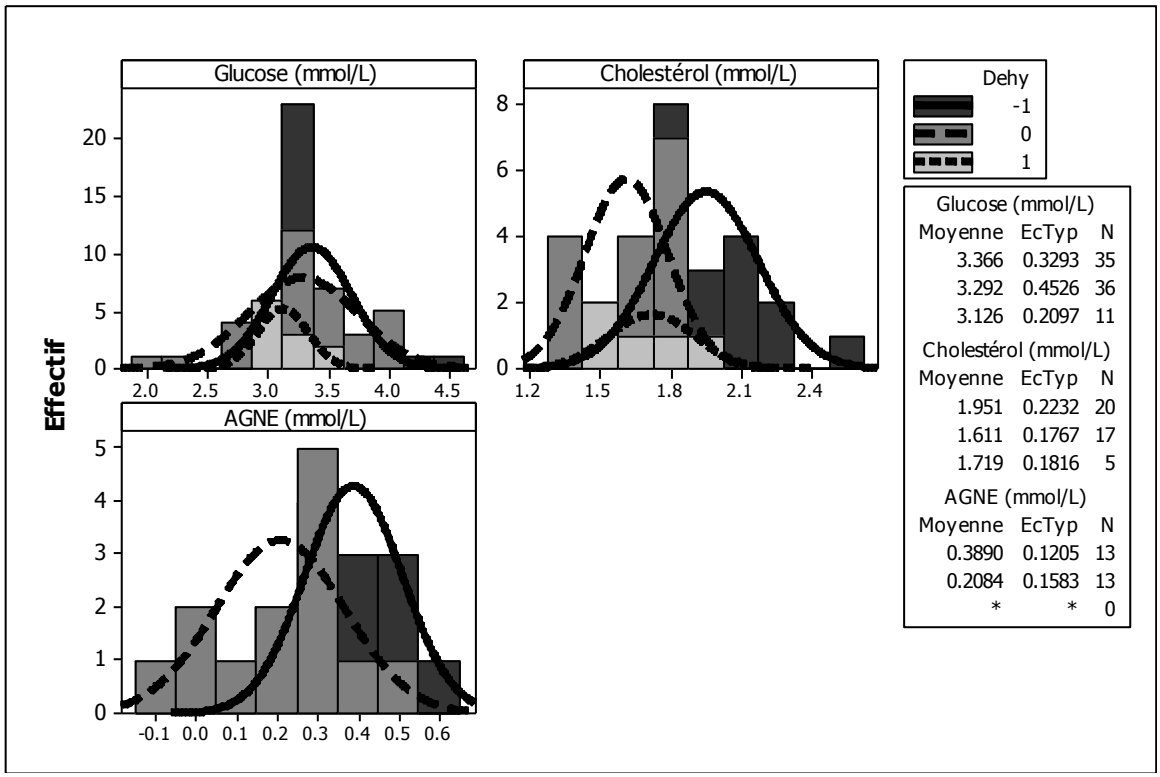


Figure 9. Histogramme du glucose, du cholestérol et des acides gras non-estérifiés (AGNE) chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et ceux réhydratés (Dehy=1)

f. <u>Effet de la restriction en eau sur la production et la composition laitière</u>

La revue de la littérature a dédié une section sur l'interaction entre l'effet de la restriction en eau et le stade physiologique des animaux, notamment la gestation et la lactation. Cependant, comme déjà remarqué dans la revue qualitative, le nombre de données à ce sujet n'était pas assez important pour pouvoir effectuer une analyse détaillée.

Dans un premier temps, nous avons étudié l'influence de la restriction en eau sur la production et la composition laitière en tenant compte de l'effet article.

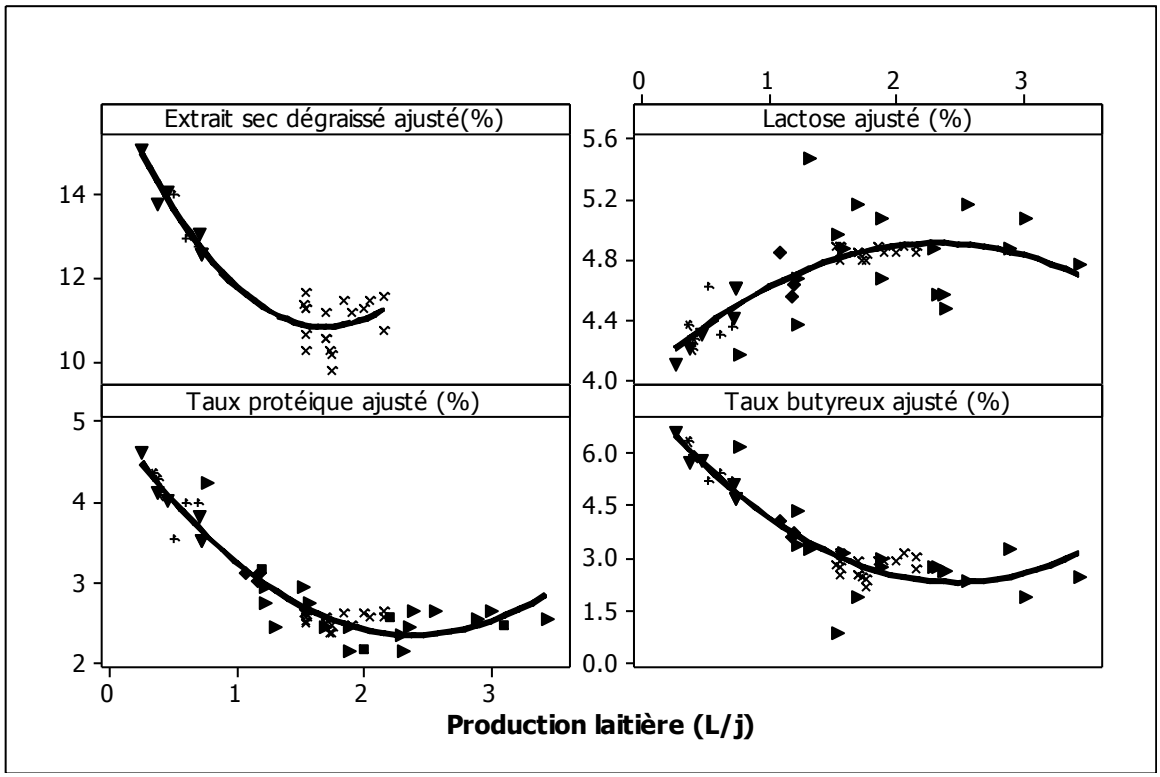


Figure 10. Relation entre la la production laitière chez les petits ruminants et les teneurs en extrait sec dégraissé (ESD), et en lactose et des taux protéique et butyreux du lait, avec l'article comme facteur de goupement

La figure 10 montre une relation négative quadratique entre les principaux constituants du lait et la production laitière quel que soit le niveau d'abreuvement, sauf pour le lactose pour lequel la relation est positive. Les équations de régressions des quatre constituants principaux du lait sont les suivantes :

Lait ESD (%) = 16.6 – (6.81 PL) + (2.01*PL^2)
N observations = 27 ; N articles = 3 ; R^2 = 0.94, Ecart type résiduel. = 0.495

Lactose (%) = 4.03 + (0.762 PL) - (0.165*PL^2)
N observations = 50 ; N articles = 6; R^2 = 0.91, Ecart type résiduel. = 0.207

Taux protéique (%) = 5.02 – (2.23 PL) + (0.466*PL^2)
N observations = 54 ; N articles = 7; R^2 = 0.95, Ecart type résiduel. = 0.220

Taux butyreux (%) = 7.51 – (4.23 PL) + (0.860*PL^2)
N observations = 50 ; N articles = 6; R^2 = 0.89, Ecart type résiduel. = 0.569.

(PL=Production laitière L/j)

Ces observations sont en accord avec la littérature (Fuertes et al., 1998 ; Ploumy et al., 1998).

De plus, dans le cas particulier de la réduction de la production laitière suite à la déshydratation, Hossaini Hilali et al. (1994) ont observé une baisse de la production avec une élévation des taux de lactose et des matières sèches du lait alors que les taux protéique et butyreux ont baissé. L'analyse préliminaire de l'effet de la restriction en eau sur la composition laitière semble indiquer que les petits ruminants déshydratés produisent un volume de lait plus réduit, mais aussi plus concentré en matières protéiques, matières grasses et lactose (figure 11). Par contre, pendant la période de réhydratation, la production laitière semble encore plus élevée qu'en temps d'abreuvement normal, alors que le lait produit est plus dilué, comme indiqué dans la figure 11. Pourtant ces différences restent statistiquement

non significatives selon l'analyse préliminaire comparant les trois groupes d'animaux (tableau 7). La figure 12 montre que la quantité totale de matière utile [Production laitière * (TP+TB)] produite est plus basse sous une restriction en eau qu'avec un abreuvement normal, bien que le lait soit plus concentré et qu'elle reste plus basse après réhydratation (tableau 7). Toutefois, ces observations restent à vérifier en contrôlant les autres facteurs qui pourraient influencer cette analyse, puisque le nombre de données est limité. Verdier-Metz et al. (2001) ont montré que les taux protéique et butyreux sont en effet les déterminants les plus importants du rendement fromager avec une relation positive et linéaire entre les deux. Soryal (2002) a suggéré que le lait produit par les brebis déshydratées pourrait être d'intérêt pour la production de certains fromages dans les milieux arides, sans diminutions du rendement par kg de lait, de la qualité et du goût du produit. Une recherche plus approfondie sur ce sujet serait très utile pour mieux comprendre les relations entre la restriction en eau et la production et la composition laitière.

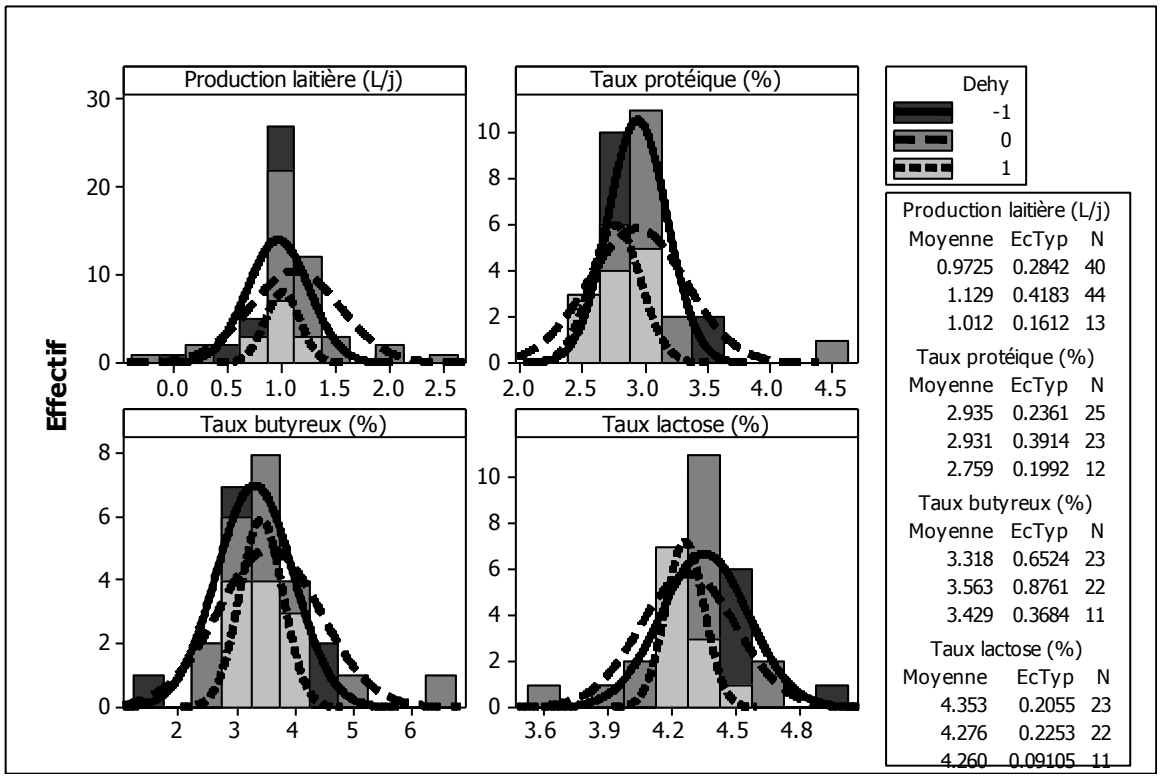


Figure 11. Histogramme de la production laitière et des taux protéique, butyreux et de la teneur en lactose du lait chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et ceux réhydratés (Dehy=1).

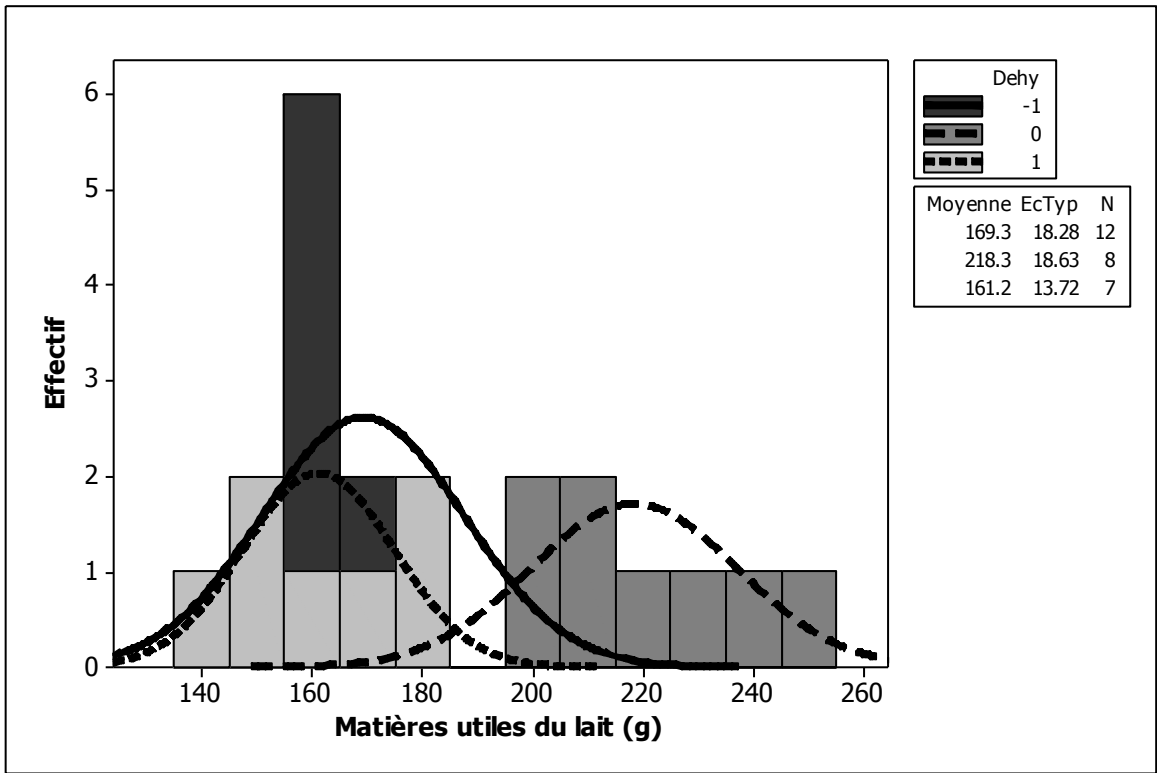


Figure 12. Histogramme des matières utiles du lait chez les petits ruminants restreints en eau (Dehy = -1), ceux normalement abreuvés (Dehy = 0), et ceux réhydratés (Dehy=1).

Tableau 7. Comparaison entre les moyennes de la production laitière (L/j), du taux protéique (%), du taux butyreux (%), du taux de lactose (%) et des matières utiles du lait (g) des groupes déshydratés, contrôles et réhydratés.

Groupe	Production laitière (L/j)			Taux protéique (%)			Taux butyreux (%)		
	Moyenne*	Ecart Type	N	Moyenne*	Ecart Type	N	Moyenne*	Ecart Type	N
Déshydraté	0.9725[a]	0.2842	40	2.935[a]	0.2361	25	3.318[a]	0.6524	23
Contrôle	1.129[a]	0.4183	44	2.931[a]	0.3914	23	3.563[a]	0.8761	22
Réhydraté	1.012[a]	0.1612	13	2.759[a]	0.1992	12	3.429[a]	0.3684	11

Groupe	Taux lactose (%)			Matières utiles du lait (g)		
	Moyenne*	Ecart Type	N	Moyenne*	Ecart Type	N
Déshydraté	4.353[a]	0.2055	23	169.3[b]	18.28	12
Contrôle	4.276[a]	0.2253	22	218.3[a]	18.63	8
Réhydraté	4.260[a]	0.0911	11	161.2[b]	13.72	7

* Les moyennes suivies des lettres différentes sont significativement différentes (P<0.05)

g. Changements dans les concentrations des constituants principaux du sang en fonction de la méthode de restriction en eau

Comme mentionné plus haut, la restriction en eau imposée dans les différents articles utilisés pour cette analyse peut se classer en deux grandes familles : celle qui impose une restriction

totale pendant une certaine période et celle qui consiste en une restriction partielle à des niveaux variables en fonction du niveau « contrôle » d'eau bue en conditions normales.

La figure 13 illustre les changements dans les concentrations des constituants principaux du sang, déjà analysés plus haut, en fonction de l'intervalle de restriction (intervalle entre deux abreuvements). La figure montre clairement une relation positive entre les paramètres considérés et l'intervalle de restriction.

De même, la figure 14 montre une relation négative entre ces paramètres et le niveau de restriction pour les articles de la deuxième famille, en notant que le niveau « 1 » indique un abreuvement normal et « 0 » note une restriction totale. A noter aussi que le nombre de données dans cette famille est plus faible que dans la précédente et que ces relations méritent donc d'être verifiées plus en détail, surtout pour les AGNE et le cholestérol.

Ces résultats renforcent l'analyse précédente qui a montré que l'osmolarité, l'urée, le sodium les AGNE et le cholestérol augmentaient avec une restriction en eau. Il est possible de suggérer que cette augmentation soit en fait linéaire en fonction de l'intervalle d'abreuvement et du niveau de restriction.

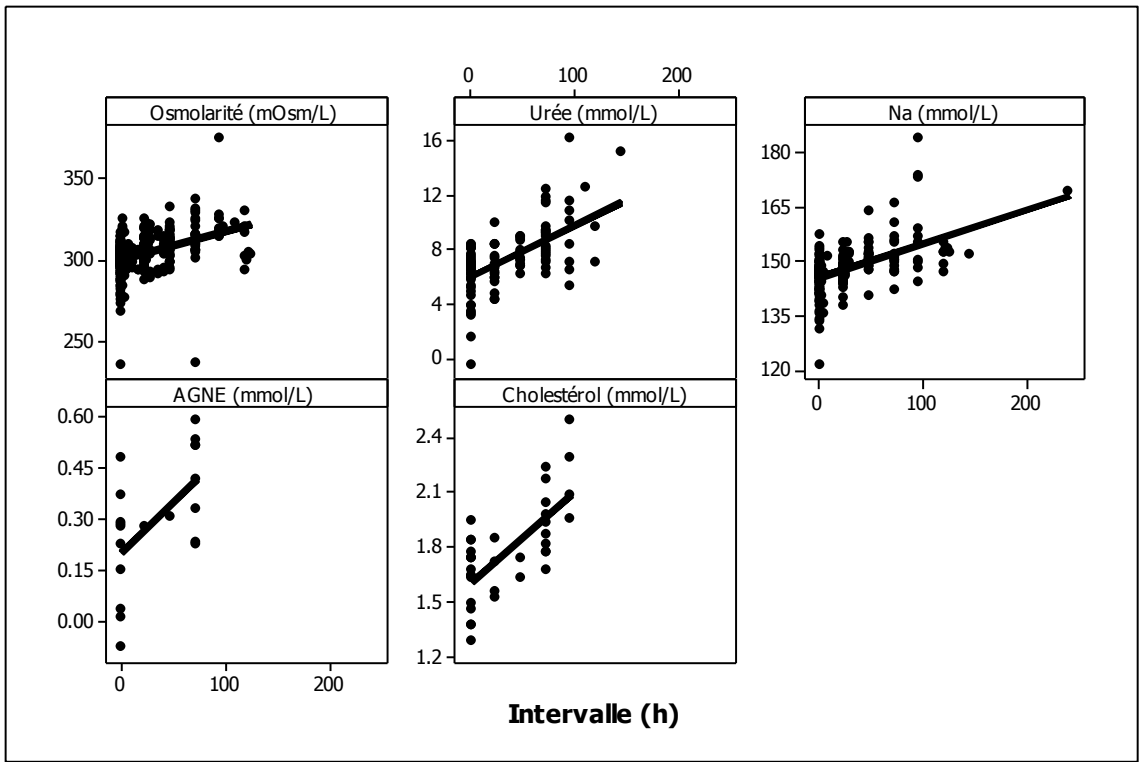


Figure 13. Nuage de points de l'osmolarité, l'urée, le sodium, les AGNE et le cholestérol en fonction de l'intervalle entre deux abreuvements chez les petits ruminants soumis à une restriction totale en eau.

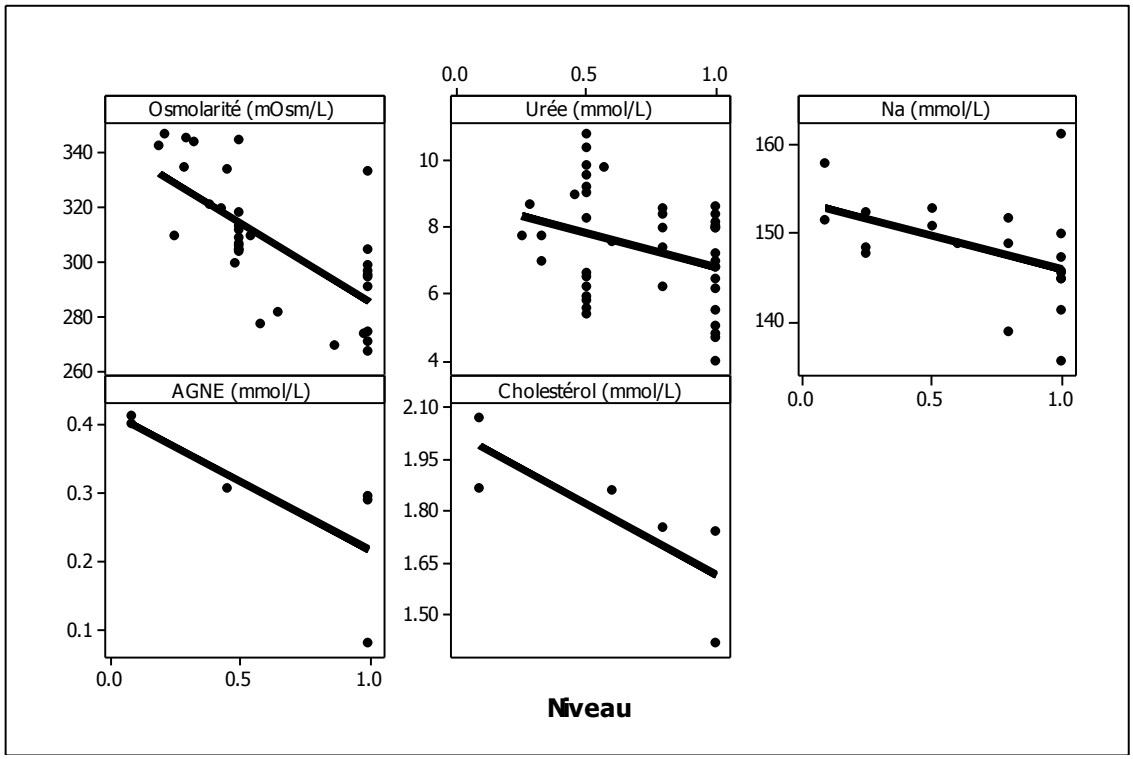


Figure 14. Nuage de points de l'osmolarité, l'urée, le sodium, les AGNE et le cholestérol en fonction du niveau de restriction en eau chez les petits ruminants soumis à une restriction partielle en eau, le niveau « 1 » étant celui de l'abreuvement normal.

h. <u>Relation entre la matière sèche ingérée, la température rectale et la température ambiante</u>

La base de données permet de visualiser et de quantifier des relations entre différents paramètres. La figure 15 illustre la relation entre la quantité de matière sèche ingérée par kg de poids vif et la température rectale, en prenant en considération l'effet article. L'équation suivante décrit cette relation quadratique où tous les termes sont significatifs :
Matière sèche ingérée (g/kg poids vif) = -8308 + 439*TR -5.776*TR^2
(TR= température rectale ^oC)
N observations = 122 ; N articles = 19 ; R^2 = 0.66 ; Ecart type résiduel. = 6.544
Le calcul du point maximal de la courbe indique qu'à partir de 38.0^oC, l'ingestion de matière sèche commence à diminuer d'une façon progressive jusqu'à approcher l'absence totale d'ingestion au delà des 40 ^oC.

Par contre, la relation entre la matière sèche ingérée et la température ambiante semble plutôt linéaire, avec l'effet article aussi pris en considération. La figure 16 illustre cette relation montrant une baisse de la prise alimentaire avec l'augmentation de la température ambiante. L'équation décrivant cette relation est la suivante :
Matière sèche ingérée (g/kg poids vif) = 37.898 – 0.4212*TA (TA= température ambiante ^oC)
N observations = 239 ; N articles = 37 ; R^2 = 0.67 ; Ecart type résiduel. = 7.211

D'autres relations restent à explorer avec la possibilité d'en tirer des modèles prédictifs.

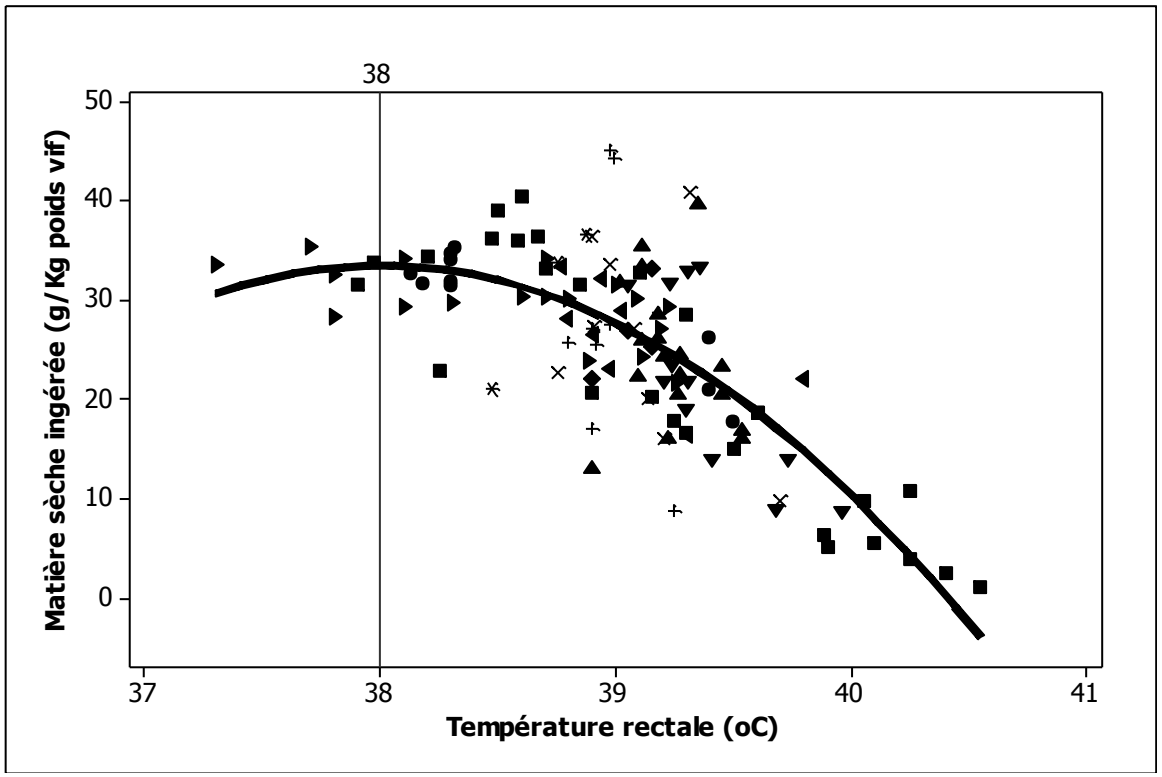


Figure 15. Nuage de points de la matière sèche ingérée par kg de poids vif en fonction de la température rectale, avec l'article comme facteur de goupement.

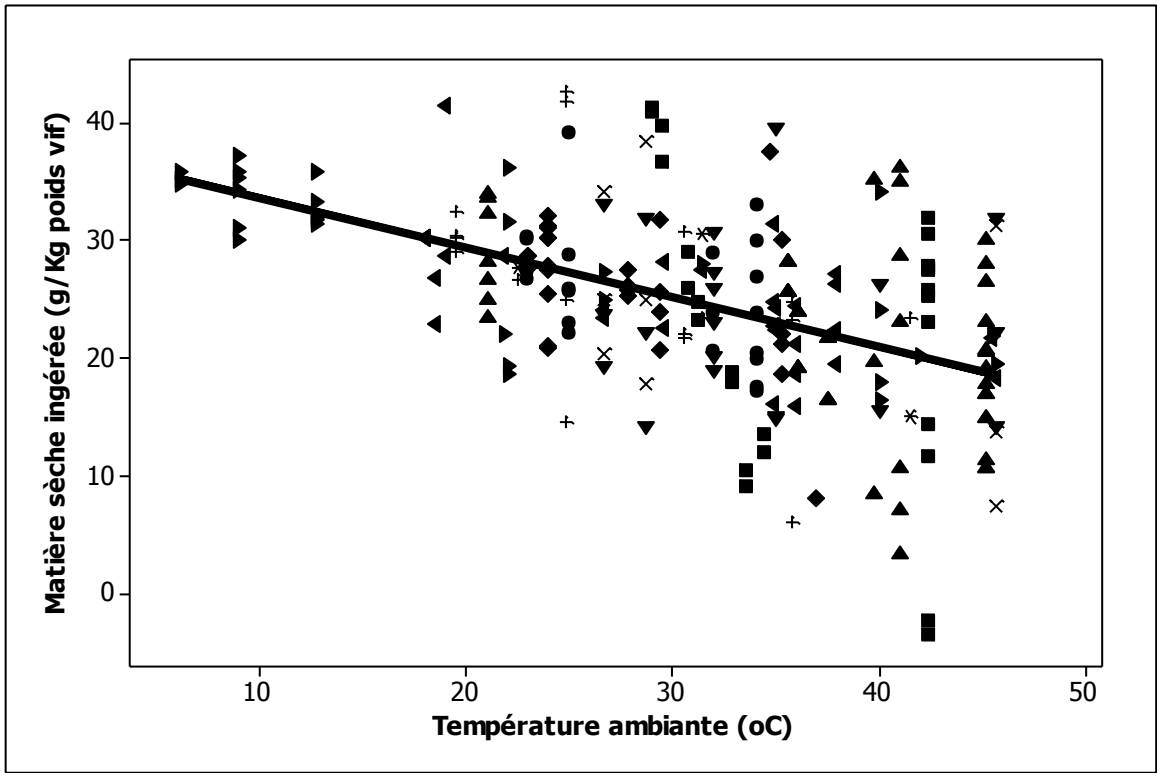


Figure 16. Nuage de points de la matière sèche ingérée par kg de poids vif en fonction de la température ambiante, avec l'article comme facteur de goupement.

La méta-analyse a, d'une part, permis de valider les observations de la revue qualitative de la littérature aussi bien sur l'effet de la restriction en eau que sur les lois générales qui règlent les relations entre les différents paramètres, quel que soit le niveau d'abreuvement. D'autre part, il a été possible de proposer des équations descriptives pour certaines relations entre des paramètres clés telle que la production laitière et les différentes composantes du lait. L'analyse approfondie de toutes les données du fichier compilé promet de révéler des pistes encore inexplorées des effets complexes de la restriction en eau sur la physiologie et la production des petits ruminants.

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CHAPITRE 2 : EFFET D'UNE RESTRICTION EN EAU CHEZ DES CHEVRES SHAMIES (EXPERIMENTATIONS EFFECTUEES AU LIBAN)

Les chèvres shamies sont indigènes au pays de l'Est de la Méditerranée. Elles sont bien connues pour leur potentiel laitier et leur adaptabilité au climat aride et semi-aride de la région et pour cela, elles sont de plus en plus exportées dans différentes régions du monde où l'eau et la végétation sont rares

Deux expérimentations ont été effectuées au Liban sur les chèvres shamies. La première a porté sur des chèvres en lactation, alors que la deuxième était réalisée sur des chèvres en gestation avancée. Les animaux étaient soumis à un régime d'abreuvement intermittent d'un jour sur quatre et différents paramètres physiologiques ont été analysés pour évaluer l'effet de ce traitement.

Les résultats de ces deux expérimentations sont présentés plus loin. La première expérimentation a donné lieu à un article accepté et publié dans un journal international à comité de lecture et à une communication dans une conférence internationale. La deuxième expérimentation a abouti à un article qui a été préparé, mais non encore soumis pour publication.

2.1. L'effet d'une restriction en eau en cycles répétés chez des chèvres shamies en lactation

a. Résumé en français

L'effet de cycles répétés de restriction en eau sur des chèvres shamies en lactation fut évalué à travers une expérience effectuée au Liban au mois de mai de l'année 2009.

Matériel et méthodes

L'expérience a porté sur 12 chèvres shamies au cinquième mois de lactation. Les chèvres avaient entre 3 et 4 ans (3ème lactation, poids moyen de 48,7± 2,39 kg). La température ambiante était entre 14.3 et 35.8°C avec un taux d'humidité variant entre 23,1 et 52,4%. Les chèvres ont été divisées en deux groupes, l'un recevant de l'eau *ad libitum* (groupe contrôle), et l'autre une fois tous les quatre jours (groupe restreint). L'alimentation se composait de quantités égales de concentré et d'ensilage de maïs, de façon à satisfaire les besoins nutritionnels. Les animaux étaient installés dans une étable commune avec une barrière séparant les deux groupes. Ils étaient alimentés et abreuvés le matin et l'après-midi, et les refus étaient mesurés chaque matin afin de calculer les quantités ingérées. Le groupe restreint a été abreuvé *ad libitum* pendant 24 heures, un jour sur quatre, ce cycle a été répété huit fois. Plusieurs paramètres physiologiques ont été mesurés notamment : le poids vif, la température rectale, l'osmolarité du sang, la protéinémie, l'albuminémie et l'urémie. La production laitière et la composition du lait ont aussi été mesurées.

Groupes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Restreint	S L P R	R		S L E	R			S L E	R			E	R			S L E
Contrôle	S L			S L				S L								S L

17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
R			E	R			S L E	R			E	R			S L P E
															S P L

S= Prise de sang
L= Echantillon de lait
P= Poids vif
E= Eau à boire
R= Restriction

Figure 17. Calendrier de l'abreuvement et du prélèvement des échantillons pour les deux groupes de chèvres shamies en lactation, l'un abreuvé tous les jours et l'autre restreint en eau avec un abreuvement d'un jour sur quatre.

Analyse statistique

Les résultats ont été analysés à l'aide d'un modèle en mesures répétées sur SPSS 19 (IBM SPSS). De plus, une analyse en composantes principales a été effectuée pour mieux comprendre les relations entre les différentes variables et la privation d'eau. Cette analyse a montré que les deux premières composantes expliquaient un peu moins de la moitié de la variance ; la première composante était expliquée par la variation de la composition laitière et

l'autre, par la variation de la composition sanguine. Ni le régime en eau, ni le jour de l'expérience n'ont eu d'effet significatif sur les paramètres mesurés.

Résultats et discussion

Ingestion et poids

Les chèvres ont maintenu le même niveau d'ingestion d'eau et d'alimentation dans les deux groupes. Ceci pourrait être dû à un faible niveau de stress, car les animaux avaient accès à l'ombre durant la journée et les températures se rafraichissaient durant la nuit. De même, ce résultat montre l'adaptabilité des animaux à de telles conditions, comme l'indique leur capacité à remplacer leur perte en eau en une seule buvée sans induire d'hémolyse. Les différences en poids vif entre les deux groupes n'étaient pas significatives, bien que le groupe restreint ait perdu du poids alors que le groupe contrôle en a gagné ; ceci pourrait être à relier à la variabilité individuelle, ainsi qu'au fait que les deux groupes ont maintenu le même niveau d'ingestion.

Paramètres sanguins

Au niveau des paramètres sanguins, un état de déshydratation chez le groupe restreint a été montré par une hausse de l'osmolarité, de l'urémie et de l'albuminémie. Ces paramètres sont connus comme des indicateurs de la déshydratation, démontrant une baisse de la volémie sanguine avec une rétention d'eau accentuée au niveau des reins, comme démontrée par la hausse de l'urémie. D'autres paramètres sanguins n'ont pas varié entre les deux groupes, notamment le taux de cholestérol et d'insuline. Ces variables reflètent les changements du bilan énergétique et une éventuelle mobilisation des réserves adipeuses. Dans cette expérience, et en cohérence avec les résultats de l'ingestion, les chèvres semblent avoir maintenu un bilan énergétique similaire et positif.
Finalement, le taux du cortisol semble indiquer que les chèvres n'étaient pas en situation de stress. On peut toutefois noter la grande variabilité individuelle qui pourrait avoir masqué des différences entre les deux groupes.

Production et composition laitière

La production laitière était similaire entre les deux groupes avec une tendance commune de baisse de production liée au fait que le pic de lactation était passé. La production laitière à ce stade est probablement moins exigeante au niveau physiologique. Bien que le taux de lactose ait été plus élevé dans le groupe restreint, les différences n'étaient pas significatives pour la composition du lait. Le lactose joue un rôle important pour maintenir le lait isotonique avec le sang, et étant donné l'hyperosmolarité observée dans le sang, une hausse de lactose aurait pu être justifiée.

Conclusion

En conclusion, cette expérience a montré que les chèvres shamies étaient effectivement capables de s'adapter à un régime d'abreuvement intermittent, à ce stade de la lactation, avec des changements sanguins et laitiers assez limités. Les recherches futures pourraient porter sur l'effet de tels régimes sur des durées plus prolongées et à des stades différents du cycle reproductif de la race shamie, vu son importance économique dans les milieux arides.

b. Texte de la publication en anglais: Responses to repeated cycles of water restriction in lactating Shami goats

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Abstract

The experiment was conducted to assess the effects of an intermittent watering regime on physiological indicators of lactating Shami goats. Twelve does in late lactation, were equally distributed to two treatments: control and watered once every 4 days. Several serum and milk variables were assessed at the beginning of the experiment and on 4 subsequent days. The does' body weight was assessed at the beginning and at the end of the experiment while milk production was recorded daily. The intermittently watered animals showed increased serum osmolarity, urea, protein and albumin concentrations, denoting dehydration. Milk production and body weight were not affected by the treatment. In addition, milk composition was similar between the control and the intermittently watered animals. It was concluded that the Shami goats could tolerate the intermittent watering regime during late lactation with minimal physiological disturbances. However, the long term consequences of the treatment on production and health warrant further research.

Keywords: Shami goats; intermittent watering; lactation; milk composition; physiological indicators

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1. Introduction

The Shami (Damascus) breed, native to arid countries, is well known for its dairy potential and it has been exported to different regions (Mavrogenis et al. 2006), where high temperature and water shortage are common constraints.

The first response to water stress reported in different animals is the reduction in feed intake (Alamer 2006,); still others have observed no effect of water deprivation on dry matter intake (Al-Ramamneh et al. 2012). The decrease in feed intake could be an adaptive measure to prevent feed accumulation and secure proper digestive function (Ahmed-Muna and El Shafei Ammar 2001). Consequently, body weight loss is observed. Furthermore, body water loss leads to hemoconcentration demonstrated by increased hemoglobin, proteins and packed cell volume due to the smaller blood volume (Alamer 2006, Mengistu et al. 2007a, Abdelatif et al. 2010). Goats also respond to dehydration by modifying their fluid regulatory mechanisms leading to an increase in plasma osmolarity and Na^+ concentration (Mengistu et al. 2007a and b). Similarly, plasma urea and creatinine are reported to increase following dehydration, denoting higher retention at the level of the kidneys in order to reduce water loss through urine (Silanikove 2000, Alamer 2006, Abdelatif et al. 2010). Increased urea retention may also be used as a source for nitrogen recycling and utilization (Silanikove 2000). The effect of water stress on serum cortisol concentration is not consistently reported in literature. Increases in cortisol were reported in water-restricted lactating goats (Olsson and Dahlborn 1989) and whether sheep (Li et al. 2000), while others reported no significant effects in Awassi sheep (Jaber et al. 2004, Ghanem et al. 2008).

One of the most important products of goats is milk. Water deprivation led to a drop in milk production in lactating black Moroccan (Hossaini-Hilali et al. 1994) and Ethiopian Somali goats (Mengistu et al. 2007b). On the contrary, Maltz and Shkolnik (1984) reported that lactating black Bedouin goats sustained their milk yield even after two days of water deprivation. The drop in milk production following dehydration resulted in an increase in milk osmolality that mirrored plasma osmolarity; in fact, Hossaini-Hilali et al. (1994) observed an increase in milk lactose and dry matter contents with no change in milk protein and fat.

The current project proposes to assess the effect of intermittent watering, a common practice in arid and semi-arid regions, on various physiological variables of lactating Shami does.

2. Materials and Methods

The experiment took place at the Agricultural Research and Education Center (AREC), of the American University of Beirut, Lebanon, with temperatures ranging between 14.3 and 35.8^{o}C and relative humidity between 23.1 and 52.4%. Twelve does, aged 3-4 years in their third lactation (average weight 48.7± 2.39 kg), were selected. The animals were in their 5th month of lactation (5 months post-partum). The month of May was selected since it is when the temperatures start to rise above the comfort zone and water shortages are likely to be experienced in extensively raised goats. They were assigned to two groups, control and water restricted (watered *ad libitum* once every 4 days), six animals in each, in a way to achieve homogeneous body-weight distribution. The water restriction was repeated over eight cycles between April 30 and May 31, 2009. They were housed in a shaded barn with access to an outdoor enclosure. The two groups were separated by a partition at all times. They were offered feed (50:50 concentrate and silage mixture) and water once in the morning (8:00 am) and once in the afternoon (16:00 pm), in common feeders and water troughs accessible to all animals in the group. Water of the restricted group was removed at 8:00 am 24 hours after watering. The left over feed was measured daily, before replenishing with fresh feed, and the

quantities consumed by the group were calculated accordingly. The same was applied for measuring water consumption, on daily basis for the control group and at the time of water removal for the restricted one. Hand milking was performed by an experienced person once in the morning and daily milk production was recorded for each animal.

Feeding was according to the NRC (2007) requirements. The daily water intake from feed was estimated based on the moisture content of the mixed feed (silage and concentrate) and the daily total feed consumption. The feed composition is presented in Table 1.

All the does were weighed at the beginning and at the end of the experiment. Blood and milk samples were taken early in the morning, at 7:00 am at the beginning of the experiment, and on days 4, 8, 16, 24 and 32, right before offering water to the restricted group. Additional blood samples were taken after one hour, right before offering water, for cortisol analysis. The double samples for cortisol analysis (1-hour apart), were taken to minimize the effect of animal handling that could create variation in cortisol levels between the different animals, especially upon the first exposure to the handler in the morning. Blood collected in heparinized vacutainers was analyzed for Packed Cell Volume (PCV) and hemoglobin concentration. PCV was measured by the microhematocrit method (Microcapillary/ centrifuge method) while hemoglobin concentration was determined using the cyanmethemoglobin method (Cork and Halliwell 2002).

Milk was frozen at -40^{o}C until it was analyzed on an ultrasonic milk analyzer (Ekomilk total ultrasonic milk analyzer, Stara Zagora, Bulgaria), previously calibrated for goat milk, for fat, protein, lactose, pH, solid-non-fat (SNF), and density. The samples were brought to a temperature of 40^{o}C to solubilize the fat, mixed manually and then were analysed after cooling to room temperature.

Serum from non-heparinized blood was also analyzed for cholesterol, total serum protein, albumin, globulin, urea and creatinine using a Roche/Hitachi 912 Analyzer (Roche Diagnostics GmbH Laboratory systems, D-68298 Mannheim, Germany). Osmolarity was assessed by freezing point depression on a Slamed osmometer (Slamed Ing GmbH, Frankfurt, Germany) and insulin was measured by Immulite Insulin Kit radioimmunoassay using Immulite Analyser (Diagnostic Products Corporation, Los Angeles, USA). Furthermore, serum samples were analyzed for cortisol concentration by a solid-phase single antibody procedure, using radioimmunoassay kits (CORT-CT2, Cisbio, Bagnols-sur-Cèze, France).

At the end of the experiment, the animals were returned to their original flock where they were offered daily feed and water.

The experiment was approved by the Institutional Animal Care and Use Committee of the American University of Beirut.

Statistical analysis

The data were analyzed using the General Linear Model-Repeated Measures application including a random effect for the animal and a fixed effect for the treatment. The data from the first collection (at the beginning of the experiment) was used as a covariate. This approach is recommended for experiments involving the use of the same animals over time (Morris, 1999). The model tests for the treatment effect while taking into consideration the fact that the repeated samples are not independent of each other. Since there were only two treatments, only two means could be directly compared for each variable, one for the control and one for the water restricted group, based on the significance. The mean daily feed and water consumption per group were compared by one way Analysis of variance (ANOVA). All the statistical analyses were run on IBM-SPSS software (Version 19, SPSS. Inc.).

In order to understand the relationships between the variables and the effects of the dehydration principal component analyses (PCA) was also performed. As there were some

data missing, we chose the variables observed during the first day of each experiment (used as a basal value) and the data after 2 weeks of dehydration. The objective of a PCA is to synthesize the overall information contained in a set of observed variables into a smaller number of linear combinations of orthogonal variables called Principal Components (PC). The PCs sequentially minimize the remaining variation in the multivariate data space. Thus, the PCA condenses the information into loadings which show the relative importance (weighing) of the original variables in accounting for the variability in the observed data. The distribution of the observed data across the PCs is shown by the scores.

3. Results

Overall feed and water consumption was similar in the two groups (Table 2). No differences were observed in body weight changes or in total milk production throughout the experimental period (Table 2). However, differences were observed in protein, albumin, urea and osmolarity, whereby all these variables were higher in the water restricted group (Table 3). On the other hand, pH, haemoglobin, cholesterol, insulin, globulin, creatinine and cholesterol showed no significant differences. Milk composition in terms of % SNF, protein, lactose, fat, pH and density was not affected by water restriction (Table 4). The Principal Component Analysis showed that the first two components explained a little less than half of the total variance (Figure 1). The first component was explained by the variation in milk composition, and the second one, by the variation in blood components. Neither the treatment nor the sampling day had an effect on the results.

The quality of the water used in this experiment, as reflected by water pH (6.7) and electric conductivity (0.47 dS/m), fell within the acceptable range for safe drinking water to all livestock at different physiological stages (de Araújo et al. 2010).

4. Discussion

The water restricted and control animals maintained similar feed consumption that is comparable to reported intake levels in other breeds based on animal weights and treatments (Hossaini-Hilali et al. 1994, Al-Ramamneh et al. 2012). In contrast, a decrease in feed intake was one of the first observations reported under water restriction in many sheep (Jaber et al. 2004) and goat breeds (Alamer 2006).

The capacity of goats, indigenous to arid and semi-arid regions, to replenish their water shortage in a very short time is well documented (Silanikove 2000, Abdelatif et al. 2010). This was demonstrated in this experiment whereby the water restricted animals drank on the day of rehydration 3.2 times more than the daily consumption of the control group. This capacity to ingest large water quantities without disruption of the homeostasis denotes the adaptation of these goats to partial dehydration. Furthermore, the provision of shade and daily temperature fluctuations were reported to greatly help animals adapt to the high heat load experienced at peak temperatures (Silanikove 2000). Seen under this light, the results of our experiment seem to indicate that all animals were consuming water above their maintenance requirement. The maintenance requirement was reported to be 107 ml/kg $BW^{0.75}$ (Giger-Reverdin and Gihad 1991). The same authors reported the requirement for milk production as 165 ml/kg $BW^{0.75}$ for a milk production level of 148g milk/kg $BW^{0.75}$, while in our study the milk production was in the range of 29.8g milk/kg $BW^{0.75}$. Therefore, the water consumption seems to reflect the combined needs of low milk production, at this advanced stage of lactation, and the requirements for coping with the hot ambient temperature.

The weight change of lactating animals was not different between the two groups although the water restricted animals lost weight while their daily watered counterparts gained

weight. This could be partially attributed to the individual variation that was observed in both groups with respect to weight changes. Furthermore, as previously mentioned, the goats in both groups showed similar feed consumption under the two treatments which probably contributed to maintaining body weight. Previous research on lactating goats (Hossaini-Hilali et al. 1994, Mengistu et al. 2007b) and sheep (Hamadeh et al. 2006) indicated that weight loss in lactating animals subjected to water restriction was usually greater than in non-lactating animals under the same treatment.

The blood chemistry reflected a state of dehydration mostly through the observed increase in osmolarity. Increased osmolarity is consistently reported in water restricted lactating and non-lactating goats (Dahlborn 1987, Hossaini-Hilali et al. 1994, Mengistu et al. 2007b). Similarly, an increase in serum urea is also reported under water restriction in lactating goats. This increase is a reflection of urea reabsorption at the level of the kidney which plays an important role in water retention and prevention of excessive water loss (Hamadeh et al. 2006). Other physiological changes were also observed in the water restricted lactating animals, namely, increase in protein and albumin. These responses further denote dehydration and the decrease in blood volume. Similar changes have been observed in lactating ewes (Hamadeh et al. 2006) and goats (Dahlborn 1987, Hossaini-Hilali et al. 1994, Megistu et al. 2007b). The increase in protein, particularly albumin, reflects its important role in maintaining the osmotic tension of the blood under dehydration (Hamadeh et al. 2006; Mengistu et al. 2007b). Serum cholesterol and insulin concentrations were similar between the two groups probably indicating that body stores were not highly mobilized (Jaber et al. 2011). This is in agreement with the weight change observations, leading to the suggestion that the observed variations in body weight are probably a reflection of body water loss and not body mass loss in the form of fat depot utilization. Damascus goats in Cyprus could tolerate a temperature between 25-30^{o}C as the upper limit of their thermal comfort zone (Giger-Reverdin and Gihad 1991). In this experiment the average of maximum temperatures recorded was 35.8^{o}C. Furthermore, blood was sampled on the last day of water restriction, in each cycle, therefore reflecting the maximum, rather than the average, effect of the treatment throughout the experiment. This suggests that the overall effect of the treatment could be milder than reported which leads to the proposition that these goats can tolerate the imposed watering regime. In fact, adapted ruminants are reported to respond to cycles of dehydration and rehydration through various mechanisms including water retention in the rumen upon rehydration and delayed diuresis to avoid hemolysis and preserve the water for use in the coming dehydration cycles (Olsson 2005).

The cortisol concentrations showed great variations, even before the start of the treatment. However, all values fell within previously reported results in goats (Marsico et al. 2009) and other small ruminants (Jaber et al. 2004; Ghanem et al. 2008). Other researchers reported lower baseline values (Komara et al. 2010). However, the interpretation of cortisol concentration results should be made carefully due to the fact that this variable is affected by different factors such as: handling, circadian rhythm, short-term versus long term stressors, etc. (Möstl and Palme 2002). In our experiments, serum sampling was done by the same trained person from the jugular vein; nevertheless close human handling could have contributed to the observed variations especially since the animals were housed in groups. With these limitations in mind it can be concluded that: 1- the animals probably did not experience high stress level due to the treatment since their cortisol serum concentrations remained within reported normal ranges (Marsico et al. 2009), and 2- other indicators such as behavioral observations (Mazurek et al. 2007) or neutrophil to lymphocyte ratio (Davis et al. 2008), or other non-invasive cortisol sampling methods such as fecal cortisol (Möstl and Palme 2002) may be more useful in similar experiments to assess animal welfare.

The physiological stress of milk production varies greatly throughout lactation with the first month post-partum being the most demanding (Dunshea et al., 1990). In the current

study, the animals of both groups showed a declining milk production over time. This is probably why overall milk production was similar between the two groups, since the physiological requirements for milk production were naturally decreasing irrespective of the imposed water restriction. Furthermore, the capacity of different goat breeds to sustain milk production under water shortage varies greatly. While the Ethiopian Somali and the black Moroccan goats reduced their milk production immediately at the start of water deprivation (Hossaini-Hilali et al. 1994, Mengistu et al. 2007b), the Bedouin goats could maintain their milk production when watered every second day (Maltz and Shkolnik 1984). The desert-adapted Aardi goats reduced their milk production by 20 and 18% when subjected to 50 and 25% water restriction, respectively (Alamer 2009). Milk flow was increased in goats given intravenous vasopressin to mimic dehydration levels although the mammary blood flow was decreased thus proving that milk production could be sustained (Olsson 2005). Long term studies over a full lactation would be interesting to reveal the adaptability of the Shami goats to an intermittent watering regime, such as commonly practiced in the field.

The intermittent watering treatment had little effect on milk composition. This is another indication that milk production, in late lactation, could be maintained under the imposed watering regime. Previous studies have showed an increase in milk osmolality, lactose and density following water deprivation for 48 hours (Dahlborn 1987, Hossaini-Hilali et al. 1994). In contrast, lactating Aardi goats subjected to 50 or 25% water restriction showed slight alterations in milk composition most notably in the form of reduction in milk fat content in the 25% restriction group and an increase in osmolality in the 50% restriction group (Alamer 2009). The author concluded that this reflected the adaptability of this breed to the harsh arid environment. Milk osmolality is strictly controlled to keep it isotonic with plasma; the increase in lactose under water restriction, being the major osmotic component of milk, is probably a response to the increase in serum osmolarity under water restriction (Dahlborn 1987). The same trend was observed in the current study but differences between the two groups were not statistically significant.

5. Conclusion

This study provided a preliminary insight into the adaptability of the Shami breed to an intermittent watering regime under lactation, a physiologically demanding condition. Intermittently watered does experienced dehydration as indicated by key physiological variables, however, overall milk production and composition were not affected over the one month study period. These findings warrant larger scale research on this economically important breed to assess its adaptability to long-term water shortage at the different stages of its reproductive cycle, and under different environmental conditions.

6. Acknowledgements

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Table 1. Composition of feed offered to lactating Shami goats subjected to daily or intermittent watering regime

Feed composition	Concentrate[a]	Silage[b]
Dry Matter (%)	90.0	28.2
Crude Protein (%)	14.9	12.2
Ether Extract (%)	2.9	2.4
Crude Fiber (%)	4.3	10.7

[a] Concentrate composition: Yellow corn (40.8%), Soybeanmeal 44 (15%), Wheat bran (20%), Barley (20%), Limestone (2.7%), Di-calcium phosphate (0.72%), Salt (0.65%), Vitamin premix (0.1%)

[b] Corn silage

Table 2. Body weight change and milk production in lactating Shami goats subjected to daily versus once every four days watering regime during 32 days

	Control	Water restricted	P value
Initial body weight (kg)	49.5 ± 4.49	47.8 ± 2.17	0.745
Weight change[a] (%)	+5.7 ± 2.90	-1.8 ± 3.00	0.100
Milk production (L/d/animal)	0.557 ± 0.044	0.509 ± 0.043	0.439
Dry matter intake (kg/d/animal)	1.1 ± 0.03	1.1 ± 0.02	0.169
Average water intake from feed (kg/d/animal)	0.7 ± 0.02	0.8 ± 0.02	0.176
Free water intake (L/d/animal)	1.8 ± 0.11	1.5 ± 0.47 (5.3±0.64)[b]	0.619
Total Water Intake (ml/d/kg $BW^{0.75}$)	135.2 ± 6.09	127.0 ± 25.95	0.761

[a] Percent weight change between the beginning and the end of the experiment over a 32 days period.

[b] Average quantity consumed during the day of rehydration

Table 3. Blood chemistry parameters in lactating Shami goats subjected to daily versus once every four days watering regime during 32 days

	D1		Mean D4-D32		P values
	Control	Water restricted	Control	Water restricted	Treatment
PCV (%)	25.9 ± 4.03	24.1 ± 1.24	24.1 ± 0.55	25.5 ± 0.55	0.114
Hb (g/L)	76.2 ± 8.03	81.5 ± 7.71	91.0 ± 1.73	91.0 ± 1.73	0.993
Cholesterol (mmol/L)	1.7 ± 0.41	1.4 ± 0.36	1.6 ± 0.07	1.8 ± 0.07	0.118
Insulin (pmol/L)	37.7 ± 13.42	17.3 ± 3.14	63.6 ± 22.70	75.6 ± 22.70	0.729
Protein (g/L)	80.2 ± 2.34	81.4 ± 1.57	78.4 ± 0.792	82.0 ± 0.792	0.011
Globulin (g/L)	47.5 ± 1.18	46.6 ± 4.16	45.6 ± 0.66	46.7 ± 0.66	0.285
Albumin (g/L)	32.7 ± 1.73	34.8 ± 0.66	32.9 ± 0.43	35.3 ± 0.43	0.004
Creatinine (µmol/L)	35.3 ± 3.11	36.8 ± 5.28	57.5 ± 2.32	54.9 ± 2.32	0.446
Urea (mmol/L)	7.2 ± 0.64	6.7 ± 0.32	5.5 ± 0.21	6.4 ± 0.21	0.013
Osmolarity (mOsm/kg)	288.2 ± 1.60	289.7 ± 2.06	290.8 ± 1.88	304.0 ± 1.88	0.001
Cortisol (nmol/L)	30.2 ± 12.12	12.0 ± 4.61	18.3 ± 2.83	24.3 ± 2.83	0.187

Table 4. Milk composition of lactating Shami goats subjected to daily versus once every four days watering regime during 32 days

	D1		Mean D4-D32		P values
	Control	Water restricted	Control	Water restricted	Treatment
Fat %	3.5 ± 0.31	3.3 ± 0.29	4.6 ± 0.28	4.9 ± 0.28	0.498
SNF %	8.3 ± 0.16	9.0 ± 0.74	8.6 ± 0.21	9.2 ± 0.21	0.121
Density g/cm^3	1.027 ± 0.002	1.032 ± 0.009	1.026 ± 0.001	1.029 ± 0.001	0.097
Protein %	3.4 ± 0.06	3.70 ± 0.28	3.6 ± 0.08	3.8 ± 0.08	0.144
Lactose %	4.2 ± 0.09	4.6 ± 0.41	4.4 ± 0.12	4.7 ± 0.12	0.130
pH	6.4 ± 0.03	6.4 ± 0.04	6.5 ± 0.04	6.6 ± 0.04	0.248

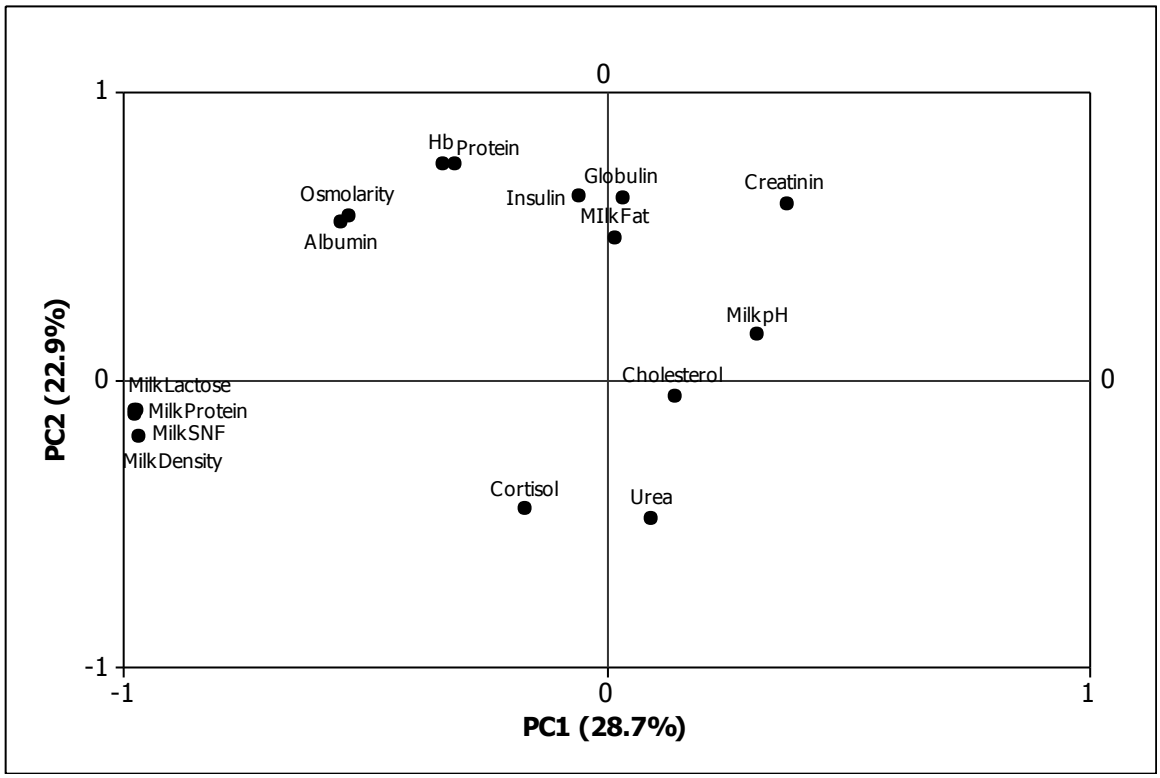


Figure 1. Results of a principal component analysis based on the blood components and the milk composition. The % of total variance accounted for by each of the first two components (PC) is shown in parentheses.

2.2. L'effet d'un régime d'abreuvement intermittent chez des chèvres Shamies en gestation

a. Résumé en français

La gestation est une période critique et importante dans le cycle reproductif des chèvres avec des besoins physiologiques, notamment des besoins en eau, supérieurs à ceux de l'état d'entretien. Cette expérience était conçue pour tester l'effet d'un régime d'abreuvement intermittent sur les chèvres shamies supposées être en gestation avancée.

Matériel et méthodes

Dix chèvres étaient incluses, dont quatre recevaient l'eau tous les jours, alors que les six autres n'étaient abreuvées qu'un jour sur quatre. La restriction en eau s'est faite graduellement et le cycle d'un jour d'abreuvement sur quatre a été répété 7 fois. La restriction graduelle s'est faite par souci de ne pas compromettre la gestation, étant donné que ce traitemnt n'avait jamais été testé sur des petits ruminants en gestation dans notre laboratoire. Des données physiologiques ont été recueillies telles que les taux d'hémoglobine, de protéine, de cholestérol, d'urée et de créatinine ainsi que le cortisol et l'insuline. De même, les quantités d'eau et d'aliments ingérées ont été mesurées. A la fin de l'expérience, les chèvres sont retournées dans le troupeau pour y mettre bas, et ont reçu le même fourrage que durant l'expérimentation. Le fourrage et l'eau étaient en accès libre (*ad libitum*). Les poids des chevreaux à la naissance et à un mois ont été mesurés. Quatre des chèvres sous régime d'eau intermittent et trois des contrôles ont mis bas, les autres se sont avérées non-gestantes. Les chevreaux étaient allaités par leurs meres jusqu'à l'âge de 2 mois. Les résultats des chèvres qui ont mis bas ont été soumis à une analyse statistique selon le modèle des mesures répétées..Une analyse en composantes principales a aussi été effectuée pour les résultats du premier et du seizième jours de l'expérience.

Groupes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Restreint	S R	E	R		E	R		S E	R			S E	R			S E	R			E
Contrôle	S							S				S				S				

21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
R			E	R			E	R			E	R			S E
															S

S= Prise de sang, E= Eau à boire, R= Restriction

Figure 18. Calendrier de l'abreuvement et du prélèvement des échantillons pour les deux groupes de chèvres shamies en gestation, l'un abreuvé tous les jours et l'autre restreint en eau avec un abreuvement d'un jour sur quatre.

Résultats et discussion

Effets physiologiques

Les chèvres ont bien toléré la restriction en eau. En ne considérant que les chèvres qui ont mis bas, les animaux à régime d'abreuvement intermittent ont eu une osmolarité plus élevée et un taux d'insuline plus bas. Ceci est cohérent avec la littérature, étant donné que l'osmolarité

reflète la rétention des électrolytes au niveau des reins, ainsi que la baisse de la volémie sanguine suite au manque d'eau. Quant à l'insuline, cette baisse dénote un état de carence énergétique et la mobilisation des réserves adipeuses, étant donné que l'ingestion alimentaire était plus basse chez ces animaux. En prenant seulement les résultats des chèvres qui ont mis bas, l'osmolarité était le seul paramètre sanguin significativement différent entre les chèvres à régime intermittent et les contrôles ; ceci est probablement dû au petit nombre d'animaux inclus, ainsi qu'à une assez grande variabilité individuelle.

Effet sur le poids des chevreaux

Le poids des chevreaux à la naissance pour ceux dont les mères étaient restreintes en eau et le gain de poids à un mois d'âge ont eu tendance à être plus faibles. Des expériences similaires ne sont pas nombreuses dans la littérature avec des résultats différents selon les races. Les uns présentent que la restriction en eau chez les chèvres gestantes adaptées aux milieux arides n'a pas d'effet sur le poids de la progéniture, alors que d'autres montrent qu'un déficit alimentaire pendant cette période peut entraîner des effets négatifs à long terme.

L'analyse en composantes principales

L'analyse en composantes principales a montré que le nombre des chevreaux, ainsi que l'effet du jour (jour 1 comparé au jour seize) avaient un effet sur les variables. Ceci indique que le profil métabolique des chèvres a été influencé par le nombre des chevreaux portés, ainsi que par la restriction en eau, même avec un nombre d'animaux relativement réduit.

Conclusion

En conclusion, cette expérience a montré que les chèvres shamies en gestation pouvaient tolérer un régime d'abreuvement intermittent avec des perturbations physiologiques limitées. Par contre, le poids de la progéniture a été influencé par la restriction. Cet aspect mérite une étude plus détaillée avec un plus grand nombre de chèvres et sur une longue durée pour suivre les effets éventuels sur le potentiel productif de la progéniture.

b. Texte en anglais préparé pour publication : Responses of Shami goats in late gestation to an intermittent watering regime

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Keywords: Shami goats; intermittent watering; pregnancy; physiological indicators

Introduction

Goats are raised as dual purpose animals for milk and kid production (Hamadeh et al., 1996). The Shami (Damascus) breed which is native to arid countries is well known for its dairy potential and it has been exported to different regions (Mavrogenis et al., 2006), where high temperature and water shortage are common constraints.

Studies on the effect of water restriction on goat reproduction are very limited. Matebele goats were able to sustain a low plane of nutrition imposed as of 100 days post mating without any negative effects on gestation length, litter size or kid birth weight (Sibanda et al., 1999), although they experienced a 25% weight loss. Similar conclusions were also reported in desert adapted sheep subjected to prolonged intermittent watering (Mittal et Gosh, 1986).

The current project proposes to assess the effect of intermittent watering, a common practice in arid and semi-arid regions, on various physiological parameters of Shami does in late gestation.

Materials and Methods

The experiment was performed on the Beirut campus of the American University of Beirut (AUB) between November 6 and December 11, 2008. The average ambient temperature ranged between 12.6^{o}C and 21.6^{o}C and relative humidity between 54.5% and 76.1%. Ten multiparous Shami goats (ages 3-4 with an average weight of 57 kg) and supposed to be in late gestation, were selected from the flock of the Agricultural Research and Education Center (AREC) of the AUB. Gestation dating was based on visual observation during the mating season when the males were introduced to the flock. The animals were randomly allocated to two groups, in a way to achieve homogenous body-weight distribution in the two groups, separated by a partition in a closed barn (7x4x3m). Four does were kept as control receiving daily feed (25:75 concentrate and hay mixture) and water. The remaining six animals were offered daily feed but received 48 L of water only once every four days. Feed and water were offered per group and not per individual, in common feeders and water troughs accessible to

all animals. The hay and concentrate were weighed, mixed and offered at 8:00 am along with the water. Water of the restricted group was removed at 8:00 am 24 hours after watering. The left over feed and water were measured daily, before replenishing with fresh feed and water, and the quantities consumed by the group were calculated accordingly. The water restriction regime was implemented gradually starting with one day of water restriction followed by two cycles of two-day water restriction and then seven repeated cycles of three-day water restriction thereafter.

Blood samples were taken from the jugular vein early in the morning, at 7:00 am at the beginning of the experiment, and on days 7, 15 and 35 of the experiment. Additional samples were taken after one hour, right before offering water, for cortisol analysis. Blood collected in heparinized vacutainers was analyzed for Packed Cell Volume (PCV) and hemoglobin concentration. PCV was measured by the microhematocrit method (Microcapillary/centrifuge method) while hemoglobin concentration was determined using the cyanmethemoglobin method (Cork and Halliwell, 2002).

Serum from non-heparinized blood was also analyzed for cholesterol, total serum protein, albumin, globulin, urea and creatinine using a Roche/Hitachi 912 Analyzer (Roche Diagnostics GmbH Laboratory systems, D-68298 Mannheim). Osmolality was assessed by freezing point depression on a SLAMED osmometer (SLAMED ING GmbH, Frankfurt, Germany) and insulin was measured by IMMULITE Insulin Kit radioimmunoassay using IMMULITE Analyser (Diagnostic Products Corporation, Los Angeles). Furthermore, serum samples were analyzed for cortisol concentration by a solid-phase single antibody procedure, using radioimmunoassay kits (CORT-CT2, Cisbio, Bagnols-sur-Cèze, France).

At the end of the experiment, the animals were returned to their original flock where the goats and kids were offered daily the same feed and water as during the experiment. Three does from the control and four from the water restricted group, respectively, gave birth within two weeks of their return; their kids were weighed at birth and at 1 month of age. The kids were nursed by their mothers after birth until 2 months of age. The remaining does did not give birth and were presumed to have been non-pregnant throughout the experiment since no abortion or fetal loss symptoms were observed.

Statistical Analysis

The serum data of the goats that gave birth were analyzed using the General Linear Model-Repeated Measures application and with the data from the first collection (at the beginning of the experiments) as well as the number of kids per litter taken as covariate. The kid weight at birth was analyzed by the general linear model for one factor with the number of kids taken as covariate. The weight gain of the kids from birth to 1 month of age was analyzed by the general linear model for one factor with the number of kids and weight at birth taken as covariates, knowing that sex distribution of the kids was identical in the control and restricted groups. Finally, the mean daily feed and water consumption per animal, of getstating and non-gestating goats in the restricted and control groups, were compared by one way ANOVA. All the statistical analyses were run on IBM-SPSS (Version 19, SPSS. Inc.).

In order to understand the relationships between the variables and the effects of the dehydration, two principal component analyses (PCA) were performed: one for each experiment. As there were some data missing, we chose the variables observed during the first day of each experiment (used as a basal value) and the data after 2 weeks of dehydration. The objective of a PCA is to synthesize the overall information contained in a set of observed variables into a smaller number of linear combinations of orthogonal variables called Principal Components (PC). The PCs sequentially minimize the remaining variation in the

multivariate data space. Thus, the PCA condenses the information into loadings which show the relative importance (weighing) of the original variables in accounting for the variability in the observed data. The distribution of the observed data across the PCs is shown by the scores.

Results

The feed composition is presented in Table 1.

Feed and water consumption was higher in the control group than in the water restricted (Table 2).

Pregnant goats were able to carry their gestation to term with successful delivery and kid survival at 1 month of age (Table 2). In fact, the analysis revealed that most serum parameters were not different between the control and water restricted group. When all the goats (pregnant and non-pregnant) were included, osmolality was higher, while insulin was lower in the water restricted group as compared to the control (data not shown). When only the does that actually delivered are retained in the analysis, only osmolality was higher in the restricted group as compared to the control (Table 3).

Moreover, the kids of the water restricted does were lighter at birth and gained less weight by one month of age as compared to the control (Table 2).

Based on the Principal Component Analysis, the first two components explained around half of the total variance (Figure 1) which is quite good in relation to the number of variables used (12). For the first component, there was an opposition between the concentrations of protein and globulin on one hand, and the other blood parameters on the other hand. For the second component, there was an opposition between insulin, cholesterol, and albumin on one hand and protein, globulin, and osmolality on the other hand.

Discussion

The decrease in feed intake in water restricted animals was expected based on previous literature. In fact, the decrease in feed intake is one of the first observations reported under water restriction in many sheep (Alamer and al-Hozab, 2004; Jaber et al., 2004) and goat breeds (Alamer, 2006).

The capacity of goats, indigenous to arid and semi-arid regions, to replenish their water shortage in a very short time is well documented (Silanikove, 2000). This was demonstrated in this experiment whereby the water restricted animals drank on the day of rehydration 1.7 more than the daily consumption of the control group. This capacity to ingest large water quantities without disruption of the homeostasis denotes the adaptation of these goats to partial dehydration.

The effect of the treatment on body weight was observed in the kids at birth and a tendency for lower weight gain at one month of age in the restricted group. Research on the Matebele goat showed that a low nutrition level during late pregnancy had little effect on kid birth weight (Sibanda et al., 1997). Similarly, a twice weekly watering regime imposed for a prolonged period had no effect on birth weight of desert adapted Magra and Marwari sheep (Mittal and Gosh, 1986). In a review by Roussel et al. (2007), it was pointed out that studies on the effects of prenatal stress on farm animals is still scarce, although work on laboratory animals seems to indicate important consequences of such stress on behavioral, physiological and immunological parameters in the newborn and mature animal. In fact, most of the published research after this review covers experiments on social prenatal stress in pigs, with

an interest in stress effects on the hypothalamic–pituitary–adrenal axis, hippocampus activities, behavior and the immune system (Lay et al., 2008; Otten et al., 2008; Couret et al., 2009; Ison et al., 2010; Otten et al., 2010). The effect of prenatal stress on birth weight of offspring was assessed in only few articles in sheep and pigs, with similar results indicating little effect of the treatment (Couret et al., 2009; Otten et al., 2008; Roussel-Huchette et al., 2008). Working on goats, Mellado et al. (2006) highlighted the importance of goat birth weight and weight gain at 25 days of age on their future reproductive performance under intensive conditions in hot arid environments. On the other hand, in a recent study by Laporte-Broux et al. (2011), the authors found that prenatal feed restriction in the last trimester resulted in lower male offspring weight in goats, but had no effects on later behavior and growth. Further studies are needed to assess the long term consequences of the observed effects on the newborns.

The higher osmolality observed in the restricted group was expected based on previous published results indicating consistently high osmolality in dehydrated animals irrespective of the physiological status (Dahlborn 1987, Hossaini-Hilali et al. 1994, Mengistu et al. 2007). This is due to the loss of body water and consequently blood volume, as well as to the retention of electrolytes at the level of the kidneys. On the other hand, water restricted animals gestating and non gestating) had a decrease in insulin; this is probably a reflection of energy deficit and body fat mobilization due to the decrease in feed intake (Jaber et al., 2011).

The Principal Component Analysis helped us to see that on the first two components, the number of kids born had an effect on the score plots, especially on the first principal component. The effect of the day was more apparent in the water restricted group, based on the marked differences between the first and the 16^{th} day of the trial. We can conclude that the number of kids modified the metabolic profile of the goats and that the water restriction had also a specific impact, in spite of the small number of animals studied.

Conclusion

This study provided a preliminary insight into the adaptability of the Shami breed to an intermittent watering regime under late gestation, a physiologically demanding condition. The results indicate that the treatment had little effect on the gestating animals, but reflected negatively the kids' birth weight and weight gain at one month of age. These findings warrant larger scale research on this economically important breed to assess its adaptability to long-term water shortage at the different stages of its reproductive cycle, and under different environmental conditions.

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Table 1. Feed composition

Feed composition	Concentrate[a]	Hay[b]
Dry Matter (%)	90.0	80.8
Crude Protein (%)	15.54	7.34
Ether Extract (%)	3.71	2.25
Crude Fiber (%)	6.95	26.12

[a] Concentrate composition: Yellow corn (40.8%), Soybeanmeal 44 (15%), Wheat bran (20%), Barley (20%), Limestone (2.7%), Di-Cal (0.72%), Salt (0.65%), Vitamin premix (0.1%)

[b] Barley and Vetch hay

Table 2. Kids weight and feed and water intake of Shami goats subjected to daily versus once every four days watering regime during 35 days

	Control	Water restricted	P value (Treatment)
Number of does	4	6	
BW at start of experiment (kg)	58.0±2.31	56.4±3.12	0.73
Dry matter intake (kg/d/animal)	1.7±0.03	1.2±0.06	0.01
Average water intake from feed (kg/d/animal)	0.3±0.00	0.2±0.01	0.01
Free water intake (L/d/animal)	4.4±0.25	2.1±0.6 (7.8)[a]	0.00
Total Water Intake (ml/d/kg $BW^{0.75}$)	224.6±12.04	115.2±28.43	0.00
Number of does delivered	3	4	
Average number of kids	2.3 ± 0.28	1.7 ± 0.28	0.122
Average kid weight at birth	4.1±0.05	4.0±0.05	0.00
Average daily weight gain at 1 month (g/d)	170.2±13.97	126.4±13.97	0.09

[a] Average quantity consumed during the day of rehydration

BW = Body weight

Table 3. Blood chemistry parameters in pregnant Shami goats subjected to daily versus once every four days watering regime during 35 days

	D1		Mean D8-D35		P values
	Control (n=3)	Water restricted (n=4)	Control (n=3)	Water restricted (n=4)	Treatment
PCV (%)	22.5±1.04	26.12±1.83	24.9±1.30	26.8±1.10	0.385
Hb	87.7±3.18	106.0±7.56	83.5±7.72	84.3±6.42	0.950
Cholesterol (mmol/L)	1.4±0.11	1.6±0.21	1.6±0.13	1.7±0.11	0.649
Insulin (pmol/L)	37.0±19.60	26.7±7.92	77.0±11.59	41.4±9.72	0.123
Protein (g/L)	78.3±0.33	81.7±2.63	80.8±2.80	78.4±2.35	0.594
Globulin (g/L)	46.0±1.45	49.2±3.68	46.0±1.47	45.3±1.25	0.745
Albumin (g/L)	32.3±1.45	32.5±1.19	33.9±0.68	33.8±0.58	0.930
Creatinine (µmol/L)	41.0±6.00	53.0±3.67	56.5±2.62	62.3±2.16	0.231
Urea (mmol/L)	6.4±0.20	6.5±0.17	6.9±0.46	8.7±0.38	0.078
Osmolality (mOsm/kg)	291.0±1.53	289.0±1.87	287.5±1.91	303.2±1.61	0.011
Cortisol (nmol/L)	12.3±4.37	33.5±10.31	37.7±10.76	34.3±9.03	0.836

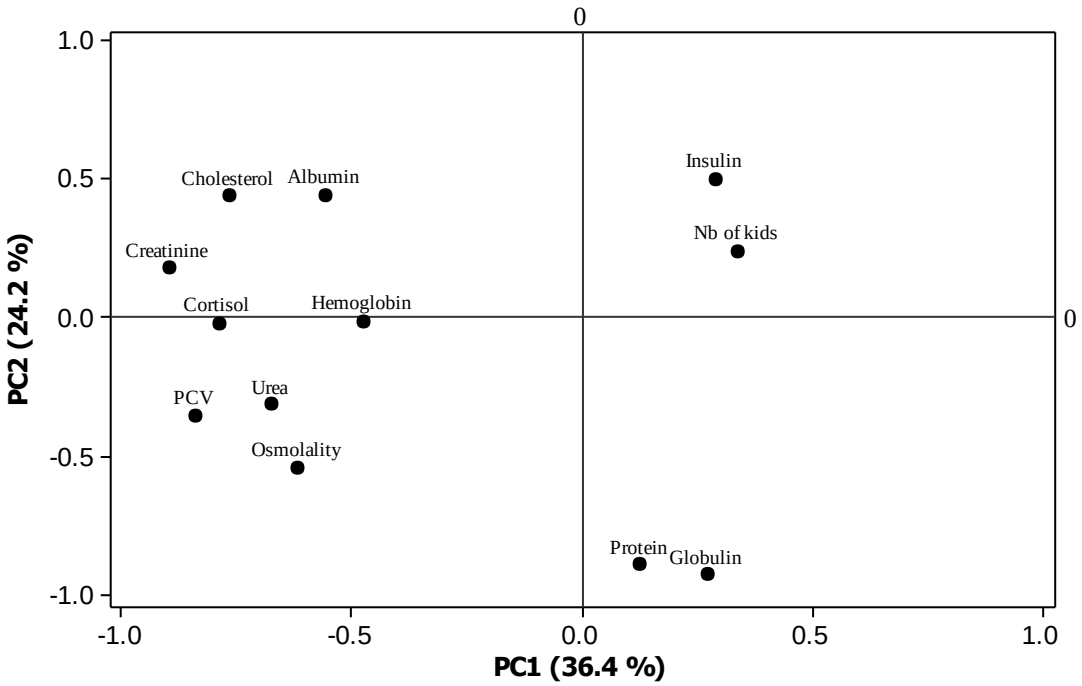


Figure 1. Results of a principal component analysis based on the blood components and the number of kids. The % of total variance accounted for by each of the first two components (PC) is shown in parentheses.

CHAPITRE 3 : EFFET D'UNE RESTRICTION EN EAU CHEZ DES CHEVRES SAANEN ET ALPINES (EXPERIMENTATION EFFECTUEE EN FRANCE)

L'élevage caprin dans les régions tempérées est bien développé et les races indigènes de ces pays sont reconnues et exportées à travers le monde pour leur grande productivité laitière. Cependant, dans ces nouvelles destinations, ces races doivent souvent faire face à des conditions climatiques défavorables caractérisées par des températures élevées et de la sécheresse, ainsi qu'une alimentation de faible valeur nutritionnelle. De plus, les épisodes de chaleur et de sécheresse deviennent de plus en plus communs dans les régions tempérées.

Cette expérimentation avait pour objectif d'évaluer l'effet d'une restriction en eau sur des chèvres Saanen et alpines en milieu de lactation. Elle a aussi été valorisée pour étudier les conséquences d'une augmentation importante de température sur les réponses physiologique et comportementale de ces chèvres. Les résultats de la première partie ont donné lieu à une communication dans une conférence internationale, et l'autre partie a abouti à deux communications dans deux conférences différentes, l'une relatant des effets de l'épisode de chaleur sur le comportement d'ingestion et de buvée des chèvres et l'autre sur les réponses physiologiques à la restriction en eau.

3.1. Un court épisode de restriction en eau chez des chèvres Saanen et alpines

a. Résumé en français

Ce projet avait pour objectif d'évaluer l'effet de deux périodes de restriction en eau, courtes et consécutives, sur la physiologie et la production de chèvres Saanen et alpines en lactation, sous un climat tempéré.

Matériel et méthodes

L'expérience s'est déroulée en France, du 21 au 25 Juin 2010, sur 8 chèvres Saanen et 8 chèvres alpines (160 jours de lactation). Les chèvres avaient libre accès à la nourriture qui était distribuée en deux fois, le matin et l'après-midi, après la traite. Le poids des animaux ainsi que les quantités d'eau et d'aliments ingérés étaient mesurés tous les jours. Grâce à des balances individuelles placées sous chaque auge et sous chaque bidon d'eau, les cinétiques des ingestions ont été enregistrées toutes les 2 minutes simultanément sur 8 des chèvres (4 Saanen et 4 alpines), les huit autres chèvres étaient en cases de digestibilité, permettant de prendre des échantillons de fèces et d'urine pour analyse. Le premier jour, l'eau et la nourriture étaient disponibles *ad libitum*, le deuxième et le troisième jour, l'eau était coupée après la traite de l'après-midi jusqu'après la traite du lendemain matin. Les deux derniers jours l'eau était offerte normalement, deux fois par jour. Des échantillons sanguins et de lait ont été prélevés tous les matins et leur composition chimique a été analysée. Les résultats des jours 2-5 ont été comparés par t-test aux résultats obtenus au jour 1 (contrôle), pour chacun des paramètres analysés. Les résultats des deux races ont été comparés et comme il n'y avait pas de différences significatives, les résultats de tous les animaux sont présentés ensemble.

J1	J2	J3	J4	J5
- Eau *ad lib*.	- Eau *ad lib*. puis retirée après la traite de l'après-midi, jusqu'au lendemain matin.		- Eau *ad lib*.	

Figure 19. Calendrier de l'expérience de restriction en eau chez des chèvres alpines et Saanen en lactation

Résultats et discussion

La restriction en eau a abouti à une baisse de la quantité d'eau bue pendant le premier jour de restriction, alors que les deux derniers jours de l'expérience, les chèvres ont bu des quantités bien supérieures au premier jour. La capacité des chèvres à compenser l'eau perdue pendant une restriction de courte durée montre leur aptitude à la réhydratation rapide sans risque d'hémolyse, ce qui est similaire aux réactions observées chez les chèvres adaptées des régions arides et semi-arides souvent exposées a des restrictions en eau. De même, les chèvres ont diminué leur ingestion pendant la restriction en eau, ceci étant une réaction prévue étant donnée l'importance de l'eau pour une fonction digestive normale. Cependant, les chèvres ont gagné du poids vers la fin de l'expérience, probablement en raison des grandes quantités d'eau bue. Pendant la restriction en eau, les huit chèvres en cases de digestibilité ont produit un volume d'urine plus réduit et des fèces à taux de matière sèche plus élevé. Ceci est une indication de l'activation des mécanismes de conservation de l'eau au niveau des reins et du système digestif, tel qu'observé dans d'autres races soumises à une restriction d'eau.

Le protocole de restriction en eau suivi dans cette expérience a été efficace pour produire les signes de déshydratation au niveau des paramètres physiologiques tels que ceux décrits dans la littérature. Le premier signe a été une hausse de l'albumine qui reflète une baisse du volume sanguin probablement à cause de la redistribution de l'eau sanguine vers d'autres compartiments pour maintenir un fonctionnement normal. De même, les taux de sodium et d'urée étaient plus élevés pendant la restriction en eau. Ceci est en accord avec la littérature à ce sujet indiquant une rétention de ces composants au niveau des reins menant à une rétention en eau. Ce résultat est confirmé par la baisse du volume d'urine durant la restriction. La rétention des électrolytes mène à son tour à une osmolarité plus élevée, ce qui a été le cas dans cette expérience. Par contre, le dernier jour de l'expérience, suite à 24 heures de réhydratation, l'osmolarité, l'urée et l'albumine ont baissé à un niveau inférieur au contrôle (jour 1). Cela semble indiquer que les grandes quantités d'eau bue après la réhydratation étaient retenues et que l'équilibre normal du sang n'était pas parfaitement rétabli au bout des 24 heures. Une analyse plus approfondie du fonctionnement des reins et du volume d'urine produit après réhydratation serait utile pour éclaircir ces observations.

Les résultats des taux de glucose et d'acides gras non-estérifiés (AGNE) semblent indiquer que les chèvres étaient en bilan énergétique positif bien qu'elles aient diminué leur quantité d'aliments ingérée. Le taux d'AGNE qui avait tendance à baisser durant l'expérience renforce la proposition du bilan énergétique positif aussi démontrée par la prise de poids. La hausse de la glycémie pendant les deux jours de restriction pourrait être due à un changement du comportement des chèvres vis à vis de la prise alimentaire ; on suppose qu'elles auraient pu manger tôt le matin, avant le prélèvement des échantillons sanguins, alors qu'en temps normal elles opteraient pour attendre jusqu'au retour de la traite. Cette hypothèse nécessite l'analyse des cinétiques d'ingestion pour être vérifiée.

Cette observation imprévue sur la glycémie a été explorée plus en détails en cherchant à établir un rapport entre la glycémie et la prise alimentaire (analyse non incluse dans les proceedings en anglais, plus bas). La quantité d'aliments ingérée pendant les deux heures précédant le prélèvement sanguin, a été relevée pour huit des chèvres (4 alpines et 4 Saanen), et analysée par rapport à la glycémie. La figure 20 montre que l'élévation de la glycémie était en effet accompagnée d'une ingestion alimentaire plus élevée chez les chèvres restreintes pendant les deux heures précédant le prélèvement sanguin. La littérature mentionne que sous l'effet du stress le taux du glucose s'élève, suite à celui du cortisol (Kannan et al., 2000). Ceci offre une autre possibilité à explorer pour l'interprétation de ces résultats, qui reste à confirmer à travers des recherches ultérieures de plus longue durée et en prenant le cortisol comme indicateur de stress.

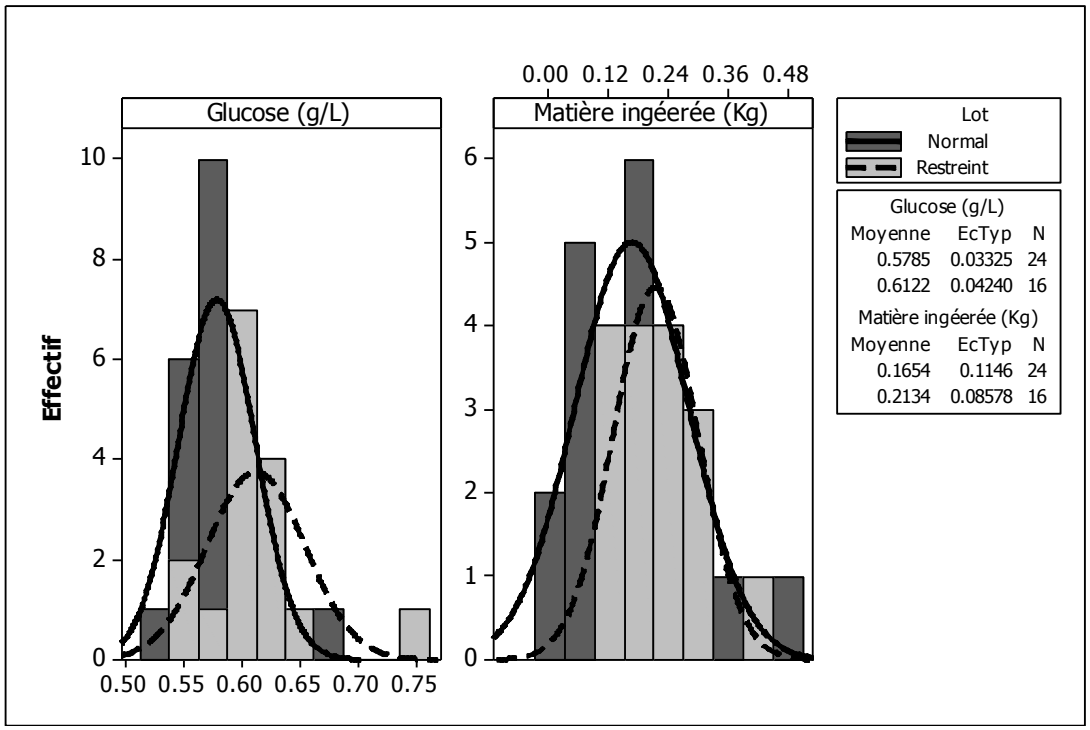


Figure 20. Histogramme du glucose à l'heure de la prise de sang et histogramme de la quantité de matière ingérée pendant les deux heures précédant la prise de sang.

La production laitière a été maintenue pendant la restriction en eau, alors que le lactose et l'urée de lait ont eu tendance à s'élever suite à la restriction. Par contre, au cinquième jour, les chèvres semblent avoir produit un volume de lait un peu plus élevé, mais à composition un peu plus diluée. Ces observations, rappellent les résultats de la composition sanguine surtout que le lait est maintenu en isotonicité avec le sang grâce au lactose. Le taux butyreux n'a pas changé significativement pendant la restriction, bien qu'il ait eu tendance à baisser au long de l'expérience. Les rapports de la littérature sur ce sujet sont rares.

Conclusion

En conclusion, cette expérience a montré l'aptitude des chèvres alpines et Saanen en lactation à s'adapter à une restriction en eau de courte durée. Bien qu'elles aient montré des signes de déshydratation, leur poids et leur production laitière ont été maintenus. Des études de plus longue durée et des données comportementales, seraient utiles pour évaluer et mieux comprendre les effets de tels traitements sur ces deux races.

b. Texte en anglais du proceeding présenté en conférence : Short water restriction episode in lactating alpine and saanen goats

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Abstract

This project aims to assess the effect of a short episode of water restriction on high producing lactating goats. Water was withheld from eight Saanen and eight Alpine goats after the afternoon milking and until the following morning, on two consecutive days. Water and feed intake, body weight and major blood parameters were assessed daily for one day before, during water restriction, and two days after. Milk production and composition was also measured on a daily basis. The results showed that the animals experienced some dehydration due to the treatment, although they were able to maintain a total water intake similar to the control values recorded on day 1. A drop in feed intake was observed on the days of water restriction although body weight was not affected. Several blood indicators also pointed to the state of dehydration the animals were experiencing namely the increase in albumin, urea, osmolality and Na^+. The goats were able to maintain milk production although milk composition was altered; milk urea and lactose increased under water restriction thus keeping milk isotonic with the blood. The observed changes reflect the activated mechanisms that limit body water loss and prevent further dehydration. It was concluded that high producing goats were able to sustain two short consecutive cycles of dehydration and rehydration, as indicated by their maintained body weight and milk production, with only transient physiological and milk changes.

Keywords: Alpine, Saanen, Lactation, Water restriction

INTRODUCTION

Goat production is an important economic activity in Europe and in rural areas around the world where it is mostly practiced under extensive systems with great dependency on natural resources and environmental conditions [8]. Heat waves and water shortage are being experienced more commonly nowadays including in Europe where a temperate weather used to prevail. Goat breeds show great variability in their adaptations to these conditions. On the one hand, native breeds to arid and semi-arid regions have been well studied and showed high resilience in facing heat and drought by resorting to special adaptive mechanisms including high renal water retention, rapid water replenishment upon rehydration with slow release into the blood to prevent hemolysis, and minimizing water loss for evaporative cooling [1, 13, 14]. On the other hand, European breeds have rarely experienced these conditions in the past but are now being challenged in their native countries as well as in the wide places to where they are exported due to their high productivity. This project aims to assess the effect of two consecutive periods of water restriction on the physiology and production of Saanen and Alpine goats in mid-lactation raised under their native European climate.

MATERIALS AND METHODS

The experiment was conducted at the Experimental Farm of the research Unit INRA-AgroParisTech MoSAR (Thiverval-Grignon, France (48°51' N; 1°55' E); 70 m above sea level). Eight Alpine and eight Saanen goats (160 DIM at the start of the experiment) were included. The animals were housed in metabolic cages and were well adapted to the experimental setting (housing, feeding and human manipulation) which was applied 20 days prior to the beginning of the experiment. The experiment period lasted for five days during which water was offered *ad libitum* during the first day, then on days 2 and 3 water was withheld after the afternoon milking until the following morning (15h of restriction), and finally on days 4 and 5 water was offered *ad libitum*. The animals had free access to feed which was composed of dehydrated lucerne (30 %), meadow hay (20 %), pressed sugar beet pulp (30 %) and compound concentrate feed (20 %), on dry matter basis. The feed was offered on *ad libitum* basis by making sure 10% was left over; feed quantities were re-adjusted accordingly, on weekly basis. Individual water and feed consumption was measured daily as well as body weight, rectal temperature and milk production. For half of the goats, urine and faecal output was measured on the first three days of the experiment. Daily milk samples were analysed for fat, protein, lactose and urea. Jugular blood samples were taken each morning, before offering fresh water and feed. Na^+ was immediately determined by a blood gas and mineral analyzer (ABL 77, Radiometer, Copenhagen Denmark). Plasma was harvested and stored at −20 °C until assays for glucose, non-esterified fatty acids (NEFA), albumin and urea using a Cobas Mira-Analyzer (Roche, Mannheim, Germany) with commercial kits for glucose (Gluco-quant, Glucose/HK, Roche Diagnostic, Mannheim, Germany), NEFA (NEFA-HR(2), Wako, Chemical GmBH, Neuss, Germany), albumin (80002, Biolabo, 02160, Maizy, France) and urea (Urea/BUN, Roche Diagnostic, Mannheim, Germany). Osmolality was determined with a MARK3, Radiometer analytical S.A. osmometer (manufactured by FISKE® ASSOCIATES, Norwood, MA) by a method based on the depression in the critical freezing point. Environmental temperature and humidity were recoded three times per day.

The data were analysed by paired-t test using the IBM-SPSS Statistics 21 software. Day 1 was used as the control for each animal and was compared separately to each of the subsequent days of the experiment.

RESULTS AND DISCUSSION

The water restriction regime caused a significant decrease in water intake (Table 1) on the first day of water restriction. However, on days 4 and 5, water consumption exceeded the control level. This could indicate a reaction of overcompensation whereby the animals tend to drink large volumes of water at a time in anticipation of future water shortage episodes. In fact, in this experiment the water drank in the morning right after rehydration was more than twice the amount taken on the day of normal watering (2.88L vs. 6.4L and 6.8L on D1 vs. D2 and D3, respectively). Such behaviour was previously observed in arid-adapted breeds and denotes the capacity to tolerate rapid rehydration without risking haemolysis [9, 14]. Another factor that could explain the increase in water consumption is the observed increase in ambient temperature during the experimental period (from 15.6^{o}C to 19.1^{o}C and 19.0^{o}C to 23.3^{o}C in the morning and afternoon, respectively). In fact, the increase in ambient temperature was also reflected by higher rectal temperatures (Table 1) although the temperature range remained within the thermoneutral zone of the animals [5]. The increase in water consumption may be needed for cooling in response to the added heat load. In contrast, the animals reduced their feed intake under water restriction (Table 1). This response to water restriction is widely observed in small ruminants since water is needed for proper digestive function [6]; it is thought to prevent feed accumulation and compaction in the digestive tract. However, the animals' body weight seemed to increase throughout the experimental period

which may indicate that water consumption has a greater effect on body weight than feed consumption during the short term of this experiment.

Table 1 Water and feed intake, body weight, rectal temperature and fecal and urine output of lactating Saanen and Alpine goats subjected to two successive 15h periods of water restriction

Parameter	D1	D2[1]	D3[1]	D4	D5
Water intake (L)	7.26 ± 0.301	6.41[2] ± 0.301	6.85 ± 0.282	8.04[2] ± 0.359	8.32[2] ± 0.381
Feed intake (kg)	5.45 ± 0.129	5.02[2] ± 0.127	5.00[2] ± 0.134	5.29[2] ± 0.136	5.40 ± 0.140
Body weight (kg)	60.6 ± 1.82	61.4 ± 2.19	62.0[2] ± 1.86	63.1[2] ± 1.96	62.5[2] ± 1.99
Rectal temperature (^{o}C)	38.54 ± 0.056	38.70[2] ± 0.044	38.80[2] ± 0.044	38.84[2] ± 0.050	38.83[2] ± 0.057
Wet Fecal material output (kg)	3.30 ± 0.171	3.45 ± 0.209	3.45 ± 0.143		
% Fecal material dry matter (%)	27.3 ± 0.71	29.2[2] ± 1.02	28.5[2] ± 0.69		
Urine (L)	1.11 ± 0.089	0.89[2] ± 0.089	1.25 ± 0.124		

[1]Water removed after the afternoon milking until next morning
[2]Means are significantly different from D1 ($P<0.05$)

Water restriction led to a decrease in urine output during the first day, in contrast, the fecal output was not significantly affected (Table 1). However, fecal dry matter content increased under water restriction. These observations indicate that the animals have activated their water conservation mechanisms at the level of the kidneys and through the digestive tract, to minimize water loss and further dehydration. Highly adapted sheep breeds have been reported to produce very small amounts of highly concentrated urine when subjected to prolonged water restriction [10, 15]. The Alpine and Saanen goats of this experiment seem to show similar trends in short-term water restriction episodes.

The protocol of water restriction applied in this experiment was effective in causing the physiological signs of dehydration as commonly reported in literature (Table 2). The first sign was the increase in blood albumin observed on D3 and D4 following water restriction and right before watering. This increase denotes a reduction in blood volume, whereby blood water may have been circulated to other body compartments to maintain normal function [9, 12]. Furthermore, blood Na^{+} and urea increased under water restriction. Previous studies have indicated that the increase in these parameters is a sign of the activation of water conservation at the level of the kidneys since Na^{+} and urea reabsorption by the nephrons leads to water reabsorption [11]. This also justifies the previously observed decrease in water urine output. The increase in blood electrolytes in turn causes an increase in osmolality which is observed in this experiment as in the literature [4, 12]. It is worth noting that osmolality, urea and albumin dropped slightly below the control levels on D5 following 24 hours rehydration. This could indicate that the animals maintained the over-drinking behavior for one day after the water restriction episode, probably in anticipation of possible future restrictions. It was previously reported that small ruminants may show a slow return to normal blood composition upon rehydration, although they ingest large volumes of water, as an adaptation to prevent hemolysis [8]. The slightly lower values observed on D5 indicate a return to normal blood volume or maybe more due to the water influx from the rumen. It would be interesting to evaluate the blood rehydration status in relation to the urinary output in order to

assess whether kidney function was also restored simultaneously to rid the body of the excess water.

Table 2 Blood chemistry parameters in lactating Saanen and Alpine goats subjected to two successive 15h periods of water restriction

Parameter[1]	D1	D2[2]	D3[2]	D4	D5
Glucose (g/L)	0.583 ± 0.0054	0.583 ± 0.0112	0.625[3] ± 0.0167	0.612[3] ± 0.0075	0.571 ± 0.0071
NEFA (mmol/L)	137± 6.6	136 ± 6.4	133.00 ± 4.771	127± 3.3	125 ± 4.2
Urea (g/L)	0.256 ± 0.0171	0.235 ± 0.0148	0.331[3] ± 0.0169	0.397[3] ± 0.0280	0.250 ± 0.0136
Albumin (g/L)	43.43 ± 0.371	43.98 ± 0.358	46.04[3] ± 0.523	44.61[3] ± 0.382	42.78 ± 0.342
Osmolality (mOsm/kg)	294 ± 0.6	293 ± 0.7	306[3] ± 0.9	307[3] ± 0.7	292[3] ± 0.5
Na^+ (mmol/L)	142 ± 0.3	143[3] ± 0.4	149[3] ± 0.4	148[3] ± 0.5	143 ± 0.3

[1]Blood was sampled in the morning before offering feed and water
[2]Water removed after the afternoon milking until next morning
[3]Means are significantly different from D1 ($P<0.05$)

The glucose and NEFA results (Table 2) seem to indicate a status of positive energy balance during water restriction although the animals have decreased their overall feed intake. It could be speculated that the significant increase in glucose on D3 and D4 is an indication of altered eating pattern by the thirsty animals which caused the surge in glucose at the time of measurement, while under normal watering the animals would delay eating until fresh feed and water are offered. Previous reports on glucose levels under dehydration are inconclusive, however, it is generally noted that a decrease in feed intake usually leads to a decrease in glucose levels [8]. Behavioral observations on the timing of feed intake under water restriction are needed to clarify the results obtained in this experiment. The NEFA tended to decline over the experimental period, further denoting that the animals were in fact in positive energy balance [7], which may also explain why there was no weight loss observed.

On the one hand, milk production was maintained under water restriction with a slight surge in production on D5 (Table 3). On the other hand, lactose and urea tended to increase following water restriction on D3 and D4. It was previously observed that lactose plays an important role in keeping the milk isotonic with the blood [4]. Therefore, in view of the increased blood urea, albumin and osmolality, the changes observed in milk composition are a reflection of the changes in blood. Similarly, the surge in production and slight drop in major milk components on D5 may be another reflection of a transient state of over-hydration as noted above, whereby the animals tended to produce larger, but more dilute, volume of milk. Milk fat was not significantly affected by water restriction but seemed to slightly decline throughout the experimental period. Alamer (2009) [2] reported a decrease in fat content of milk in 25% water restricted goats while those that were 50% restricted maintained normal fat content. Longer term experiments maybe helpful to determine the effect of water restriction on milk composition of high producing European goats.

Table 3 Milk production and composition of lactating Saanen and Alpine goats subjected to two consecutive 15h periods of water restriction

Parameter	D1	D2[1]	D3[1]	D4	D5
Milk production (L)	3.61 ± 0.119	3.59 ± 0.108	3.57 ± 0.110	3.60 ± 0.110	3.73 ± 0.107
Milk fat (g/kg)	33.1 ± 1.07	33.0 ± 1.056	32. 8 ± 1.137	32.3 ± 1.05	32.0 ± 0.87
Milk protein (g/Kg)	31.9 ± 0.58	31.6[2] ± 0.56	31.8 ± 0.59	31.6 ± 0.46	31.5[2] ± 0.52
Lactose (g/kg)	43.8 ± 0.36	43.8 ± 0.37	44.6[2] ± 0.41	44.1 ± 0.45	43.5[2] ± 0.37
Milk urea (g/kg)	0.567±0.0142	0.536[2] ± 0.0141	0.592±0.0199	0.596±0.0182	0.517[2]±0.0167

[1]Water removed after the afternoon milking until next morning
[2]Means are significantly different from D1 ($P<0.05$)

CONCLUSIONS

This experiment demonstrated the capacity of high producing Alpine and Saanen goats to adapt to a short term water restriction regime. Although signs of dehydration were observed, they were temporary and did not seem to affect the overall status of the animal as attested by their maintained body weight and milk production. Longer-term studies would be interesting to assess the effect of such watering regimes over an extended period; in addition behavioral data on water and feed intake would be helpful to explain all aspects of these breeds' adaptability to water shortage.

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3.2. Les effets d'un stress de chaleur chez des chèvres laitières élevées en conditions tempérées

a. Résumé en francais

L'objectif de cette expérience était d'évaluer les effets d'une période de forte chaleur chez des chèvres alpines et Saanen en lactation. Des paramètres physiologiques, ainsi que la cinétique de l'ingestion d'eau et d'aliment ont été considérés. Les résultats ont été présentés sous la forme de deux proceedings en anglais à deux conférences différentes, mais ils sont résumés en un seul texte français ci-dessous.

Matériel et méthodes

L'expérience s'est déroulée en France sur quatre chèvres Saanen et quatre chèvres alpines en cases individuelles. Les chèvres avaient libre accès à l'eau et à la nourriture qui était distribuée le matin et l'après-midi après la traite. Les animaux étaient pesés chaque semaine alors que les quantités d'eau et d'aliments ingérés étaient mesurées tous les jours. Grâce à des balances individuelles placées sous chaque auge et sous chaque bidon d'eau, les cinétiques des ingestions ont été enregistrées toutes les 2 minutes. De même, les latences entre le début de l'ingestion alimentaire et la buvée ont été notées. La proportion d'aliments et d'eau ingérée dans les 180 minutes suivant la traite du soir a aussi été calculée.

L'expérience a eu lieu sur deux périodes de 5 jours chacune en juin 2010. La première période a servi de contrôle, alors que, pendant la seconde période, la température ambiante était plus élevée. La température et l'humidité ont été enregistrées à trois reprises chaque jour. La production laitière a été mesurée tous les jours et des échantillons de lait ont été prélevés pour l'analyse des taux protéique et butyreux. Finalement, des échantillons sanguins ont aussi été prélevés à deux reprises dans chaque période et analysés pour leur concentration en métabolites et gaz.

Les résultats ont été analysés par la procédure mixte de SAS® pour mesures répétées avec l'effet période (Periode contrôle *vs.* periode de stress thermique), chèvre (variabilite individuelle) et l'interaction chèvre x période inclus dans le modèle. Une analyse en composantes principales a aussi été effectuée pour évaluer l'effet de la période et de la race sur les douze paramètres les plus importants de l'étude.

Résultats et discussion

Les conditions climatiques de la seconde période peuvent être considérées comme marginalement stressantes étant donné que l'index THI n'a dépassé 72 que dans l'après-midi de la seconde période. Cependant, la température et l'humidité enregistrées pendant la seconde période étaient toutes plus élevées, et plus basses, respectivement, que celle de la première période, à l'exception de l'humidité du matin. Avec ces conditions, les chèvres n'ont pas modifié leurs quantités d'aliments ingérés, mais elles ont bu une plus grande quantité d'eau, probablement pour compenser l'eau perdue pour se rafraîchir. Ainsi, les taux d'urée et de Na^+ sanguins ont été plus élevés pendant la deuxième période (tendance pour le Na^+), ce qui indique un état de déshydratation modérée par rapport à la première période. Les résultats ont montré une différence entre les Saanen et les alpines pour le rapport eau/matière sèche ingérée, les alpines ayant un rapport plus élevé. Cette observation peut être due au fait que les alpines ont ingéré une plus grande quantité d'aliment, ce qui a nécessité une plus grande quantité d'eau pour dissiper la chaleur issue de la fermentation ruminale. De plus, ayant un pelage plus foncé, les alpines pourraient être plus touchées par la chaleur, comme l'ont noté

d'autres chercheurs en étudiant l'effet de la couleur du pelage en cas de stress thermique chez les vaches. Les résultats ont aussi montré que les chèvres s'étaient mises à boire plus tôt pendant la seconde période, indiquant une soif plus prononcée. Les chèvres ont montré une alcalose respiratoire pendant la seconde période (baisse du pCO_2) probablement due à l'hyperventilation souvent observée sous stress thermique comme moyen de rafraîchissement, et qui a mené à l'expiration accélérée de CO_2. Cette perte de CO_2 a probablement abouti à la baisse du HCO_3 observée pendant la seconde période. Un autre indicateur de stress thermique ressenti pendant la seconde période a été la hausse de la température rectale, telle qu'aussi observée dans la littérature. La glycémie a baissé pendant la seconde période ainsi que le taux des AGNE (tendance). Ces résultats peuvent être dus à la variabilité individuelle, surtout que l'ingestion alimentaire n'a pas changé. Le stress thermique n'a pas eu d'effet sur la production laitière. Par contre, les taux protéique et butyreux ont baissé. D'autres chercheurs avaient observé une baisse de la production laitière ainsi que du taux protéique et butyreux chez des animaux sous stress thermique. Le libre accès à l'eau pendant cette expérience pourrait expliquer le maintien de la production laitière. Finalement, l'analyse en composantes principales a montré qu'un peu moins de la moitié de la variabilité pouvait être attribué aux deux premières composantes. Cette analyse a montré que lorsque la température ambiante s'élève, l'ingestion d'eau et la température s'élèvent, tandis que le pCO_2 et les composantes du lait baissent. L'analyse en composantes principales a aidé à établir l'effet de la période et de la race sans qu'il y ait d'interaction entre les deux facteurs. Les deux races ont présenté des lignes de réponses parallèles, montrant que le stress hydrique avait les mêmes effets sur les deux races.

Conclusion

En conclusion, les chèvres européennes à haute production semblent bien tolérer un épisode de stress thermique modéré de courte durée. Cependant, des recherches plus approfondies sur l'équilibre et le mouvement de l'eau dans le lait, l'urine et les fèces seraient intéressantes pour compléter les données de cette expérience. De même, des études de plus longue durée pourraient être utiles pour étudier l'effet du stress thermique à long terme sur la production de ces chèvres, en vue du réchauffement climatique global.

b. Texte en anglais du premier proceeding présenté en conférence : Effect of a heat stress episode on feed and water intake in dairy goats bred under temperate climate

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Abstract. The effect of a heat stress episode was studied in eight dairy goats bred under temperate climate with *ad libitum* access to water. The increase in temperature from 19 to 28°C (recorded at 5 pm) modified neither feed intake nor the global shapes of feed and water intake patterns. However, there was a 40% increase in water intake and the latency from the beginning of the afternoon meal to the first water intake decreased from 35 to 26 min. Blood PCO_2 decreased because the animals hyperventilated to reduce their body temperature, whereas rectal temperature increased by around 0.6°C. Milk production was not modified, but milk fat content decreased. A significant goat effect was observed for almost all the results. Goats from the Alpine breed drunk more water when expressed on a dry matter intake basis than those from the Saanen breed. This could be explained either by their higher level of feed intake which enhanced the post-prandial heat production or by the difference in latent heat dissipated through sweating linked to coat colour.

Keywords. Heat stress – Intake behavior – Lactating goats – Temperate climate – Water intake.

Title. Effet d'un stress de chaleur sur le l'ingestion d'aliment et d'eau chez des chèvres laitières élevées en conditions tempérées

Résumé. *L'effet d'un stress de chaleur a été étudié chez huit chèvres laitières élevées en climat tempéré et disposant d'eau à volonté. L'augmentation de la température de 19 à 28°C (mesurée à 17 h) n'a modifié ni la quantité de ration ingérée, ni l'allure globale de la cinétique d'ingestion des aliments et d'eau. Par contre, la quantité d'eau bue a été accrue de 40 % et le temps de latence entre le début du repas et la première buvée, réduit de 35 à 26 min. La teneur en CO_2 du sang a diminué, car les animaux ont hyperventilé pour réduire leur température corporelle, alors que leur température rectale a augmenté de 0,6°C. La production laitière n'a pas été modifiée, mais le taux butyreux du lait a diminué. Un effet chèvre significatif a été observé sur la majorité des paramètres étudiés. En moyenne, les chèvres de race Alpine ont bu plus d'eau par rapport à la quantité de matière sèche ingérée que les chèvres de race Saanen. Ceci pourrait être dû à leur niveau d'ingestion plus élevé qui accroîtrait le dégagement de chaleur post-prandial, ou à une différence de chaleur latente dégagée par sudation liée à la couleur de leur pelage.*

Mots-clés. Stress de chaleur – Comportement d'ingestion – Chèvres en lactation – Climat tempéré – Ingestion d'eau

I – Introduction

In recent years, temperate European regions suffered from unusually hot periods, as for example during the summer of 2003. The aim of this work was to study the effect of a hot period on feed and water intake of high-producing dairy goats bred in the Paris area, because most previous studies concerned ruminants under hot climates in areas where water is scarce. Moreover, drinking behavior is seldom studied in ruminants (Cardot *et al.*, 2007).

II – Material and Methods

This study was conducted at the Experimental Farm of the research Unit INRA-AgroParisTech MoSAR (Thiverval-Grignon, France (48°51' N; 1°55' E); 70 m above sea level). Four Alpine and four Saanen goats (160 DIM at the start of the experiment) were housed in individual pens with free access to feed and water. Goats were fed a total mixed ration (TMR) twice daily after milking, in the proportion of two thirds at 4 p.m. and one third at 8 a.m., according to the milking intervals. The ingredients of the diet, on a dry matter basis, were dehydrated lucerne (30 %), meadow hay (20 %), pressed sugar beet pulp (30 %) and compound concentrate feed (20 %).
Animals were weighed weekly. Individual amounts of feed offered and refusals were weighed daily. Intakes of feed and water were recorded separately using, for each animal, two weighing-scales (Balea, Saint-Mathieu de Tréviers, France): one was fitted under the feeding trough and the other one under a water container linked to the drinking trough. This system continuously recorded every 2 min the weight of the feed in the feeding trough and of the water in the container with a precision of 5 g. Cumulative dry matter intake (DMI) or water drunk (WD) per kilogram of body weight (BW) was calculated for the 22 hours following the afternoon feeding, using the body weight and the dry matter percentage of the diet (ISO, 1983) measured weekly. Animals had no access to food during the two remaining hours of the 24 h period (around afternoon milking). The evolution of the percentages of DMI and water drunk was studied during the nycthemere by 20-min intervals. The percentage of DMI or water drunk during the first three hours after the afternoon feed allowance was also calculated and called P180DMI and P180WD respectively, because it was the period during which the maximum of variability between goats was observed for food and water intakes (Giger-Reverdin *et al.*, 2011). The latency from the beginning of the afternoon meal to the first water intake was also calculated.

Two periods of five consecutive days were compared: the first one was between the 17th and the 22th of June 2010, and the second one between the 26th of June and the 1st of July 2010. Milk production was measured at each milking and averaged for 5 days. Milk samples were analysed for fat and protein contents at the beginning and end of each period. Blood samples were also analysed twice at each period for gas composition with a blood gas analyzer ABL77 (Radiometer®). Temperature (T in °C) and humidity (H %) were measured in the experimental facility at three times each day: 9 am, 1.30 pm and 5 pm (GMT + 2 h). The temperature-humidity index (THI) was calculated according to the formula of West (1994):

$THI = 0.81\ T + (H/100) * (T - 14.3) + 46.3.$

Data were analysed using the MIXED procedure of SAS® for repeated measurements with the following model: $Y_{ij} = \mu + P_i + G_j + P_i*G_j + \varepsilon_{ij}$

where μ represents the overall mean, P_i, the period effect, G_j, the goat effect, P_i*G_j, the interaction between the period and the goat effects.

The model included the repetition of the day within the period with the use of a mixed procedure First autoregressive AR(1).For the temperature and humidity data, the only effect tested was that of the period.

III – Results

1. Temperature and humidity in the goat unit

During both periods, the temperature increased during the day while the humidity decreased. However, the modifications were very small in the first period and more marked in the second one. This last period can be considered as a heat episode for the country with a mean temperature of 27.5°C at 5 pm (26.7 to 28.4°C) and a mean humidity of 41% (35 to 50%). The period effect was significant except for the humidity in the morning (Table 1).

Table 1. Temperature and humidity in the goat unit during Periods 1 (control) and 2 (Heat stress)

	Time	Period 1	Period 2	SEM	Period effect
Temperature (°C)	9 am	17.0	21.3	0.52	0.001
	1.30 pm	18.0	25.4	0.56	<0.0001
	5 pm	19.0	27.5	0.41	<0.0001
Humidity (%)	9 am	66.4	64.8	1.32	NS
	1.30 pm	60.0	45.4	2.95	0.01
	5 pm	57.4	40.6	2.83	0.01

NS: not significant

2. Feed and water intake

Dry matter intake (DMI) was not modified by temperature, but water intake increased by 40% when the temperature increased (Table 2). The percentage of dry matter intake during the first three hours after the afternoon feeding did not vary, but there was a decrease in the percentage of water drunk. All the goats started to eat before drinking. Moreover, the latency to the first water intake after feeding allowance decreased with the increase in temperature. Feeding behavior expressed as % DMI per 20min intervals was not modified by heat stress (Fig. 1).

Table 2. Feed and water intakes during Periods 1 (control) and 2 (Heat stress)

				Effect		Interaction
	Period 1	Period 2	SEM	Period	Goat	Period*Goat
DMI[1]	47.1	47.2	0.36	NS	<0.0001	0.02
Water drunk[2]	107	143	2.3	<0.0001	<0.0001	0.004
P180DMI[3]	0.38	0.37	0.009	NS	NS	NS
P180WD[3]	0.41	0.35	0.012	0.01	0.001	NS
Latency before the first water intake[4]	35	26	1.5	0.001	<0.0001	NS

[1]in g per kg of body weight, [2]in ml per kg of body weight, [3]Proportion of the daily intake eaten (DMI) or drunk (WD) during the first 180 min after the afternoon feeding, [4]in min after the afternoon feeding, NS: not significant

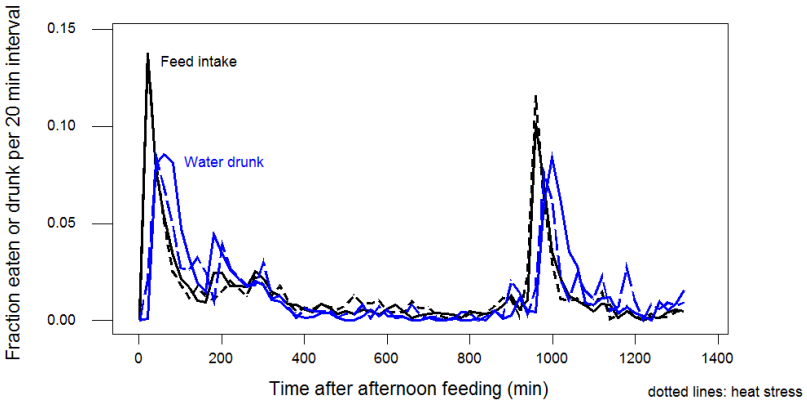


Fig. 1. Evolution of the quantities of water drunk and feed intake during the nycthemere

3. Blood parameters

Blood PCO_2 decreased with the increase in temperature, whereas rectal temperature increased:

Table 3. Blood parameters and rectal temperature during Periods 1 (control) and 2 (Heat stress)

				Effect		Interaction
	Period 1	**Period 2**	**SEM**	**Period**	**Goat**	**Period*Goat**
pH	7.39	7.40	0.004	0.04	0.001	NS
PCO_2 (mm Hg)	44.4	40.6	0.69	0.01	NS	NS
PO_2 (mm Hg)	35.6	36.6	1.12	NS	0.05	NS
Bicarbonates (mmol/L)	25.6	24.7	0.37	NS	NS	NS
Rectal Temperature °C	38.5	39.1	0.07	<0.0001	NS	NS

NS: not significant

4. Milk production

Raw milk yield was not modified by heat stress, but the fat content and the fat yield decreased, (Table 4). Protein content and protein yield were not affected by the increase in temperature.

Table 4. Milk yield and composition during Periods 1 (control) and 2 (Heat stress)

				Effect		Interaction
	Period 1	**Period 2**	**SEM**	**Period**	**Goat**	**Period*Goat**
Raw milk yield[1]	3.55	3.61	0.031	NS	<0.0001	0.03
Fat content[2]	33.3	30.2	0.31	<0.0001	<0.0001	0.01
Protein content[2]	31.9	31.3	0.09	0.01	<0.0001	NS
Fat yield[3]	116	108	1.7	0.01	0.001	NS
Protein yield[3]	113	113	1.0	NS	<0.0001	0.02

[1]in kg/day (mean of 5 days)

[2]in g/kg of milk
[3]in g/day
NS: not significant

5. Breed and goat effects

There was a breed effect on live-weight (Alpine: 58.3 kg vs Saanen: 64.2 kg; SEM = 0.52; $P < 0.001$) and intake: Alpine goats ate more dry matter per kg of body weight than Saanen (49.3 vs 45.9 g DMI/kg BW; SEM = 1.15; P = 0.02), and drank more water when expressed on a dry matter intake basis: 2.82 vs 2.46 L/kg DMI; SEM = 0.073; P = 0.01). The increase in this latter ratio with the temperature was more pronounced for the Alpine goats (Period 1: 2.38; Period 2: 3.26) than for the Saanen goats (Period 1: 2.15; Period 2: 2.76).

IV –Discussion

In this experiment, heat stress can be considered as a very moderate one, because the THI index was slightly above 72 during the afternoon in Period 2 which is the threshold level above which there is heat stress (West, 1994). It did not modify eating behavior on the contrary to other situations where goats were bred in harsh conditions (Silanikove, 2000). Nevertheless, total water intake was increased and the latency between the afternoon feeding and the first water intake was decreased, meaning that the animals felt thirsty earlier after TMR allowance (Olsson *et al.*, 1997). The respiratory alkalosis (decrease in PCO_2) observed during Period 2 could be explained by the hyperventilation of the animals during the heat stress as already observed in cows (Kadzere *et al.*, 2002) or in goats (Augustinsson *et al.*, 1986). When the animals are panting, which is a way to decrease their inner temperature, they release CO_2. Although moderately heat-stressed, the experimental goats showed increased rectal temperature as previously observed in other animals exposed to hot periods (Augustinsson *et al.*, 1986; Kadzere *et al.*, 2002). The decrease in milk fat content has already been observed in dairy cows under a mild heat stress (Bandaranayaka and Holmes, 1976). The difference between breeds in terms of the water/DMI ratio might be explained by the higher level of intake of Alpine compared to Saanen goats and probably by a need to dissipate more heat from rumen fermentation (West, 1994; Kadzere *et al.*, 2002). It could also be due to the difference in coat colours: in Holstein cows, the temperature of the skin is higher in black areas than in white ones, leading to an increase in sweating rate in the black areas compared to the white ones (Da Silva and Maia, 2011). This could explain why Alpine goats with their dark-brown coat drank more water/kg DMI than the white coated Saanen goats.

V – Conclusion

High-producing European dairy goats seemed to cope well with short periods of moderate heat stress when water was available *ad libitum*. This study, which included feeding and drinking patterns, needs to be completed with a larger scale experiment and with measurements of the water fluxes and water losses *via* urine, faeces and milk. Long term adaptation and effects on production warrant future research in view of rampant global warming.

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c. Texte en anglais du second proceeding présenté en conférence : Responses to a heat stress episode in lactating Saanen and Alpine goats

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This study aims to assess the effect of a sudden heat episode on lactating Saanen and Alpine goats bred under temperate climate (Paris area, France). Eight Saanen and eight Alpine goats were included in the experiment. They were offered *ad libitum* water and a total mixed ration twice daily; feed and water intake were recorded daily. The study extended over two 5-day periods: the first period served as control with a maximum thermal heat index (THI) of 64.5 and the second 5 days period represented the heat episode with a minimum THI of 68.0. Selected physiological parameters were analyzed including rectal temperature, plasma glucose, NEFA and urea, and blood pCO_2, Na^+ and HCO_3^-. Milk production and composition was also individually assessed. Data were analyzed using the mixed procedure of SAS® for repeated measurements. Blood analysis showed that the does resorted to hyperventilation to dissipate the extra heat load. In addition, heat stressed animals drank more water probably to compensate for water lost for cooling especially since rectal temperature increased. Finally, milk production was maintained, although milk fat and protein content dropped during the heat episode. The data were also subjected to PCA analysis which revealed a significant effect of the period and of the breed with no interaction between these two factors.

In conclusion, the experiment showed that although the animals were born and raised under a temperate climate, they could handle a short heat wave with minimal physiological disturbances.

Introduction

The effect of heat stress on small ruminants is more commonly studied in arid and semi-arid regions where the native breeds are regularly exposed to this environmental challenge. Heat stress can induce a wide range of physiological changes including a reduction in feed intake, hyperventilation, increased rectal temperature, etc. (Lu, 1989; Fuller et al., 2007). In lactating animals, heat stress can also affect milk production and composition. It is usually noted that there's a wide breed variation in tolerating heat stress. The Black Bedouin Goat for instance has a remarkable capacity to maintain milk production under heat and drought conditions (Maltz and Shkolnik, 1984).

The current project aimed to evaluate the response of Saanen and Alpine lactating does to a natural heat episode that occurred in June 2010.

Materials and methods

This study was conducted at the Experimental Farm of the research Unit INRA-AgroParisTech MoSAR (Thiverval-Grignon, France (48°51' N; 1°55' E); 70 m above sea level). Eight Alpine and eight Saanen goats (160 DIM at the start of the experiment) were

included. They were given free access to feed and water. The feed consisted of a total mixed ration (TMR) offered twice daily after milking, in the proportion of two thirds at 4 p.m. and one third at 8 a.m., according to the milking intervals. The ingredients of the diet, on a dry matter basis, were dehydrated lucerne (30 %), meadow hay (20 %), pressed sugar beet pulp (30 %) and compound concentrate feed (20 %). Individual amounts of feed offered and refusals were weighed daily.

Two periods of five consecutive days were compared: the first one was between the 17th and the 22th of June 2010, and the second one between the 26th of June and the 1st of July 2010. Milk production was measured at each milking and averaged for 5 days. Milk samples were analysed for fat and protein contents on two consecutive milkings at the beginning and the end of each period. Blood samples were also analysed twice at each period for gas composition with a blood gas analyzer ABL77 (Radiometer®). Temperature (T in °C) and humidity (H %) were measured in the experimental facility at three times each day: 9 am, 1.30 pm and 5 pm (GMT + 2 h). The temperature-humidity index (THI) was calculated according to the formula of West (1994):

THI = 0.81 T + (H/100) * (T - 14.3) + 46.3.

Data were analysed using the MIXED procedure of SAS® (SAS Institute, 2000) for repeated measurements with the following statistical model:

$Y_{ij} = \mu + P_i + G_j + P_i*G_j + d_{ij} + \varepsilon_{ijk}$

where Y_{ij} is the response variable, μ represents the overall mean; P_i, the period effect; G_j, the goat effect; P_i*G_j, the interaction between the period and the goat effects; d_{ij} . effect of the day of recording nested within week; ε_{ijkl} : random residual error.

The model was tested with a first order autoregressive procedure: AR(1). For the temperature and humidity data, the only effect tested was that of the period. Finally, a principal component analysis (PCA) was performed to test the relative effect of the period (control *vs*. heat stress) and breed (Alpine *vs*. Saanen) on the 12 most significant parameters.

Results

For all parameters, the statistical analysis showed no interaction between Goat and Period, therefore the results will be presented and discussed from the perspective of the period effect only. The goat effect was significant for most of the parameters (Table 2).

The THI at 9:00, 13:30 and 17:00 were always higher in period 2 (heat episode) than in period 1 (control) (Table 1).

Goats drank more water during period 2 than period 1 however their DMI was similar between the two periods (Table 2). In addition, rectal temperature was higher during the heat episode than during the control period.

Table 1. The temperature humidity index during the control (Period 1) and heat stress (Period 2) period.

	Period 1	Period 2	SEM	Period effect
THI9	61.9	68.0	0.81	0.0007
THI13 30	63.1	71.9	0.77	<0.0001
THI17	64.5	73.9	0.62	<0.0001

At the level of the blood chemistry parameters, a drop in the glucose level was noted in period 2, while urea concentration increased and Na+ tended to increase (Table 2). A few blood gases and electrolytes were also affected by the heat episode namely, pCO_2 and bicarbonate levels dropped (Table 2).

Milk production was not affected by the heat episode, however, milk fat and protein decreased (Table 3).

Table 2. Changes in physiological parameters of lactating goats during the control (Period 1) and heat stress (Period 2) period.

	Period 1	Period 2	SEM	Period (P value)	Goat (P value)
Rect. Temp. ^{o}C	38.6°C	38.9°C	0.04	<0.0001	0.0014
Dry Matter Intake (g/kg body weight)	46.7	47.4	0.33	0.16	<0.0002
Water drunk (ml/kg body weight)	105	146	2.0	<0.0001	<0.0001
Glucose (g/L)	0.582	0.569	0.0040	0.03	0.001
NEFA (mmol/L)	149	134	1.2	0.07	0.12
Urea (g/L)	0.249	0.269	0.0059	0.02	<0.0001
pCO_2 (mmHg)	43.6	40.6	0.10	0.03	0.13
Na^+ (mmol/L)	142.3	143.0	0.04	0.06	0.14
$HCO3^-$ (mmol/L)	27.6	25.5	0.08	0.04	0.11

Table 3. Changes in milk production and composition of lactating goats during the control (Period 1) and heat stress (Period 2) period.

	Period 1	Period 2	SEM	Period (P value)	Goat (P value)
Milk yield	3.62	3.69	0.029	0.10	<0.0001
Fat content	33.5	30.3	0.09	0.04	0.06
Protein content	31.6	31.2	0.07	0.0002	<0.0001

For the first axis of the Principal Component Analysis (PCA1) which explained 26.2 % of the total variance, an inverse relationship was observed between rectal temperature and quantity of water drunk on one hand, and milk composition (fat and protein contents), plasma NEFA and glucose, and blood components (PCO_2 and HCO_3) on the other hand (Figure 1).

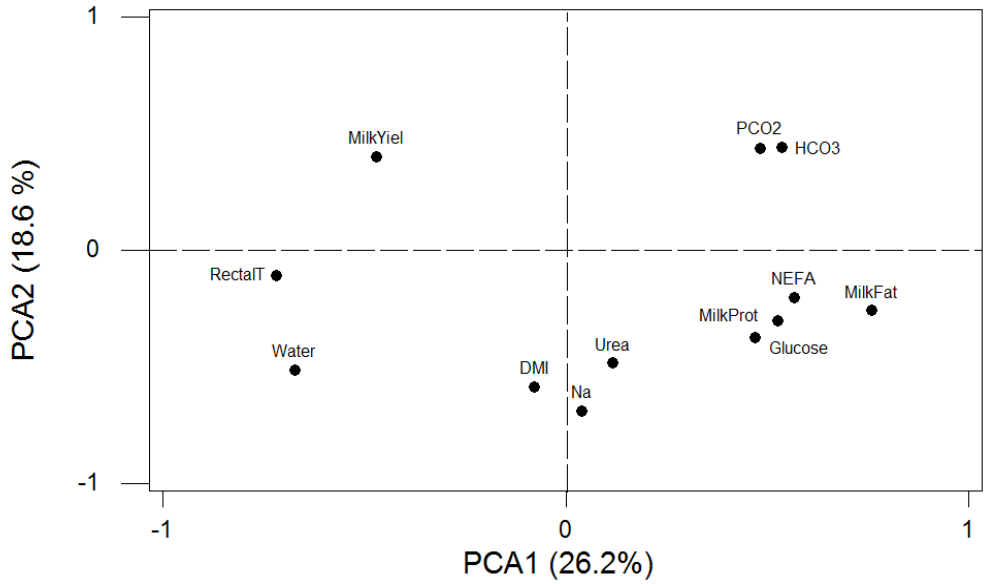


Figure 1. Results of a principal component analysis based on the mean values per goat-period combination for 12 variables. The percentage of total variance accounted for by each of the first 2 principal components (PC) is shown in parentheses aside the name of the axis.

The second axis (PCA2) explained 18.6 % of the total variance. The projection of the individuals on the first 2 components showed similar evolutions for all the goats between periods. There was a significant effect of the period as well as of the breed with no interaction between these two factors (Figure 2). As also shown by the breed average lines which were parallel.

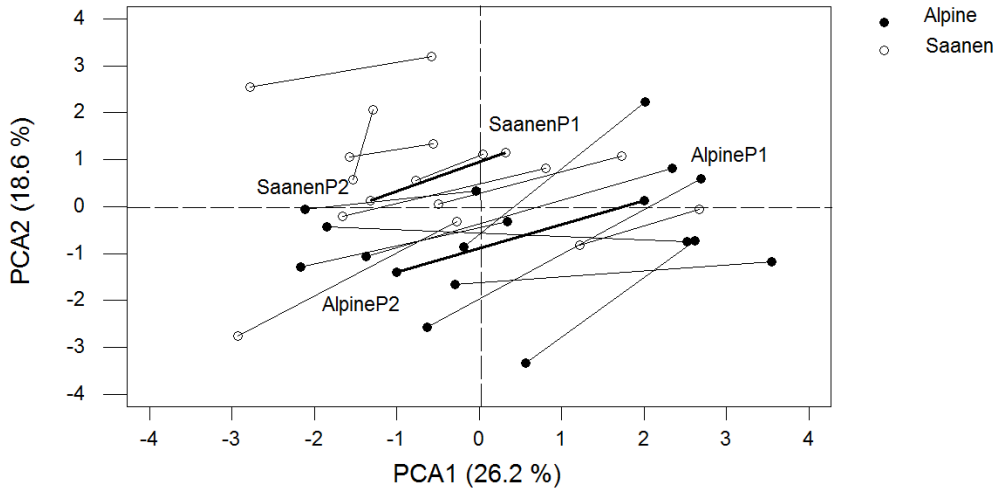


Figure 2. Results of a principal component (PC) analysis based on 12 variables presented as a score plot of 16 mid-lactating dairy goats from either Saanen or Alpine breeds. The percentage of total variance accounted for by each of the first 2 principal components (PC) is shown in parentheses. A line connects the score for a given goat and bold lines correspond to mean values per breed.

Discussion

The upper limit of THI of the goats comfort zone is 72 (West, 1994), therefore period 2 of this experiment lies just at the borderline. However, physiological changes have been observed that indicate the animals were indeed under some heat stress. The first indication comes from the rectal temperature results that increased in period 2. As expected, the change was small and the temperatures remained well within the normal range since goats are thermostable, however, this observation is a reflection of the increase in ambient temperature (Lu, 1989).
The observed increase in water intake is another sign of heat stress. The additional water mostly serves to replace water lost for evaporative cooling. In fact, looking at key blood parameters, such as urea and Na+, that are usually good indicators of the hydration status (Jaber et al., 2013), they tended to increase in period 2. This leads to the conclusion that the animals were actually slightly more dehydrated in period 2 despite the greater water intake; this confirms that most of the water drank must have been lost for cooling and not retained in the blood.
Hyperventilation is an important cooling approach in goats. This was demonstrated in the current study by the decrease in pCO_2. It is speculated that hyperventilation serves simultaneously for cooling, including brain cooling, while minimizing water losses (Fuller et al., 2007). The heat stress also led to a decrease in HCO_3 probably due to increased elimination of CO_2 as observed by Srikandakumar and Johnson (2004) in heat stressed dairy cows.
The heat stressed goats did not modify their feed intake as compared to their consumption in period 1. Literature indicates that animals under heat stress usually resort to reducing their feed intake in an attempt to reduce the metabolic heat associated with digestion (Lu, 1989; Silanikove, 2000). The current results may indicate that the heat stress was probably not strong enough to illicit this response. The blood chemistry results give a slightly contradictory picture about the energy status of the animals; while glucose decreased indicating a possible deficit in energy intake, the NEFA tended to decrease as well indicating on the contrary a rather positive energy balance. However, it is worth noting that the levels remained within the normal ranges thus confirming that the animals were physiologically healthy and the observed variations could be attributed to natural fluctuations as well as individual variability.
The heat stressed goats were able to maintain their milk production in this experiment although fat and protein contents dropped. Previous studies have indicated that heat stress could lead to a drop in milk production as well as milk fat and protein (Hamzaoui et al., 2012). The free availability of water in the current experiment could have helped in sustaining milk production, however, further studies are needed to assess the effect of heat stress for longer periods.
With around 45% of the total variance explained with the first 2 components, PCA pointed out the effect of a heat stress episode on the production and physiological parameters: when indoor temperature increased, rectal temperature and water intake increased, but PCO_2 and milk components decreased. PCA was helpful in highlighting the significant effects of the period and the breed, with no interaction between those two factors: breed average lines were parallel indicating that although the breed values might have differed, they still behaved in the same way when subjected to heat stress.

In conclusion, the experiment showed that although the animals were born and raised under a temperate climate, they could handle a short heat wave with minimal physiological disturbances.

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CHAPITRE 4: DISCUSSION GENERALE ET RECOMMANDATIONS

Ce travail de thèse a présenté deux parties complémentaires, l'une portant sur une synthèse qualitative et quantitative de la littérature et l'autre expérimentale qui a exploré le sujet du stress hydrique sous différents angles. Cette approche a permis de mieux valoriser les résultats en les comparant à ceux de la littérature, mais aussi de mettre en évidence les pistes de recherche encore peu explorées dans la littérature, ainsi que dans les expérimentations déjà effectuées pour ce projet et qui pourraient guider un travail ultérieur dans ce domaine.

4.1. La revue de la littérature et la méta-analyse

La revue de la littérature a permis de bien se familiariser avec le sujet et de se faire une idée globale des avancées de la recherche scientifique au sujet de la restriction en eau chez les petits ruminants. Cette revue a montré que certains aspects des effets physiologiques de la restriction en eau sont bien étudiés, tandis que d'autres restent à élaborer et à étudier plus en détails. Par exemple, Dahlborn et Olsson et leurs collaborateurs ont largement contribué à l'explication des changements physiologiques au niveau des changements de la production et composition laitière sous restriction en eau (Dahlborn, 1987 ; Dahlborn et al., 1998 ; Dahlborn and Holtenius, 1990 ; Dahlborn et al., 1997 ; Hossai-Hilali et al., 1994 ; Mengistu et al., 2007 a and b, Olsson et al., 1982 ; Olsson and Dahlborn, 1989 ; Olsson et al., 1997 ; Olsson, 2005). De même, Silanikove a présenté des recherches et des synthèses récapitulatives permettant surtout de comprendre les réponses des chèvres à la déshydratation en milieux arides avec un aperçu sur les races les plus adaptées telles que la chèvre bédouine noire (Silanikove, 1985, 1991, 1992, 1994, 2000, Maltz et al., 1984). Les références précédentes sont celles qui ont été utilisées dans la production de ce document de thèse.

L'analyse quantitative de la base de données effectuée pour ce projet a montré des relations prometteuses qui sont encore à compléter. Dans l'ensemble, les résultats de la méta-analyse étaient en accord avec les observations déjà faites dans la revue qualitative de la littérature. En résumé, la restriction d'eau semble mener à :

- Une baisse de la matière sèche ingérée et de la production laitière
- Une perte de poids
- Une élévation au niveau sanguin de l'osmolarité, de l'albumine, de l'urée, du sodium, du cholestérol et des AGNE, et au niveau des constituants du lait (des taux protéique, taux butyreux et de l'extrait sec dégraissé)

Il était aussi possible de distinguer les effets physiologiques en fonction de la restriction en eau imposée. Les résultats semblent indiquer que la réponse s'accroît avec la sévérité de la restriction. Ceci a été observé pour les restrictions totales avec des intervalles variables entre les abreuvements et pour les restrictions partielles avec des niveaux d'abreuvement variables. De plus, un exemple de modèle qui pourrait être tiré de la base de données était illustré avec la relation entre la matière sèche ingérée et la température rectale, ceci quelles que soient les conditions expérimentales.

Par ailleurs, cette partie du projet a aussi aidé à identifier des paramètres de grande importance, mais qui ne sont pas encore bien étudiés dans la littérature. Ces paramètres ressortent de la base de données dans laquelle ils sont mentionnés au travers de quelques articles seulement et donc ne permettent pas une analyse adéquate de leur relation en cas de restriction en eau. La liste suivante résume les paramètres qui pourraient être d'intérêt pour des études futures, à partir de cette base de données :

- Effets hormonaux : vasopressine, aldostérone, leptine, insuline, ocytocine, etc
- Mobilisation adipeuse : AGNE, diamètre des adipocytes, etc
- Liquide ruminal : volume et composition
- Urine : volume et composition
- Progéniture : nombre, poids à la naissance et croissance ultérieure
- Volume des différents compartiments d'eau corporels
- Paramètres de la digestion
- Paramètres du rafraîchissement évaporatif : eau perdue par transpiration, eau perdue par la respiration, température de la peau, etc.

Les résultats que nous avons obtenus dans nos expériences sur la matière sèche ingérée (g/kg poids vif) en fonction de la température ambiante (^{o}C) ont été confrontés à l'ensemble des résultats de la méta-analyse dans la figure 21. Cet exercice a confirmé que nos résultats sont bien conformes à ceux issus de la littérature.

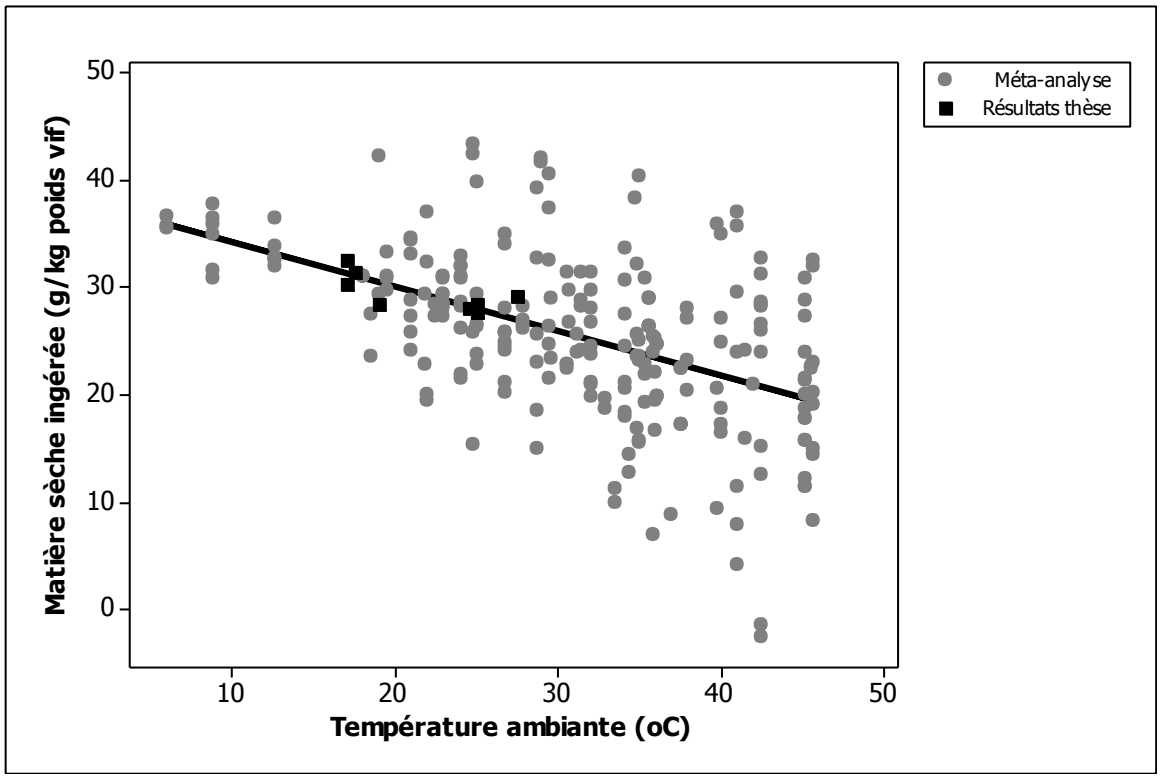


Figure 21. Nuage de points pojetant les résultats des expérimentations de la thèse sur l'ensemble de ceux de la méta-analyse concernant la relation entre la matière sèche ingérée (g/kg poids vif) et la température ambiante (^{o}C).

4.2. Effet de la restriction en eau sur les chèvres shamies

a. <u>Système d'élevage extensif</u>

Les chèvres shamies, comme d'autres races originaires des pays arides ou semi-arides, sont souvent élevées dans des systèmes de production extensifs. Ces systèmes dépendent

largement du cycle saisonnier marqué par le retour de l'œstrus pour débuter un nouveau cycle de reproduction/production (Hamadeh et al., 1996).

L'expérience sur l'effet de la restriction en eau chez les chèvres shamies s'est faite sur des animaux issus d'un système d'élevage similaire.

Dans ces conditions, la détermination de la gestation est plutôt subjective et dépend largement de la compétence du personnel en charge du troupeau. De même, une confirmation de la gestation par des technologies plus avancées est rarement effectuée sur les petits ruminants, étant donné le prix élevé de tels services et leur absence dans la plupart des régions rurales où le service vétérinaire est aussi peu répandu (Hamadeh et al., 1996). Ces systèmes regroupent souvent des animaux à fortes variations individuelles, étant donné que les conditions de l'élevage et les lignes de parenté sont peu contrôlées. Cela rend le choix des animaux pour une intervention expérimentale assez difficile avec l'absence de documentation bien organisée et de test de confirmation de la gestation, du nombre de fœtus, etc.

Le désavantage de cette situation s'est traduit par l'exclusion de trois chèvres qui se sont avérées être non gravides et donc un nombre des animaux réduit qui a rendu l'analyse statistique peu sensible pour la détection des effets physiologiques de la restriction en eau. Par contre, cette expérience permet d'avoir une idée de la situation en conditions réelles, sur des chèvres qui n'ont subi aucune altération de leur mode vie avant l'expérience.

Idéalement, pour des expériences de ce genre, un troupeau expérimental serait utile. Un tel troupeau serait synchronisé et suivi par un vétérinaire pour bien suivre l'état des animaux, avec un système de documentation individuelle pour le suivi de la reproduction, de la production et de la santé des animaux.

Ci-dessous, est présenté un tableau récapitulatif (tableau 8) des principaux résultats obtenus en France et au Liban, permettant une approche comparative des réponses des races tempérées (Saanen et alpines) avec celles adaptées aux pays arides et semi-arides (shamie). Bien que les conditions expérimentales aient été différentes avec une restriction bien plus marquée appliquée aux shamies (1 jour d'abreuvement sur quatre) qu'aux Saanen et alpines (deux périodes de 15 heures de restriction, deux jours de suite), les réponses physiologiques etaient assez similaires. La production laitière semble s'être maintenue dans ces conditions, alors que certains indicateurs physiologiques de déshydratation sont évidents, tels que la hausse de l'osmolarité, de l'urée et de l'albumine. Ces deux expériences mettent en évidence la similarité des réponses, mais aussi la différence dans le niveau de restriction pouvant être subi par ces races.

Tableau 8. Comparaison des effets du stress hydrique chez des chèvres Saanen et alpines *vs* shamies sous des conditions expérimentales différentes

Race	**Saanen & alpine**			**Shamie**		
Paramètre	**J1 (Contrôle)**	**J4 (Après restriction)**	**Différence* (%)**	**Contrôle**	**Restreint**	**Différence* (%)**
Poids (kg)	60.6	62.0	-	49.5	47.8	-
MSI (kg)	3.0	2.91	**-7.4**	1.1	1.1	-
Lait (L/j)	3.61	3.60	-	0.557	0.509	-
Urée (mmol/L)	4.33	6.66	**53.8**	5.5	6.4	**16.4**
Albumine (g/L)	43.4	44.6	**2.8**	32.9	35.3	**7.3**
Osmolarité (mOsm/kg)	294	307	**4.4**	290.8	304.0	**4.5**

*La différence (%) est calculée seulement pour les paramètres où les animaux restreints diffèrent significativement ($P<0.05$) des contrôles.

De même, et à titre indicatif de la comparaison des résultats de la thèse avec ceux de la littérature, la figure 22 ci-dessous permet de voir que les résultats d'osmolarité obtenus chez les shamies et les Saanen et alpines de nos expérimentations sont similaires à ceux utilisés dans l'ensemble de la méta-analyse. Pour un intervalle de restriction de 72h, comme celui subi par les shamies, les résultats de la thèse semblent un peu plus faiblesque la droite moyenne ; par contre, la restriction de 15h subie par les Saanen et alpines a entraîné des osmolarités touchant les 307 mOsm/L un peu plus élevés que la droite moyenne.

Cette visualisation, en plus de la comparaison entre les races présentée plus haut, montre l'intérêt d'explorer plus profondément la piste des effets de la restriction en eau sur des races différentes en milieux et conditions variés à travers des expérimentations bien planifiées dans ce but.

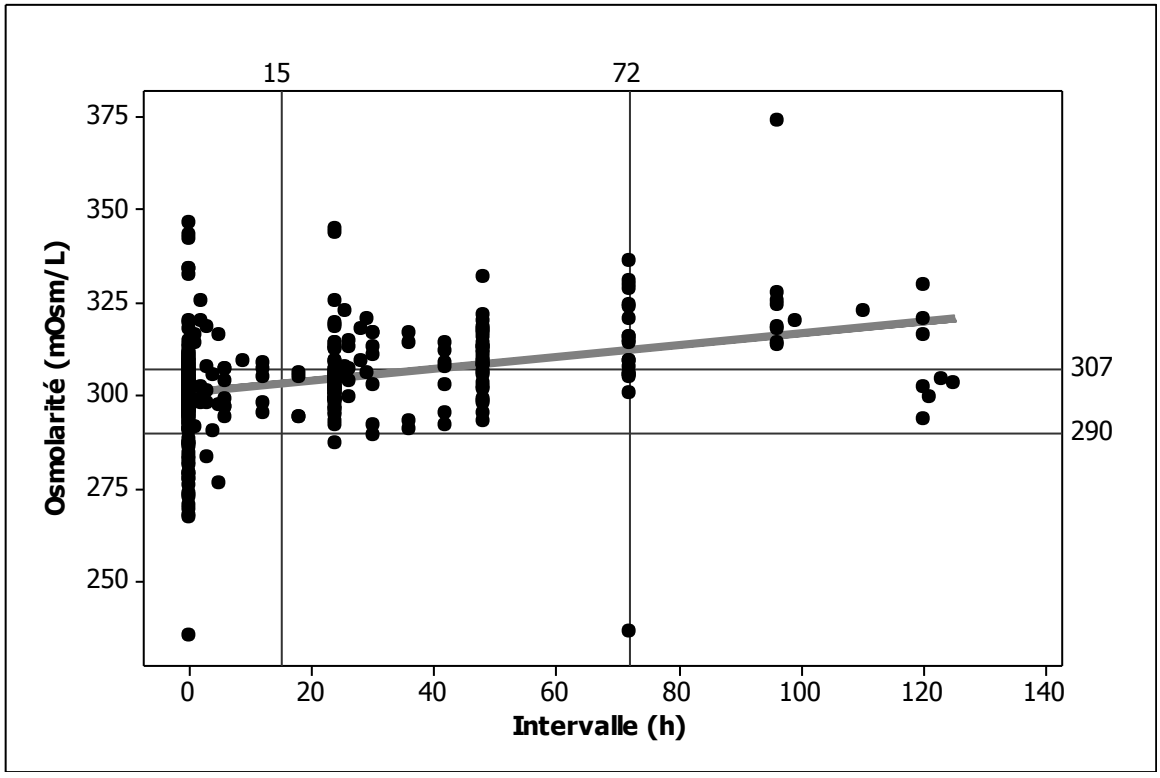


Figure 22. Visualisation des valeurs minimales et maximales de l'osmolarité (mOsm/L) obtenues dans les expérimentations de la thèse (indiquées par une ligne horizontale) en fonction de l'intervalle de restriction (h) par rapport à ceux de la méta-analyse

b. Suivi de la lactation

L'expérience sur les chèvres shamies allaitantes s'est déroulée assez tard dans la lactation et donc, l'effet de la restriction n'était pas assez prononcé sur la production laitière. Par contre, la littérature semble indiquer que la restriction d'eau a tendance à baisser la production laitière (Hossaini-Hilali et al. 1994 ; Mengistu et al. 2007). Ceci dit, il serait intéressant dans des expériences futures d'étudier cet effet à différents stades de la lactation, se focalisant particulièrement sur les deux premiers mois, période durant laquelle les chevreaux sont souvent nourris par leur mères, dans les systèmes d'élevages extensifs (Hamadeh et al. 1996).Une baisse de production à ce niveau pourrait influencer leur développement.

c. Suivi de la progéniture

L'expérience sur les chèvres gestantes a montré un effet sur le poids des chevreaux à la naissance et à un mois. Outre le poids, cette expérience prénatale pourrait avoir un effet à long terme sur le potentiel productif de la progéniture (Laporte-Broux et al. 2011). Un suivi sur plusieurs générations serait intéressant du point de vue de l'effet physiologique à long terme, ainsi que du point de vue économique vis-à-vis du potentiel productif du troupeau, dans le cas où les chèvres gestantes sont soumises à une restriction en eau.

L'un des objectifs de la thèse était d'explorer l'effet de l'état physiologue des animaux sous restriction en eau. Ceci a été abordé à travers la revue qualitative de la littérature et reste à etudier plus en details dans la méta-analyse. De même, les deux expérimentations effectuées sur les shamies en gestation et en lactation au Liban, servent à comparer les réponses de ces animaux soumis à un régime d'abreuvement similaire. Cette comparaison reste quand même limitée par les conditions expérimentales non contrôlées telles que la température ambiante assez différente pendant les deux saisons naturelles de chaque stade physiologique (gestation en hiver et lactation en printemps). De même, l'alimentation disponible pendant ces deux périodes était différente. Avec ces limites prises en considération, le tableau comparatif ci-dessous semble indiquer que la restriction en eau imposée à des chèvres en lactation était plus pénalisante au niveau physiologique. Cette observation reste toujours à renforcer par des recherches plus poussées avec des conditions plus contrôlées et avec un nombre d'animaux plus important.

Tableau 9. Comparaison des effets du stress hydrique chez des shamies en gestation *vs* en lactation, avec des conditions expérimentales différentes

Paramètre	Gestation			Lactation		
	Contrôle	Restreint	Différence* (%)	Contrôle	Restreint	Différence* (%)
Urée (mmol/L)	6.9	8.7	-	5.5	6.4	**16.4**
Albumine (g/L)	33.9	33.8	-	32.9	35.3	**7.3**
Osmolarité (mOsm/kg)	287.5	303.2	**5.5**	290.8	304.0	**4.5**

*La différence (%) est calculée seulement pour les paramètres où les animaux restreints diffèrent significativement ($P<0.05$) des contrôles.

4.3. Effet de la chaleur sur les chèvres alpines et Saanen

Dans cette expérience,les conditions climatiques n'étaient pas contrôlables et ont été subies. L'épisode de température élevée était imprévu, mais étant donné que les animaux étaient déjà en cases et étaient suivis régulièrement avec des prélèvements de sang et de lait en vue d'analyse chimique, la situation était propice pour suivre les réponses des chèvres à ce changement soudain dans les conditions climatiques. Les conditions sont restées cependant à la limite de la zone de confort thermique des chèvres (West, 1994), par conséquent les effets ont été faibles. Par contre, les chèvres européennes des milieux tempérés peuvent faire face à des températures plus élevées et ceci surtout quand elles sont exportées dans des pays des zones semi-arides.

Cette expérience a montré que les chèvres ont apparemment perdu de l'eau, bien qu'elles en buvaient de grandes quantités, et ceci était plus marqué chez les alpines probablement du fait de leur pelage plus sombre. Cette observation serait intéressante à explorer à partir des mécanismes de rafraîchissement que les chèvres mettent en action. Des données sur la transpiration, le halètement, et les flux d'eau dans les différents compartiments du corps seraient importantes, chez les deux races.

Par contre, au niveau de la température rectale en fonction de la température ambiante, les réponses des chèvres Saanen et alpines dans cette expérimentation, étaient bien alignées avec la courbe générale de l'ensemble des résultats de la méta-analyse (figure 23) .

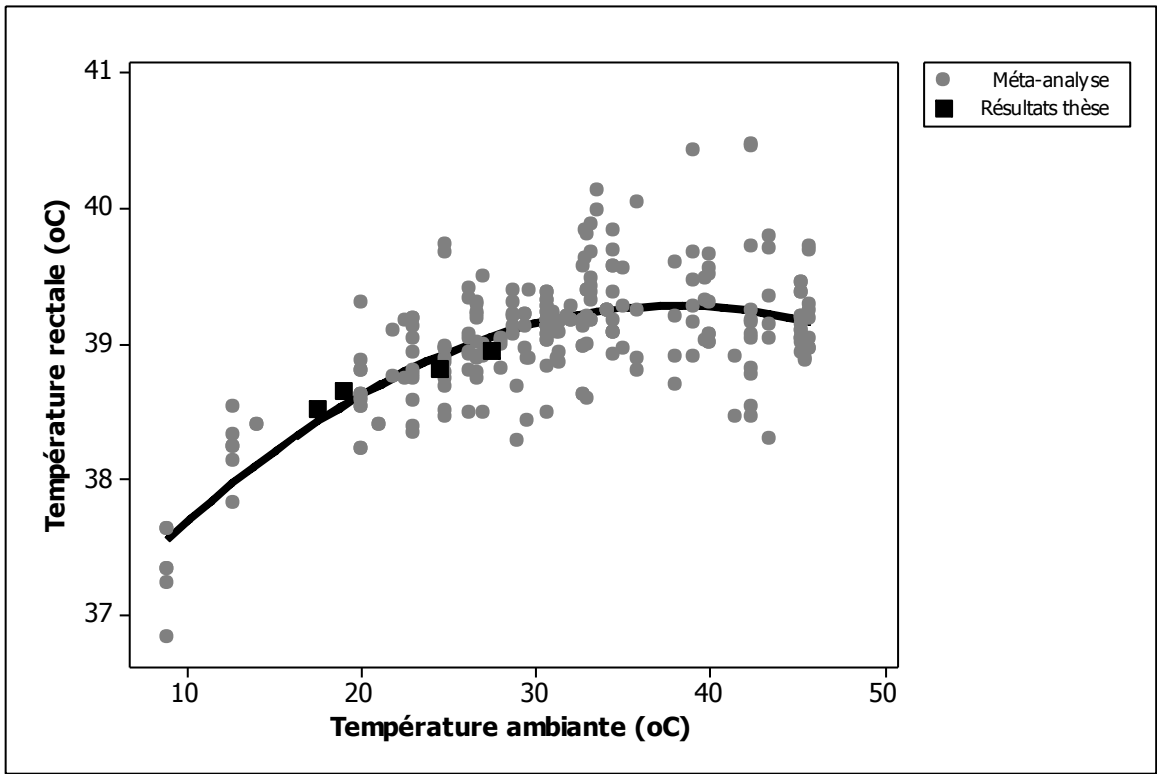


Figure 23. Visualisation des résultats de la température rectale (^{o}C) en fonction de la température ambliante (^{o}C) obtenues dans les expérimentations de la thèse par rapport à l'ensemble de ceux de la méta-analyse.

Des études comparant la physiologie et la production de ces races dans leurs pays d'origines et dans leurs nouvelles destinations, semblent d'un grand intérêt pour évaluer la validité économique de ces exportations en prenant en compte, outre les conditions climatiques, la qualité du fourrage disponible dans ces régions et les systèmes d'élevage.

4.4. Effet de la restriction d'eau sur les chèvres alpines et Saanen

Etant donné que c'était la première fois que les chèvres faisaient face à un tel traitement, la restriction en eau était choisie pour être de courte durée. Cependant, les signes d'un état de déshydratation étaient observés par rapport au début de l'expérience. Apparemment, les chèvres étaient capables de tolérer ce régime de restriction d'eau, mais il reste à savoir quels auraient été les effets si le traitement s'était prolongé. D'autres chercheurs avaient indiqué que les animaux montrent des réponses différentes sur le long terme, à comparer avec leurs réponses initiales au début du stress, dû à l'adaptation au stress imposé régulièrement sur une longue durée (Jaber et al. 2004). Des réponses physiologiques telles que le mouvement de

l'eau à travers différents compartiments notamment, le sang, l'urine, le fluide ruminal, la salive, le lait et la transpiration seraient utiles pour montrer les mécanismes employés par les chèvres pour conserver l'eau et résister à l'état de déshydratation. Une telle étude montrerait aussi la capacité des chèvres à retrouver l'équilibre après abreuvement ; un défi physiologique important en vue du risque d'hémolyse au cas d'une dilution rapide du sang.

Cette expérience, ainsi que d'autres décrites dans la littérature (Hamadeh et al. 2006 ; Jaber et al. 2011), ont montré un rôle important du métabolisme de l'énergie qui reste encore peu exploré chez les animaux déshydratés. Dans cette expérience, les valeurs élevées du glucose chez les animaux restreints en eau, reste à clarifier. Ceci nécessite des recherches futures qui exploiteraient ce sujet en particulier. Des données plus précises sur les hormones clés qui jouent un rôle dans le métabolisme de l'énergie, telles que l'insuline et la leptine par exemple, seraient importantes, ainsi que l'exploration des changements au niveau des réserves adipeuses. L'effet additif de la déshydratation et de la baisse de la prise alimentaire devrait être mieux étudié pour bien distinguer les conséquences des deux stress séparés ou simultanés, sur le bilan énergétique.

Finalement, dans le cas des deux expériences sur les chèvres alpines et Saanen, l'effet du stress thermique ou hydrique sur le comportement pourrait être élaboré, tel que le temps passé à la rumination, ingestion, buvée, ou dans différentes positions (debout, couché), etc. La présence des chèvres en cases individuelles était pratique pour bien étudier les cinétiques d'ingestion d'eau et d'aliments. Par contre, la restriction de mouvement dans les cases masque d'autres modifications comportementales auxquelles les animaux pourraient avoir recours pour réduire les effets du stress, telles que la recherche d'abris, le temps et la durée des différentes activités et les positions corporelles, etc.

Les deux expérimentations sur l'effet du stress thermique et celui du stress hydrique, étant appliquées au même groupe d'animaux, cela permet d'établir une comparaison préliminaire entre les différentes réponses physiologiques des animaux face à ces conditions. Le tableau 9 ci-dessous semble indiquer que le stress hydrique a un effet physiologique plus marqué au niveau de l'urée marquant un etat de déshydratation, alors que le stress thermique influence plus la composition laitière. Ces observations marquent un départ intéressant pour une exploration plus approfondie des différents mécanismes mis en action sous stress hydrique et thermique.

Tableau 10. Comparaison des effets du stress hydrique et du stress thermique chez des Saanen et alpines en lactation

Paramètre	Stress hydrique			Stress thermique		
	J1	J4	Différence* (%)	J1	J4	Différence* (%)
Urée (mmol/L)	4.33	6.66	**53.8**	4.2	4.5	**8**
Lait (L/j)	3.61	3.60	-	3.62	3.69	-
TB (g/L)	33.1	32.2	-	33.5	30.3	**-9.6**
TP (g/L)	31.8	31.6	-	31.6	31.2	**-1.3**

*La différence (%) est calculée seulement pour les paramètres où J1 et J4 diffèrent significativement ($P<0.05$).

4.5. Recommandations pour les recherches futures

Ce projet a permis de faire le point sur le stress hydrique ches les chèvres, un sujet qui fait l'objet de nombreuses recherches, mais pour lequel il reste encore plusieurs aspects à explorer et approfondir. Il semble que les études dans ce domaine aient deux objectifs essentiels :

1- Comprendre l'aspect physiologique détaillé des réponses à l'hydratation et à la déshydratation. Souvent, ces expériences se réalisent avec un modèle artificiel imposé, assez loin des conditions réelles auxquelles l'animal pourrait faire face. Par exemple, dans ce projet, les cinétiques d'ingestion seraient difficiles à obtenir si les animaux étaient en troupeau.

2- Comprendre l'aspect pratique de la restriction d'eau. Ces manipulations tentent de reproduire le stress tel qu'il est vécu dans des situations réelles ; souvent ce modèle manque des données physiologiques assez détaillées à cause de la difficulté de les acquérir sur le terrain. Les difficultés expérimentales rencontrées avec les expériences sur les chèvres shamies sont un exemple des limitations des expériences en conditions réelles.

Ces deux approches ont leur mérite et aident à compléter l'image des effets du stress hydrique. Les applications en conditions réelles ont le potentiel de servir comme base de recommandations pour les éleveurs étant donné qu'elles se réalisent en conditions similaires, alors que l'approfondissement physiologique peut dévoiler les mécanismes d'adaptation et aider à identifier des interventions futures qui pourraient aider à adoucir le stress et promouvoir le bien-être de l'animal.

Une piste importante pour les recherches futures, physiologique et pratique, serait d'explorer l'interaction du stress hydrique avec le cycle reproductif des chèvres à commencer par l'œstrus, la gestation, la lactation, ainsi que le développement de la progéniture. Un des aspects pratiques à considérer serait l'impact économique du stress hydrique qui pourrait se traduire par des pertes importantes en production de lait ou de viande, et ceci sur le long ou le court terme.

Une autre piste d'intérêt serait l'interaction entre le stress hydrique et d'autres stress extérieurs, tels que le stress thermique et la sous-nutrition dans le cas de fourrage de mauvaise qualité. Cette interaction simulerait les conditions réelles auxquelles les animaux sont souvent soumis dans les régions arides ou semi-arides. Bien que plus complexe à explorer d'un point de vue physiologique, une telle approche revêtirait une importance particulière pour comprendre les défis naturels auxquels les animaux et leurs éleveurs doivent faire face pour survivre.

Ce projet a permis de percevoir les différences et les similarités entre les races des régions tempérées et celles des régions semi-arides. Tandis que les Saanen et alpines ont commencé à ressentir le stress thermique alors que les températures n'avaient pas dépassé les 28^{o}C, les shamies s'adaptaient bien à des températures au-dessus de 30^{o}C. De même, pour la restriction en eau, les expériences effectuées ainsi que la revue de la littérature, ont montré l'effet de la race sur l'aptitude à tolérer et à s'adapter à la déshydratation : les Saanen et les alpines ont montré un état de déshydratation bien qu'elles n'étaient privées d'eau que pour près de 15 heures par jour et pour deux jours de suite seulement, alors que les shamies ont toléré un régime d'abreuvement d'un jour sur quatre avec des signes de déshydratation similaires. Ces comparaisons pourraient avoir des répercussions sur les recommandations pratiques en ce qui concerne le choix de la race la plus adaptée pour un certain climat et des conditions de

production données. Les critères pour ce genre de sélection reposeraient sur la productivité de la race, mais aussi sur son adaptabilité au climat, au système d'élevage, à la qualité du fourrage disponible ainsi qu'à sa résistance aux maladies répandues dans la région (Mirkena et al. 2010). La durabilité de la production reposerait sur le bon choix de la race qui pourrait optimiser l'utilisation des ressources disponibles et permettre un certain niveau de productivité. En effet, Mirkena et al. (2010) montrent clairement qu'une sélection en faveur de la productivité se fait souvent aux dépends des paramètres de fertilité et de santé. Les auteurs notent aussi l'interaction avec l'environnement qui rend les races les plus productives souvent les plus vulnérables aux changements de l'environnement.

Dans la même perspective, il est important de noter le rôle du système d'élevage lors d'un changement de zone climatique. Les animaux élevés en systèmes extensifs semblent être moins sensibles aux conditions arides (Hamadeh 1997). Par contre, leur niveau de production pourrait en souffrir. En effet, les résultats rapportés sur l'effet du changement de climat et de système d'élevage sur la productivité des Saanen exportées en pays semi-arides ou tropicaux indiquent un niveau de production bien inférieur à celui souvent atteint dans leurs pays tempérés d'origine (Ishag et al. 2012 ; de Souza et al. 2013).

Une autre piste de recherche à approfondir à partir de ce projet est celle de l'importance de la variabilité individuelle. Cet aspect a été souligné malgré le petit nombre d'animaux, au niveau des réponses physiologiques et comportementales. L'exploration de ces différences serait importante à approfondir afin de mieux distinguer la variance due à cette variabilité individuelle de celle due au traitement que ce soit le stress hydrique ou thermique. Silanikove (2000) a rapporté que dans le cas la baisse de la production laitière chez les vaches sous stress thermique, la variabilité individuelle joue un grand rôle ainsi que d'autres interactions complexes des animaux avec l'environnement. Ceci pourrait avoir des effets sur la gestion du troupeau pour prendre en considération les différents besoins des individus.

Afin de sauvegarder le bien-être des chèvres ainsi que la profitabilité des productions caprines face à la restriction en eau, un plus grand effort semble nécessaire pour identifier et explorer de nouveaux moyens d'atténuation du stress hydrique. En l'absence d'eau, certaines interventions ont quand même le potentiel d'adoucir les effets du stress sur les animaux et de réduire les pertes de production. De telles interventions déjà mentionnées dans la littérature seraient liées à la nutrition et au choix des aliments (Abdel-Samee et al. 2008). D'autres auteurs ont testé des médicaments et/ou suppléments nutritionnels anti-stress ou antioxydants (Sivakumar et al. 2010, Ali et al. 2005) pour voir leur efficacité dans le cas du stress, surtout le stress thermique. D'autres possibilités restent à identifier au niveau de la conduite du troupeau, telles que les moyens d'atténuation du stress thermique s'il est concomitant avec la restriction d'eau, ainsi que l'exploration de l'option de la sélection génétique parmi les races locales ainsi qu'à travers le croisement avec des races plus productives.

Dans tous les cas, ces expériences ont montré que les races européennes, ainsi que celles originaires des pays semi-arides, sont capables de bien tolérer des courtes périodes de restriction en eau. Les conditions de ces expériences, notamment celles sur les chèvres alpines et Saanen, ne semblent pas être particulièrement gênantes sur les animaux qui se sont rétablis assez rapidement. Loin d'être recommandée comme traitement régulier, une telle approche pourrait être envisagée lors d'une période de sècheresse pour optimiser l'utilisation de l'eau disponible.

CONCLUSION

Le stress hydrique est une réalité à laquelle les chèvres font face à un certain moment de leur vie, même pour une courte durée, telle que pendant le transport. Cette réalité risque de devenir plus fréquente en raison du changement climatique global. Les résultats de ce projet ont permis de montrer que loin d'être globalement négatif, l'effet du stress hydrique varie en fonction de la sévérité, la durée, la race, la température ambiante, l'alimentation, etc. Ceci indique qu'il serait peut-être un jour possible de faire des recommandations permettant de mieux gérer une situation de pénurie d'eau dans les élevages caprins selon des conditions qui optimiseraient le bien-être animal et la production économique.

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ANNEXE

Texte en anglais de l'abstract présenté en conférence sur les changements des paramètres du sang et du lait chez les chèvres shamies soumises à un abreuvement intermittant : Changes in blood and milk parameters in lactating shami goats subjected to intermittent watering



Anatomy, Physiology, Welfare, Milking

A-4

Changes in blood and milk parameters in lactating Shami goats subjected to intermittent watering

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Shami goats are an important economic resource in semi-arid regions around the Mediterranean area, largely grown for milk production. An experiment was conducted to assess the effects of an intermittent watering regime on physiological indicators of Shami goats in mid-lactation. Twelve does in mid lactation, were equally distributed to one of two treatments: daily watering and watered once every four days, respectively. The experiment lasted for 32 days under hot conditions (temperature between 14-35ºC). Blood and milk samples were taken at the beginning of the experiment and on days 4, 8, 16, 24 and 32 thereafter, coinciding with the days of watering of the restricted group. The animals were weighed at the beginning and the end of the experiment and the daily milk production was also recorded. Several serum parameters were assessed as well as milk composition. The data were analyzed by ANOVA (repeated measures) using the IBM-SPSS Software. The serum concentrations of urea, protein and albumin, as well as osmolality, were increased in intermittently watered animals, denoting a state of mild dehydration. Other blood parameters including PCV, hemoglobin, creatinine, cholesterol, globulin, insulin and cortisol were not affected by the treatment. On the other hand, the does maintained similar weight and milk production in both groups. The differences in milk composition between the two groups were not significant. It was concluded that the Shami goats in mid lactation could tolerate the intermittent watering regime however, the consequences of the treatment under different physiological conditions warrants further research on a larger scale to account for high individual variability.

RESUME

a. Résumé en français

La pénurie en eau est un problème répandu dans les régions arides et semi-arides auquel l'élevage caprin doit faire face. Ce projet a étudié les effets de la restriction en eau sur les chèvres en milieu semi-aride et tempéré. Au départ, une revue de la littérature a été accomplie donnant lieu à deux manuscrits. De plus, les articles sur la restriction en eau ont été sélectionnés pour former une base de données qui a servi pour initier une méta–analyse ayant pour but la visualisation de l'effet de la restriction en eau sur différents paramètres physiologiques et de production. La revue qualitative et quantitative a couvert les chèvres et les moutons.

Deux expériences sur les chèvres shamies allaitantes et gestantes en milieu semi-aride et une sur les chèvres alpines et Saanen allaitantes en milieu tempéré ont été réalisées. Un régime d'abreuvement intermittent d'un jour sur quatre a été imposé aux chèvres shamies pour une durée d'un mois alors que les chèvres alpines et Saanen ont été privées d'eau pendant 15 heures, de l'après-midi jusqu'au lendemain matin, pendant deux jours consécutifs. L'effet d'un court épisode de chaleur ambiante élevée (19^{o}C vs. 28^{o}C) a été aussi étudié chez les chèvres Saanen et alpines. Des données physiologiques ont été relevées, la composition sanguine et la production et composition laitières.

Les chèvres shamies en lactation restreintes en eau ont montré une élévation de l'osmolarité, et des taux d'urée, protéines et albumine sanguins indiquant un état de déshydratation. La production et composition laitière et le poids vif n'ont pas été influencés par le traitement. Par contre, chez les chèvres shamies gestantes restreintes en eau, l'osmolarité a été plus élevée alors que l'insuline a baissé indiquant un état de bilan énergétique négatif. Le poids des chevreaux issus de mères déshydratées à la naissance et à un mois était plus faible, mais cela nécessite confirmation.

Les chèvres Saanen et alpines, bien que soumises à une restriction moins sévère, ont aussi montré un état de déshydratation à travers l'élévation des taux sanguins d'albumine, urée et sodium et de l'osmolarité. Par contre, les chèvres ont pu maintenir leurs poids vif et production laitière bien que les taux d'urée et de lactose du lait aient augmenté sous la restriction en eau permettant ainsi de garder le lait en isotonie avec le sang.

Le stress thermique n'a eu d'effet ni sur la quantité ingérée ni sur les cinétiques d'ingestion sauf pour l'ingestion d'eau qui a augmenté de 40%. Le pCO_2 sanguin a baissé à cause de l'hyperventilation à laquelle les animaux ont eu recours pour se rafraîchir, alors que la température rectale a augmenté. La production laitière n'a pas changé, mais le taux butyreux a baissé. Les chèvres alpines ont bu plus d'eau par kg de matière sèche que les Saanen ce qui peut être dû, soit à une prise alimentaire plus grande chez les alpines, soit à l'effet de la couleur du poil.

La revue de la littérature quantitative et qualitative et les expérimentations ont permis d'identifier les effets du stress hydrique les plus importants chez les petits ruminants notamment : la baisse de la prise alimentaire, de la production laitière et du poids, une élévation de l'osmolarité et du taux sanguin d'albumine, d'urée, de sodium, de cholestérol et d'acides gras non estérifiés ainsi que des constituants du lait, tels que le lactose et le taux protéique. Les pistes de recherche les moins étudiées ont été suggérées telles que l'interaction entre stress hydrique et d'autres contraintes de l'environnement, la comparaison entre les

races, l'effet de la variabilité individuelle et les moyens d'atténuation du stress et l'effet sur le bien-être animal, etc.

En conclusion, ce projet a aidé à condenser toutes les informations disponibles au sujet du stress hydrique chez les chèvres en une ressource accessible pour guider les recherches futures et peut-être aussi les producteurs face à une pénurie d'eau.

b. Summary in English

Water scarcity is a widespread problem in arid and semi-arid regions affecting goat production. This project aimed to study the effects of water restriction on goats from semi-arid and temperate regions. A first step consisted in reviewing the literature on the subject leading to two review manuscripts. In addition, research articles specifically addressing the topic of water restriction in sheep and goat were retained for the compilation of a large database that was used for a preliminary quantitative review (meta-analysis) with the aim of visualizing the effects of water restriction on different physiological and production parameters as reported in literature. The qualitative and quantitative reviews covered sheep and goat as species of interest. The subject of water stress was also addressed experimentally through two experiments on lactating and gestating Shami goats, respectively, raised under semi-arid environment and one experiment on lactating Saanen and alpine goats raised under temperate conditions. An intermittent watering regime of once every four days was imposed on the Shami goats for a period of around 1 month while the Saanen and alpine goats were subjected to a 15-hour overnight water restriction for two consecutive days. The effect of heat stress was also studied during a short episode of rise in ambient temperature from 19^{o}C to 28^{o}C in Saanen and alpine goats. Physiological data, key blood parameters and milk production and composition were recorded and analyzed.

Lactating Shami goats subjected to intermittent watering showed increased serum osmolarity, urea, protein and albumin concentrations denoting dehydration. Milk composition and production, and body weight were not affected by the treatment. However, in the gestating shami goats osmolarity was higher while insulin was lower indicating a possible state of negative energy balance. The kids born to the restricted goats had lower body weight at birth and at one month of age which warrants further research.

Similarly, alpine and Saanen lactating goats, although subjected to a milder water restriction regime showed signs of dehydration reflected by the increase in albumin, urea, osmolarity and Na^{+}. The goats were able to maintain body weight and milk production although milk urea and lactose increased under water restriction thus keeping milk isotonic with the blood.

Heat stress had no effect on feed intake or on feed and water intake patterns in lactating Saanen and alpine goats. However, there was a 40% increase in water intake. Blood pCO_2 decreased because the animals hyperventilated to reduce their body temperature, whereas rectal temperature increased. Milk production was not modified, but milk fat content decreased. Alpine goats drank more water per kg of dry matter intake than the Saanen. This could be explained either by their higher level of feed intake or by the effect of coat colour.

The qualitative and quantitative reviews as well as the experimental part helped in determining the most prominent physiological effects of water restriction in small ruminants that are consistently reported namely: decrease in feed intake and milk production and weight loss, increase in osmolarity, urea, sodium, cholesterol and fatty acids and of milk components such as lactose and protein content. At the same time, understudied areas in relation to the effects of water restriction were identified such as water stress in interaction with other

environmental factors, the comparison between breeds, the impact of individual variability, methods of water stress alleviation and impact on animal welfare, etc.

As a conclusion, this project helped in condensing the relevant information on the effects of water stress on goats thus serving as an accessible resource for guiding future research and possibly goat producers, in facing water scarcity.

c. Résumé non-scientifique en français

Ce projet de thèse avait pour but d'étudier les effets d'une restriction en eau chez les chèvres. Les articles publiés à ce sujet ont été collectés et synthétisés et les données ont été analysées afin d'identifier les effets de la restriction en eau les plus importants chez les chèvres et les moutons. La partie expérimentale a comporté deux expériences de restriction en eau sur les chèvres shamies allaitantes et gestantes en milieu semi-aride, et une sur des chèvres allaitantes Saanen et alpines en milieu tempéré. De plus, l'effet d'un épisode de température ambiante élevée a été étudié chez les chèvres allaitantes Saanen et alpines.

Ce travail a montré que la restriction en eau mène à une baisse de poids, de la prise alimentaire et de la production de lait ainsi qu'à des changements importants dans la composition du sang et du lait. D'autres aspects de la restriction en eau sont aussi suggérés comme pistes de recherches futures.

d. Non-scientific summary in English

This thesis project aimed to study the effects of water restriction on goats. At first, all scientific information published on the subject was gathered and synthesized into a general review and the gathered data was analyzed to identify the most important effects of water restriction on goats and sheep. The experimental part of the thesis consisted of two water restriction experiments on Shami goats, milking and gestating under a semi-arid environment, and another on lactating Saanen and alpine under a temperate environment. In addition, the effect of an episode of elevated ambient temperature was studied in lactating Saanen and alpine goats.

This project showed that water restriction leads to a drop in body weight, feed intake and milk production in addition to important changes in milk and blood composition. Other aspects of water restriction are suggested at the end as possible areas for future research to advance knowledge on the subject.